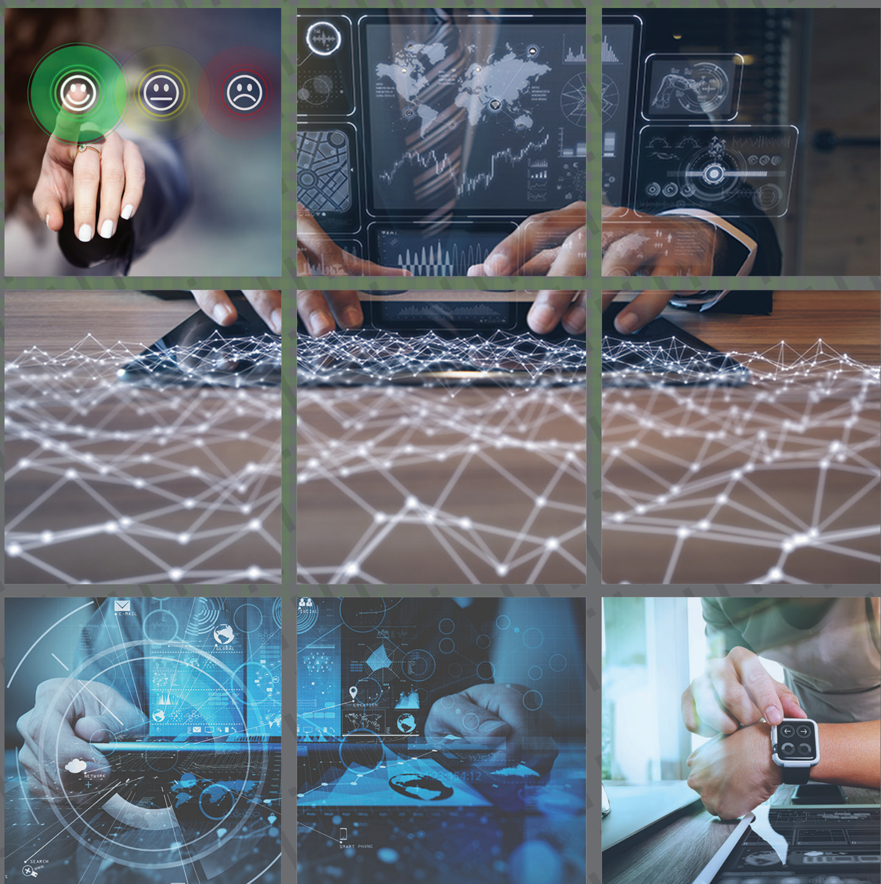
REGULATORY & MARKET ENVIRONMENT

Quality of Service
REGULATION MANUAL

Manual



Telecommunication Development Sector

Quality of service regulation manual

2017

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Foreword

I am pleased to present the Manual on Quality of Service (QoS) Regulation published to serve as a reference and guiding tool for regulators and policy makers in dealing with QoS and Quality of Experience (QoE) matters in the ICT sector.

Regulation and management of QoS are increasingly important and complex in today's highly competitive, challenging and globalized digital environment. Ensuring fairness and high quality user experience requires effective regulatory frameworks. The profusion of ever-evolving technologies, networks, services and devices with different QoS capabilities further adds to the complexity of regulation in this area. Quality can be impacted by many factors at the network level and along the value chain. In this regard, a common approach to regulating QoS can enable greater quality prospects irrespective of the locations of the consumer and service provider.

This manual builds upon ITU-T recommendations and extends the ITU regulation guidelines further by introducing hands-on information and practical approaches in regulating QoS for telecommunication/ICT services. It provides a 360 degree assessment of QoS regulation, ranging from the technical and regulatory perspectives to issues such as traffic management, network neutrality, consumer protection, economic principles and enforcement mechanisms.

This manual is a key resource to advance QoS regulation in the fast changing digital world. Its recommendations and the sharing of good practice will provide useful guidance in addressing QoS to ensure that both individual and business consumers benefit from quality ICT services, an essential element in this fast-paced transformational digital environment.

Brahima Sanou

Director, ITU Telecommunication Development Bureau

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1 Introduction

In this digital, globally connected world where all functions and aspects of life are being transferred to communication networks and services, citizens everywhere rely on ICTs to conduct their everyday socio-economic activities. Telecommunication networks are interconnected on a national, regional, and global basis, and the quality of telecommunication services applied in one network or one country influences the end-to-end quality of that service, so the quality cannot be considered only at national or regional level, but also needs to be considered globally.

Ensuring quality of service (QoS) in this ever-changing environment is increasingly critical. A harmonized and common approach to regulating QoS would enable greater quality prospects irrespective of the locations of the consumer and service provider.

This manual refers to different standards and regulatory practices from different regions and countries worldwide noting that each region and each country has its own specificities. It is intended to be used as a guiding tool for telecommunication national regulatory agencies (NRAs) or government ministries in charge of QoS and QoE (quality of experience) parameters and measurements as defined by ITU-T, as well as enforcement mechanisms. It extends ITU regulation guidelines further by introducing more hands-on information regarding the QoS and QoE big picture, as well as outlining practical approaches in QoS regulation for telecommunication/ICT services. It puts forth the case that NRAs should have the appropriate skill-set to carry out QoS regulation, and how continuous capacity building is key to adapting to market and regulatory changes. NRAs can benefit greatly by learning from each other. The argument for cooperation between regulators is strong, bringing substantive benefits through the sharing of good practice and mutual learning.

1.1 The ICT sector today

The ICT world is increasingly broadband, as illustrated in Figure 1.1. Twenty years ago, only one per cent of the global population had a mobile cellular subscription, and 11 per cent had a fixed telephone subscription. Today, mobile cellular penetration is approaching saturation with more than 7.5 billion subscriptions worldwide. Globally, 3.57 billion people are expected to be using the Internet by end 2017. Mobile broadband is the most dynamic market segment – globally, mobile broadband penetration is expected to reach 56.4 per cent with fixed broadband access expected to reach more than 979 million fixed broadband subscriptions by the end of 2017. The number of Internet users is growing, reaching 48 per cent of the world population.

Broadband provides access bit rates in downstream and upstream that support all available types of services offered through good quality Internet access. A decade ago, broadband access was mainly offering hundreds of kbit/s, today it provides access within Mbit/s or tens of Mbit/s (i.e. speeds), enabling such things as the provision of high-definition (HD) video as well as ultra-HD videos.

Fixed broadband access technologies can be provided either by copper (twisted-pairs) by reusing local-loops for fixed telephony, cable access (by reusing coaxial cable networks, primarily developed for television distribution, for IP-based access via asymmetric digital subscriber line (ADSL), very high bit rate digital subscriber line (VDSL or generally xDSL where DSL stands for digital subscriber line), and FTTH (fibre-to-the-home or more generally FTTx), which is the long-term future for fixed broadband access in all regions (Figure 1.2). For example, almost all transport networks are now fibre based, and the differences shown in Figure 1.2 refer mainly to the last mile.

Figure 1.1: Global ICT developments, 2001-2017

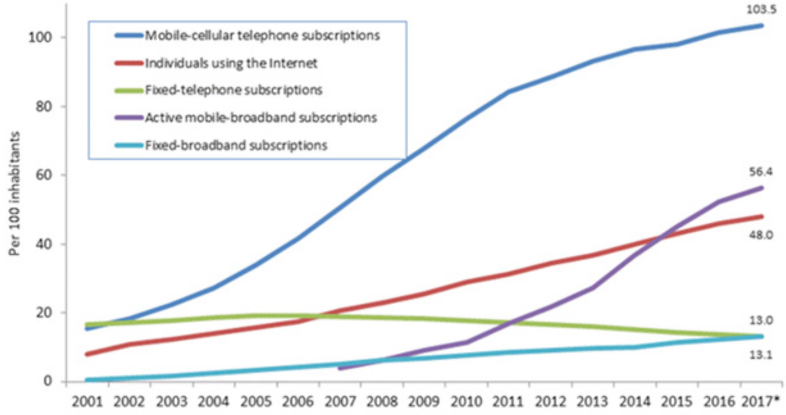
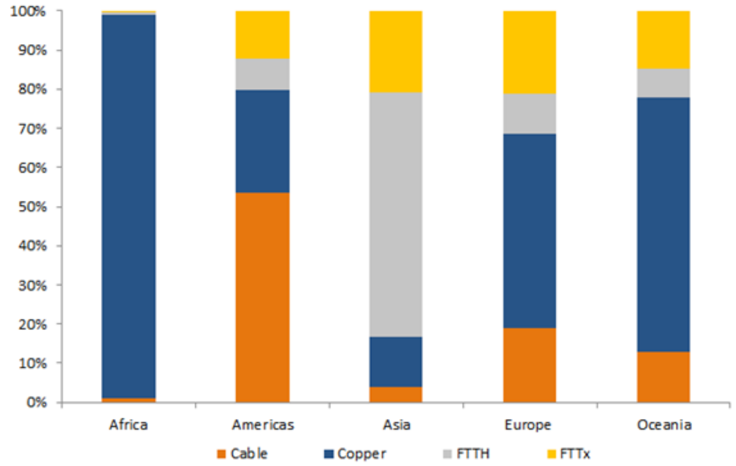
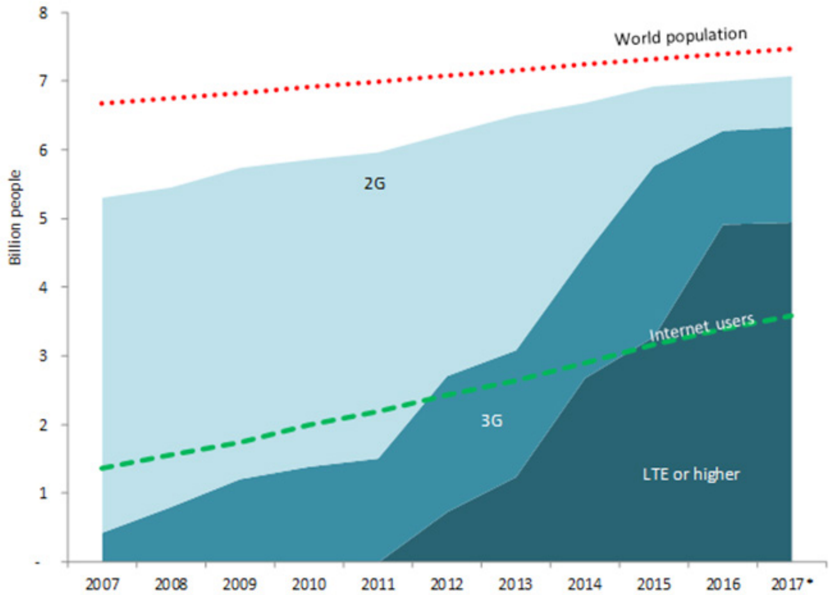


Figure 1.2: Fixed broadband access, technology market share by region (Q1 2017)



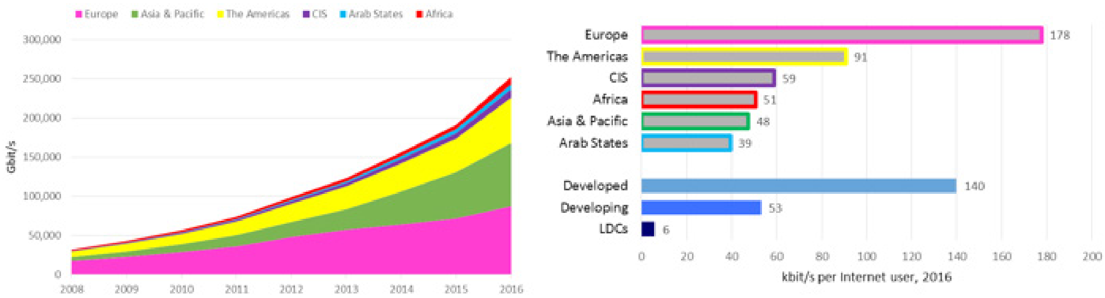
Mobile broadband access is provided currently with 3G (e.g. Universal Mobile Telecommunications System/High Speed Packet Access (UMTS/HSPA)) and 4G mobile technologies (e.g. Long-Term Evolution (LTE) / LTE-Advanced). In 2016, LTE networks were offered in at least 165 countries world-wide. Figure 1.3 shows mobile broadband network deployment trends. Seven billion people (95 per cent of the global population) live in an area that is covered by a mobile-cellular network. Mobile broadband networks (3G or above) reach 85 per cent of the global population. LTE networks have spread quickly over the last three years and reach more than 4.9 billion people today (66 per cent of the global population), enhancing the quality of Internet use for many.

Figure 1.3: Mobile broadband network deployment trends



Source: ITU World Telecommunication/ICT Indicators database (* Estimate)

Figure 1.4: Internet bandwidth distribution in the world in 2016



Source: ITU World Telecommunication/ICT Indicators database

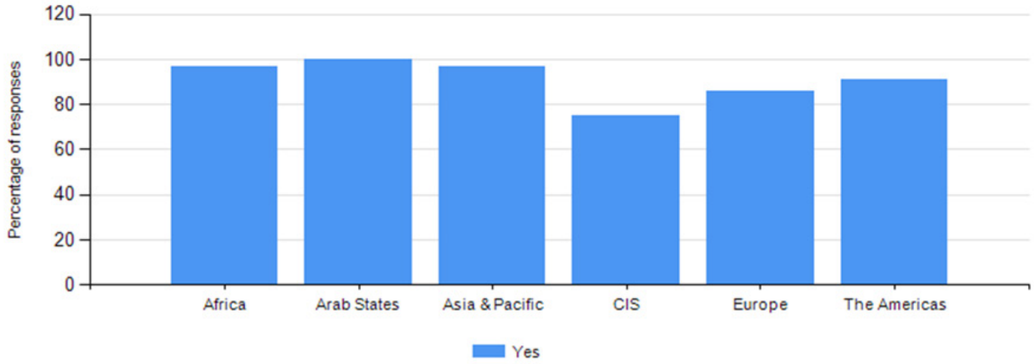
By the end of 2016, total international Internet bandwidth had reached more than 250 000 Gbit/s, up from 30 000 in 2008, which shows remarkable growth in speed (Figure 1.4). However, the Africa region has the lowest international connectivity of all regions: there is twice as much bandwidth per inhabitant available in the Asia-Pacific region, four times as much in the Commonwealth of Independent States (CIS) region, eight times as much in the Americas region, and more than twenty times as much in Europe. Mobility, always on access, and the massive adoption of broadband enabled devices have irreversibly changed consumer social and economic behaviour and their quality of service expectations as well.

Quality of service and quality of experience measuring is becoming more and more complex. Quality can be impacted by many factors at the network level and along the value chain, including the device, hardware, infrastructure, service and applications. In addition, differences may arise between perceived and assessed QoS.

QoS is important for both customers and service providers. Specific QoS policies should be established in each country by the appropriate authority (e.g. NRA, ministry or other government authority), based on QoS standards. QoS provisioning should be monitored as well as encouraged and enforced when needed.

1.2 Quality of service regulatory trends

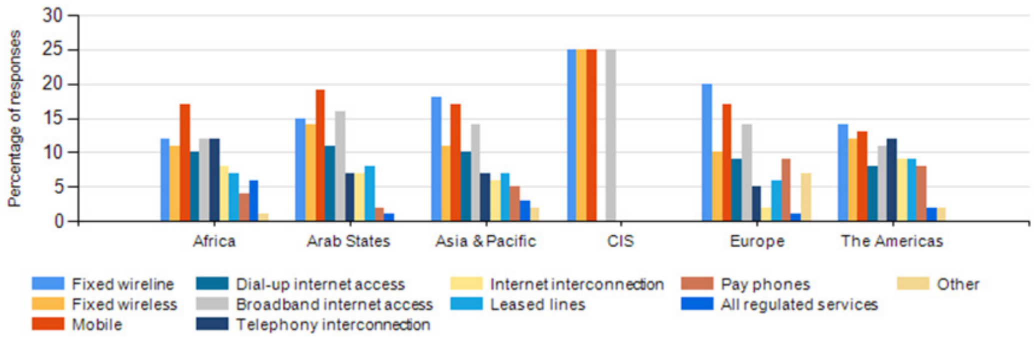
Figure 1.5: Monitoring QoS in different regions in the world, 2016



Source: ITU Telecommunications/ICT Regulatory Database (total country responses: 171)

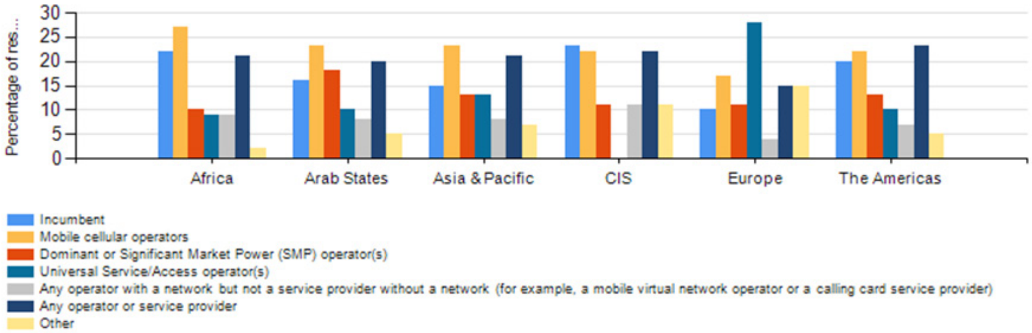
Today, QoS is being monitored in at least 158 countries (Figure 1.5). Historically speaking, QoS requirements have been applied to voice services (provided by telecommunication operators), but more recently regulators have been incorporating minimum QoS requirements for data services (through Internet access service (IAS)). These requirements can vary from high level transparency guidelines on how the information on traffic management techniques is disclosed to end-users, to requiring actual indicators for data network performance for fixed and mobile broadband providers. QoS monitoring is required in 82 per cent of the 193 ITU Member States. There are some differences when looking at which services and who is subject to QoS monitoring between regions. In Africa, mobile services are subject to monitoring in 32 countries, followed by fixed wireline (26 countries), telephony interconnection (15 countries) and broadband Internet access (23 countries). Services subject to QoS monitoring by region in 2016 are presented in Figure 1.6.

Figure 1.6: Services subject to quality of service monitoring, 2016



Source: ITU Telecommunications/ICT Regulatory Database (total country responses: 145)

Figure 1.7: Operator/service providers subject to quality of service monitoring, 2016



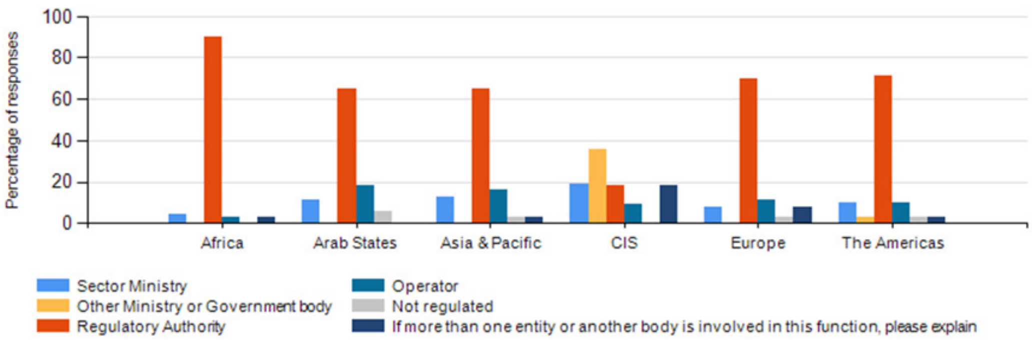
Source: ITU Telecommunications/ICT Regulatory Database (total country responses: 158)

Figure 1.7 shows which operators and service providers are subject to QoS monitoring. In most countries, QoS monitoring targeted incumbent and mobile operators. For example, for various reasons most countries in Africa have little fixed infrastructure, and the focus on QoS monitoring is mostly on mobile operators, which typically provide broadband access in that region.

In most countries, the NRA monitors QoS as shown in Figure 1.8. However, in some countries, QoS monitoring is performed by the sector ministry or another ministry or government body (e.g. CIS region countries).

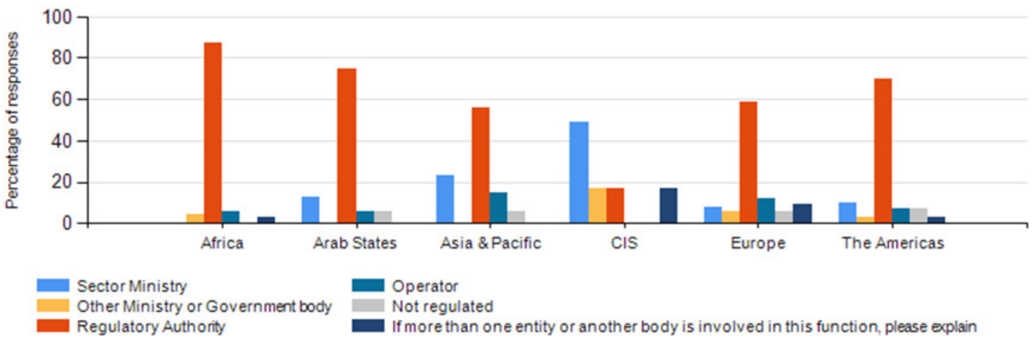
In most countries, if QoS standards are defined, it is the NRA that defines them (Figure 1.9) although other arrangements are possible, but generally, the authority that sets QoS standards also carries out QoS enforcement (Figure 1.10).

Figure 1.8: Agency responsible for monitoring QoS standards, 2016



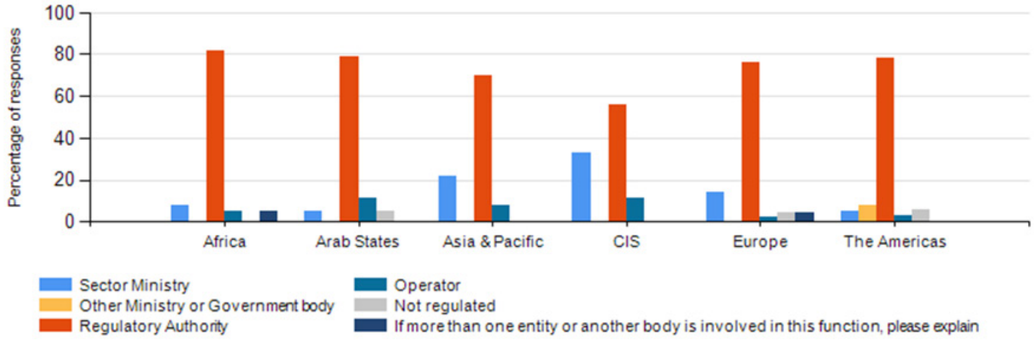
Source: ITU Telecommunications/ICT Regulatory Database (Total country responses: 140)

Figure 1.9: Agency responsible for setting QoS standards, 2016



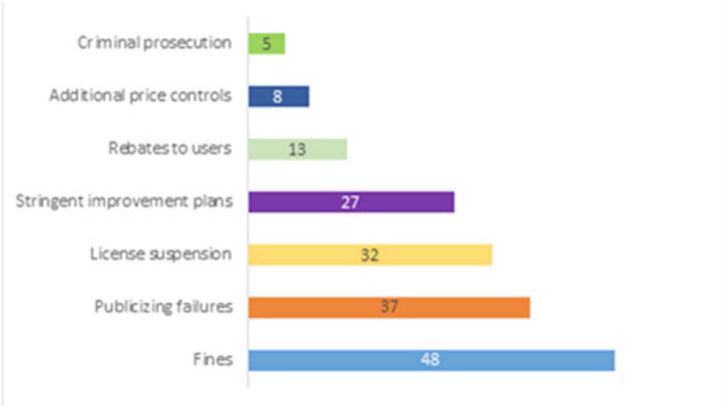
Source: ITU Telecommunications/ICT Regulatory Database (Total country responses: 127)

Figure 1.10: Agency responsible for enforcing QoS, 2016



Source: ITU Telecommunications/ICT Regulatory Database (Total country responses: 170)

Figure 1.11: Types of sanctions regulators can impose, 2016



Source: ITU Telecommunications/ICT Regulatory Database (total country responses 77 countries)

Regulators may impose different types of sanctions to operators not meeting their QoS obligations, ranging from publicizing failures, fines, licence suspension, to criminal prosecution in some cases (Figure 1.11). In terms of sanctions that have been most commonly used, 22 countries indicated they had imposed fines, required operators to publicize failures and provided rebates to users. The kind of sanctions applied will depend on national circumstances and market maturity (see Chapter 10).

1.3 Structure of the manual

The manual is divided into the following chapters:

- Chapter 2: QoS framework from a technical perspective, drawing from the work by ITU-T on QoS standardization.
- Chapter 3: QoS regulatory framework and the role of national regulatory authorities in addressing QoS.
- Chapter 4: Traffic management.
- Chapter 5: QoS parameters and key performance indicators.
- Chapter 6: Broadband QoS measurement, and different measurement tools and platforms.
- Chapter 7: Economic principles for QoS regulation.
- Chapter 8: Network neutrality and its regulation worldwide.
- Chapter 9: Consumer protection and privacy aspects.

- Chapter 10: QoS enforcement.
- Chapter 11: Concluding remarks.

2 Quality of service framework: Technical aspects

The section will:

- examine the technical aspects of quality of service (QoS);
- define the concepts to better understand how migration from public switched telephone (PSTN) to IP networks has impacted QoS; and
- explore the difference between Internet and next generation networks (NGNs) in order to identify the QoS regulatory framework needed in a broadband digital environment.

Standards developing organizations (SDOs), such as ITU-T, the European Telecommunications Standards Institute (ETSI), or the Internet Engineering Task Force (IETF) have collective QoS knowledge and expertise related to the change of paradigms in networks and terminals in terms of planning and possible regulation of end-to-end QoS. The basis for setting quality parameters for publicly available electronic communication services should include technical recommendations, standards, technical specifications and guidelines published by different SDOs in the telecommunication/ICT sector globally.

ITU has a long standing history of QoS work, which includes the following cornerstones:

- Since 1957 the ITU has been conducting expert work in the fields of transmission planning, subjective testing and standards for telephone sets.
- Since 1986 the Speech Quality Experts Group (SQEG) has provided coordination of the quality requirements and subjective testing methodologies for speech coding algorithms.
- Since 1997 the Video Quality Experts Group (VQEG) has provided coordination of quality requirements and subjective testing methodologies for video coding algorithms.

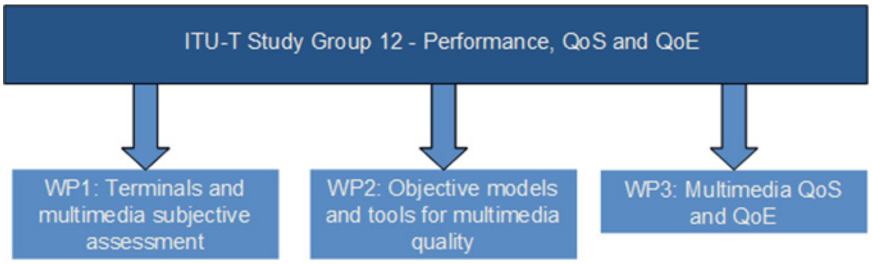
In ITU-T, Study Group 12 (SG12) is responsible for performance, QoS, and QoE. SG12 is developing recommendations on performance, QoS and QoE for the full spectrum of terminals, networks, services and applications ranging from speech over fixed circuit-based networks to multimedia applications over networks that are mobile and packet based. Included in this scope are the operational aspects of performance, QoS and QoE; the end-to-end quality aspects of interoperability, and the development of multimedia quality assessment methodologies, both subjective and objective. SG12 works proactively to help bridge the standardization gap in the area of QoS/QoE, in particular through its Regional Group on QoS for the Africa Region (SG12RG-AFR) and the Quality of Service Development Group (QSDG).

Recommendations under the responsibility of SG12 include:

- ITU-T E.420 – ITU-T E.479, ITU-T E.800 – ITU-T E.859
- ITU-T G.100-series, except ITU-T G.160- and ITU-T G.180-series
- ITU-T G.1000-series
- ITU-T I.350-series (including ITU-T G.820/I.351/Y.1501), ITU-T I.371, ITU-T I.378, ITU T I.381
- ITU-T J.140-, ITU-T J.240- and ITU-T J.340-series
- ITU-T P-series
- ITU-T Y.1220-, ITU-T Y.1530-, ITU-T Y.1540-, ITU-T Y.1560-series

Each Study Group (SG) of ITU-T has working parties (WPs), as shown in Figure 2.1. Each WP has one or more Question under its jurisdiction. Each Question is related to one or more ITU-T Recommendations. The current structure of SG12 and the Questions under study are listed at http://itu.int/net4/ITU-T/lists/loqr.aspx?Group=12&Period=16.

Figure 2.1: Organization of work within ITU-T SG12



Source: ITU-T SG12

Among other series of recommendations of great interest to regulators and policy-makers, the E.800 series (Quality of telecommunication services: concepts, models, objectives and dependability planning) primarily refers to QoS. Some important recent ITU-T Recommendations on QoS include the following:

- ITU-T Rec. E.800 (09/2008): Definitions of terms related to quality of service
- ITU-T Rec. E.801 (10/1996): Framework for Service Quality Agreement
- ITU-T Rec. E.802 (02/2007): Framework and methodologies for the determination and application of QoS parameters
- ITU-T Rec. E.803 (12/2011): Quality of service parameters for supporting service aspects
- ITU-T Rec. E.804 (02/2014): Quality of service aspects for popular services in mobile networks
- ITU-T Rec. E.807 (02/2014): Definitions, associated measurement methods and guidance targets of user-centric parameters for call handling in cellular mobile voice service

At a global level, the importance of QoS is acknowledged in the Final Acts of the World Conference on International Telecommunications (WCIT-12), and Resolution 95 on ITU Telecommunication Standardization Sector initiatives to raise awareness on best practices and policies related to service quality of the World Telecommunication Standardization Assembly (WTSA-16).

The following subsections introduce the definition of QoS and QoE, give an overview of the Internet QoS mechanism, and cover QoS parameters in IP networks and end-to-end QoS provisioning. QoS requirements apply not only to traditional telecommunication and broadcast services, but increasingly to broadband, wireless/mobile and multimedia services as well. In general, communications services from 2010 onwards are increasingly delivered through IP-based networks, including:

- IPbased networks (access, core/backbone, and transit); and
- IP-based services, including QoS-enabled (i.e. managed services); and OTT (over-the-top) services, which are provided in best effort manner, without end-to-end QoS, and based on the principle of network neutrality in current Internet use.

QoS is moving from its initial definitions targeted to traditional telecommunication networks (e.g. public switched telephone network/integrated services digital network (PSTN/ISDN), broadcast networks) to QoS in IP networks and services.

Networks and systems are gradually being designed according to the end-to-end performance required by user applications. However, the term QoS is usually not well-defined, is used loosely and even misused. Depending on what aspects of quality are examined and what kind of services/technologies are involved, different definitions and concepts of quality are used. The variety of different definitions demonstrates the difficulties in assessing all aspects related to the term QoS.

In many industry standards, reports and specifications, either QoS is not clearly defined or reference is made to ITU-T Rec. E.800. Therefore, a first step is to define QoS and have a clear understanding of general QoS terminology.

2.1 Definition of quality of service

ITU-T Rec. E.800 defines quality of service as:

Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service.

In its technical report[1], ETSI defines QoS from the network perspective as: "*Quality of Service (QoS): the ability to segment traffic or differentiate between traffic types in order for the network to treat certain traffic differently from others*", and in the ISO definition, quality is defined as "*the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs*" (**ISO** 8402).

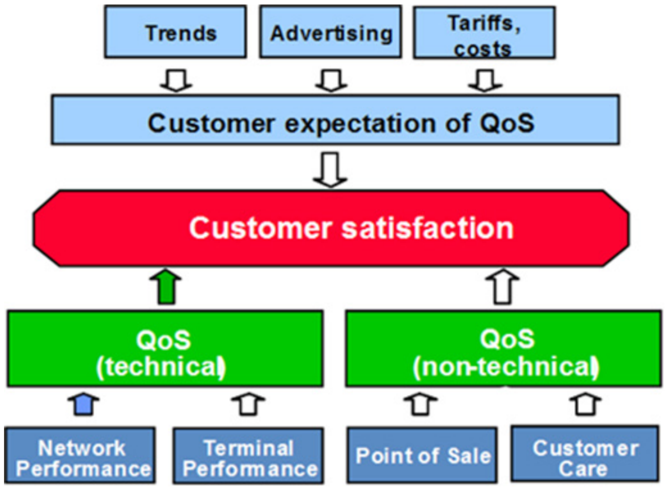
In this manual, the ITU definition of QoS is used, which is consistent with the ISO definition of quality of a service. Compared to the ETSI definition from a network perspective, the ITU and ISO definitions focus on the service as the entity under consideration. It is important to note however, that the various definitions tend to reflect views on the telecommunication/ICT systems, networks, and services/applications from user and network perspectives.

Traditionally, QoS was mainly addressed from the perspective of the end-user being a person (e.g. telephony), with abilities to hear and see and be tolerant to some degradation of services (e.g. low packet loss ratio is acceptable for voice, while end-to-end delay for voice should be less than 400 ms). But with the advent of new types of communications where services may not require real time delivery and where the sender or the end-user may not be a person but a machine, it is important to keep in mind that not all services are the same (e.g. Internet of Things (IoT)). Even similar services can be treated in different ways depending on whether they are used by machines or by humans on one or both ends of a given communication session or connection.

The end-user perception of a telecommunication/ICT service is also influenced by different factors such as social trends (in terms of popular devices, services, applications, social networks, etc.), advertising, tariffs and costs, which are interrelated to the customer expectation of QoS. The user perception of quality is not limited to objective characteristics at the man-machine interface. For end-users, the quality that they personally experience during their use of a telecommunication service also counts.

[1] **ETSI**-TR102157: www.etsi.org/deliver/etsi_tr/102100_102199/102157/01.01.01_60/tr_102157v010101p.pdf This definition is from the perspective of broadband satellite.

Figure 2.2: QoS technical and non-technical point of view, and customer satisfaction



Source: ITU-T Supplement 9 to Rec. Series E.800 (12/2013)

As illustrated in Figure 2.2, QoS depends on end-to-end technical aspects, which include network performance and terminal performance, and on non-technical aspects (not directly related to the equipment), such as point of sale, customer care, etc.

QoS terminology

General QoS terminology, as defined in ITU-T E.800, includes the following:

QoS requirements of user/customer (QoSR): A statement of QoS requirements by a customer/user or segment/s of customer/user population with unique performance requirements or needs.

QoS offered/planned by service provider (QoSO): A statement of the level of quality planned and therefore offered to the customer by the service provider.

QoS delivered/achieved by service provider (QoSD): A statement of the level of QoS achieved or delivered to the customer. These parameters should be the same as specified for the offered QoS so that the two can be compared to determine what was actually achieved in order to assess the level of performance obtained.

QoS experienced/perceived by customer/user (QoSE): A statement expressing the level of quality that customers/users believe they have experienced. Perceived QoS is assessed by customer surveys and from a customer's own comments on levels of service.

Characteristic: A property which helps to differentiate between the individuals of a given population.

Criterion: Collections of characteristics or a single characteristic, as appropriate, to describe benefit to a user of a product or a service.

Parameter: A quantifiable characteristic of a service with specified scope and boundaries.

Objective (quantitative) parameters: Parameters that are measurable (with instruments or observations) and a performance value assigned quantitatively may be classified as objective parameters.

Subjective (qualitative) parameters: Parameters that can be expressed using human judgment and understanding may be classified as subjective or qualitative parameters.

Measure: A unit by which a parameter may be expressed.

Metric (also called *Indicator***):** Value calculated from observed attribute/s of a measure.

Service: A set of functions offered to a user by an organization.

Item: Any part, device, subsystem, functional unit, equipment or system that can be individually considered.

User: A person or entity external to the network, which utilizes connections through the network for communication.

Customer: A user who is responsible for payment for the services.

Network performance: The ability of a network or network portion to provide the functions related to communications between users.

Network provider: An organization that owns a telecommunications network for the purpose of transporting bearers of telecommunication services.

Service provider: An organization that provides services to users and customers.

2.2 Definition of quality of experience

According to ITU-T Recommendation P.10/G.100, quality of experience (QoE) was initially defined as the overall acceptability of an application or service, as perceived subjectively by the end-user.

> ITU-T Study Group 12 replaced the QoE definition developed in 2007 with a new definition in 2016, although the on-going research on this topic means that this is a working definition and it is expected to evolve for some time…
>
> *Quality of experience (QoE) is the degree of delight or annoyance of the user of an application or service.*
>
> The same ITU-T recommendation defined two new terms:
>
> *1. QoE influencing factors: This includes the type and characteristics of the application or service, context of use, the user expectations with respect to the application or service and their fulfilment, the user cultural background, socio-economic issues, psychological profiles, emotional state of the user, and other factors* whose number *will likely* expand *with further research.*
>
> *2. QoE assessment: This is the process of measuring or estimating the QoE for a set of users of an application or a service with a dedicated procedure, and considering the influencing factors (possibly controlled, measured, or simply collected and reported). The output of the process may be a scalar value, multi-dimensional representation of the results, and/or verbal descriptors. All assessments of QoE should be accompanied by the description of the influencing factors that are included. The assessment of QoE can be described as comprehensive when it includes many of the specific factors, for example a majority of the known factors. Therefore, a limited QoE assessment would include only one or a small number of factors.*
>
> **Source: ITU** https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-P.10-201607-I!Amd5!PDF-E&type=items

QoE includes complete end-to-end system effects (end-user equipment, as well as network and service infrastructure). Overall acceptability may be influenced by user expectations and the context. QoE takes into account additional parameters:

- user expectations;
- user context (e.g. personal mood, environment, work/home/outside, etc.);
- potential discrepancy between the service offered and individual user awareness of the service and additional features (if any) for that service.

One may conclude that QoE is different from QoS as it is based on customer perception of the given service. QoE includes the complete end-to-end system elements (client, terminal, network, services infrastructure, etc.) and may be influenced by user expectations and context. In principle, QoE is measured subjectively by the end-user and may differ from one user to another.

The most used measure for QoE is the mean opinion score (MOS). Initially, the MOS scale referred to voice service only (ITU-T P.800), but is now used for other services such as video (e.g. Internet Protocol Television (IPTV)). MOS is expressed as a single number in the range from 1 to 5, where the value of 1 corresponds to the lowest quality experienced by the end-user and 5 is the highest quality experienced (as shown in Table 2.1).

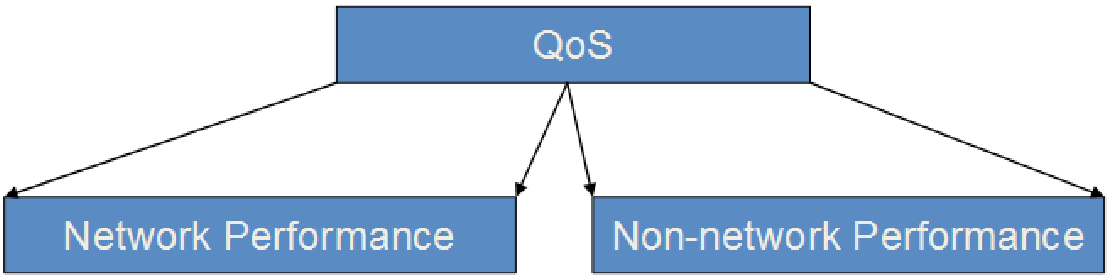
Table 2.1: Mean opinion score

Mean Opinion Score	Quality
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

2.3 Definition of network performance

Network performance is determined by the performances of network elements one by one, or by the performance of the network as a whole, i.e. the combination of the performance of all single elements. However, network performance has an influence on QoS, and it represents a part of it. Simply said, QoS consists of network performance and non-network performance, as shown in Figure 2.3.

Figure 2.3: Network performance and QoS



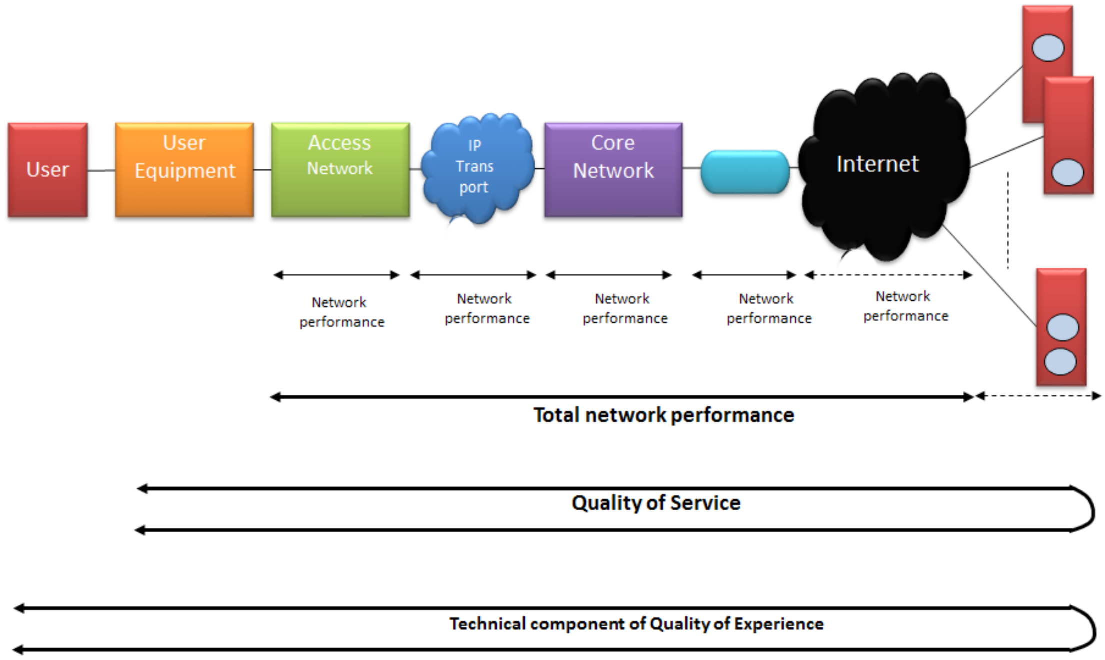
Source: ITU

2.4 The relationship between quality of service, quality of experience, and network performance

QoE is different from QoS and network performance as it has a subjective feature in its definition. QoE depends on the end-user perception in addition to features of services that may result in quite different ways of specifying the value. It is clear, however, that QoE is impacted by QoS and network performance.

Network performance applies to network provider planning, development, operations, and maintenance. As illustrated in Figure 2.4, total network performance is the detailed technical part of the QoS offered. As indicated in ITU-T Rec. G. 1000, it contributes to QoS as experienced by the user. The functions of a service depend on the performance of the network elements and the performance of user terminal equipment. QoS is always end-to-end, i.e. user-to-user or user-to-content. Therefore, QoS measurements are also carried out end-to-end. End-to-end QoS depends on the contributions made by the components as described in Figure 2.4, including user, user equipment, access network, IP transport, core network, and the rest of the path end-to-end (e.g. through the Internet). QoE has a broader scope as it is impacted by QoS as well as by user expectations and context.

Figure 2.4: Network performance, QoS and QoE



Source: ITU

To provide QoS support for a given service, QoS criteria and parameters are required. ITU-T Rec. G.1000 defines these terms, which provide the general QoS framework. Seven QoS criteria are specified:

- speed (refers to all service functions);
- accuracy (e.g. speech quality, call success ratio, bill correctness, etc.);
- availability (e.g. coverage, service availability, etc.);
- reliability (e.g. dropped call ratio, number of billing complaints, etc.);
- security (e.g. fraud prevention);
- simplicity (e.g. ease of software updates, ease of contract termination, etc.); and
- flexibility (e.g. ease of change in contract, availability of different billing methods such as online billing, etc.).

The seven service quality criteria are mapped on a set of service functions by using a given matrix, as illustrated in Table 2.2 where the example provided is a matrix for mobile telephony service. Such mapping is also referred to as a performance model in ITU-T E.802. It is one of the three possible models for identification of user QoS criteria that is needed before defining QoS parameters (one must specify criteria used for definition of QoS parameters).

1. **Universal model:** A generic and conceptual model. In this model, all QoS criteria may be grouped under four categories: performance, aesthetic, presentational and ethical. Each functional element of the service is cross-checked against the four predefined quality components and criteria.
2. **Performance model**: This model is more suited for determining the performance criteria of a telecommunication service, as illustrated in Table 2.2 for mobile telephony service.
3. **Four-marked model**: This model is especially suited for multimedia services (as most services nowadays) since the separation between the transport and service layer is taken into account.

In general, QoE is influenced by all seven QoS criteria. For example, speed influences the available throughput and latencies and it is of crucial importance for QoE. That is why in moving towards broadband access and higher access bit rates (including fixed and mobile broadband), overall QoE improves. Availability and reliability are also very important, which depends upon the capability of the network to recover from a failure (e.g. self-organizing networks (SON) solutions in 4G, resilience solutions in optical networks, etc.) as well as appropriate planning and dimensioning of the network (to suit to the expected number of users for a given service or services). For example, typical quality metrics for network availability from the era of synchronous digital hierarchy (SDH) onwards are so-called 'five nines', i.e. service to be available 99.999 per cent of the time to end-users, and which requires certain survivability mechanisms to be implemented in the network (e.g. re-routing of traffic in a case of failure over alternative or reserved paths in the network). Security aspects, accuracy, flexibility regarding the services, and user friendliness of the service further influence QoE.

Table 2.2: Performance model for a mobile telephony service with matrix of mapping service quality criteria and service functions (Source: ITU-T E.802.)

		Service quality criteria						
		Speed 1	Accuracy 2	Availability 3	Reliability 4	Security 5	Simplicity 6	Flexibility 7
Service function								
Service management	Sales & pre-contract activities 1	Processing time						
	Provision 2	Supply time		Coverage				
	Alteration 3	Response time						Ease of change in contract
	Service support 4	Response time		Availability of call centre			Professionalism of help line	
	Repair 5	Processing time						
	Cessation 6	Call set-up time					Ease of contract cessation procedure	
Connection quality	Connection establishment 7	Call set-up time		Service availability				
	Information transfer 8	One-way delay			Dropped call ratio within a specific time period			
	Connection release 9	Release time						
Billing 10		Billing frequency			Number of billing complaints within period	Fraud protection/ prevention		Availability of different billing methods (e.g. online billing)
Network/Service management by customer 11							Ease of software updates	

The management of QoS can be divided into four viewpoints, as described in ITU-T Rec. G.1000, which covers QoS from both the customer and service provider viewpoints (see Figure 2.5).

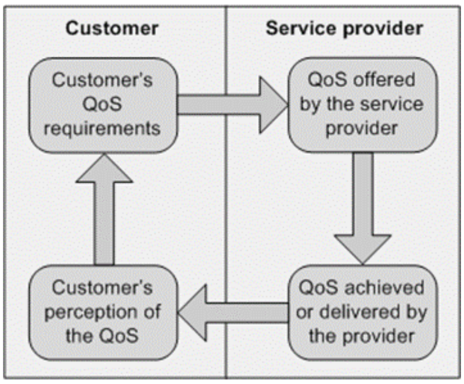
The customer viewpoints are:

- Customer requirements: This is the QoS level required by the subscriber.
- Customer perception: The QoS level obtained by user ratings of the provided QoS by the service operator, which can be used for comparison purposes among QoS levels provided from different service providers, as well as for corrective actions (e.g. when perceived QoS level is below the QoS offering by the provider).

The service provider viewpoints are:

- QoS offered by the service provider (or planned/targeted QoS): This includes QoS criteria or parameters offered by the service provider (which includes network providers that provide access to the Internet as a service), which may be used for several offerings:
  - Service level agreement (SLA) as a bilateral agreement between the customer and the service provider.
  - Public offering (i.e. declaration) of the service level that can be expected by the subscriber.
  - Planning and maintaining the service to a given performance level.
  - For subscribers to make the best choice from the given service provider offerings.
- QoS achieved: the actual level of QoS achieved or delivered by the service provider, which can be used as a check for delivered QoS (e.g. according to a given SLA) or as a basis for any corrective action regarding QoS.

Figure 2.5: QoS four viewpoints concept



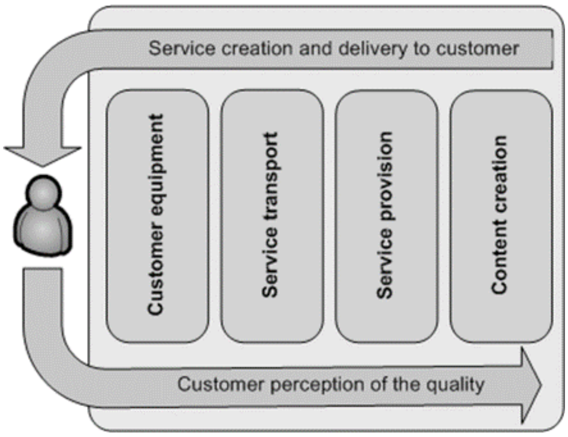
Source: ITU-T (Rec. G.1000)

The four-market model (see Figure 2.6) is better suited for multimedia services. It defines the chain of action from content creation towards service provision, service transport and customer equipment. There are four elements, content, service provision, service transport, and customer equipment, which are generally supplied and which work independently of each other. Different parties may be in charge of installation, operation, and maintenance. Different services have different QoS requirements. The four-market model provides the possibility to identify QoS criteria for one or more components in the model. For example, for file download service (e.g. download of music contents), the following criteria can be applied in the four-market model:

- Content creation: Suitability of the content, its popularity, codec format and its quality, piracy aspects, etc.
- Service provision: Ease of navigation to requested music files, fair contract, security of personal data, pricing, customer care, etc.

- Service transport: Bandwidth (in bits/s), latency, (i.e. delay), jitter (i.e. delay variation), error rate, contention, round-trip delay (including delay budget of server, application and network), distortion, etc.
- Customer equipment: Quality of playback, required storage capacity (in bytes), easy of selection and playback, easy of navigation and downloading, ergonomic aspects of the user device, etc.

Figure 2.6: Four-market model



Source: ITU-T (Rec. E.802)

The ITU-T QoS framework, including the four viewpoints as well as four-market model, provides the basis for the definition of QoS and further QoS regulation. QoS regulation can be targeted to NGN services regulation and to Internet services regulation. In particular, QoS regulation may apply:

- between operators at the interconnection level, and
- between operators and end-users.

However, regulation of QoS in these instances raises a number of questions[2]:

- Which QoS issues for certain services (e.g. voice, television) have to be changed when transitioning from the public switched telephone network/public land mobile network and broadcast networks to all-IP based networks, such as NGN?
- Which QoS criteria should be included for services regulated and monitored by national regulatory authorities when differences exist between countries (e.g. differences in the quality of the network infrastructure, network capacity or server capacity, human resources, etc.)?

In addition, the specificities of the networks need to be taken into consideration, such as the best effort nature of the Internet and its architecture, which although not suited well for QoS provision (e.g. voice over IP (VoIP)) that can evolve accordingly by adding certain functions in the network nodes and the service platforms, as standardized for NGN. The technical parameters for QoS are also different between packet-switched Internet and circuit switched traditional telecommunication networks. However, the differences in terms of regulatory implications are related to the multi-service and multi-operator environment of the Internet and to its fundamentally global character. Regulation may be required to ensure/enforce interconnection service level agreement (SLA) between Internet dominant players in a given market (e.g. dominant network providers in a given country). QoS for certain services such as voice (e.g. latency for QoS-enabled voice delivery) in any IP-based network infrastructure should not be lower than the delay experienced in circuit switched plain old telephone services. In general, the Internet environment is mostly competitive due to its openness to new services and applications either locally (provided in a given network) or globally (e.g. websites), hence

[2] ITU and InfoDev *ICT Regulation Toolkit: Key Points and Recommendations on QoS Regulations* www.ictregulationtoolkit.org

regulatory intervention should be limited. However, in cases where markets for Internet access service are not sufficiently competitive, then there is a need for regulation.

3 QoS regulatory framework and role of national regulatory authorities

Policy-makers want consumers to have services of good quality and to develop appropriate QoS regulation. In defining the QoS regulatory framework, a number of questions need to be addressed by policy-makers and regulators. These include:

- What level of QoS do consumers want and need? (This is the job of the ITU-T SG-12.)
- Which national policies and laws, country benchmarking and practices are relevant to QoS matters?
- What QoS are consumers willing to pay for? Provision of services with higher quality tends to have higher costs for both operators and customers when compared to the same services with lower quality (e.g. Internet access service with 1-2 Mbit/s in downlink or uplink direction will provide lower QoS than Internet access with bit rates of 50-60 Mbit/s, respectively).
- Which policy measures if any are conducive to consumers having services available at the levels of QoS they want and need? In the absence of policy interventions, would network operators be motivated to provide services with good QoS at prices that are reflective of cost? If so, might policy interventions make things worse for consumers? If not, what kind of policy interventions might make things better?
- Should the regulatory authority impose QoS standards? Are market forces alone sufficient to ensure appropriate QoS? This is a longstanding debate among policy-makers.

Countries have taken different approaches to answer these questions depending on their national circumstances (e.g. existing infrastructure, national targets, etc.). There is no global consensus as to a single, best way; different approaches are needed. The answer to this question obviously has to do with the degree of competition in the market in question; for this reason, the approach in mature markets is, in principle, different from the approach in less mature markets.

If a national regulatory authority imposes QoS standards, the delivery of services in excess of what many consumers strictly require can result (e.g. some users may prefer low price for lower quality). In countries where competition is weak or non-existent, this may not be a concern as there might not have been any low price lower quality offerings in any case. In countries with little or no competition, QoS standards and higher prices may be preferable to low quality and nonetheless high prices. In countries with competition, however, it is often the incumbent that promotes QoS regulatory standards since they limit the ability of other network operators to compete aggressively on price.

In countries with greater competition, or at least with strong prospects of competitive entry, it is often preferable to leave QoS to market forces that may lead to different levels of quality, with correspondingly different prices. Different consumers have different willingness to pay (WTP) for different levels of quality, or even different WTP for QoS for different conversations. Price and quality differentiation benefit the network operators overall as they can capitalize on these differences and extract more revenue. Consumers also benefit from differentiated services that match their preferences. Aggregate consumption tends to be higher, benefiting broader society.

These questions are relevant to many aspects of QoS, and are equally relevant to traditional networks and to IP-based networks.

Developed countries tend to adopt a light touch approach when enforcing QoS standards. Some developed countries (including all of those in the European Union) require network operators to publish statistics on the QoS that they offer and/or the QoS that they achieve. In other countries, persistent failure to achieve committed levels of QoS can be actionable, not as a matter of telecommunication regulation, but rather as a matter of truth in advertising.

A key advantage of this light touch approach to QoS regulation is that it encourages network operators to tailor the QoS of their offerings to meet the requirements, and the corresponding WTP of customers.

The possible approaches for QoS regulation in these countries include:

- Neither monitoring nor enforcement: A minimal role for the regulator.
- Passive monitoring without enforcement: Typically a watching brief.
- Self-regulation: Possible monitoring and a watching brief.
- Co-regulation: Market participants play a key role, but the regulatory authority oversees the process and steps in if needed.
- Regulation: The regulatory authority is typically involved not only in setting standards and monitoring compliance, but also when enforcement is needed.
- Publication of QoS commitments, and enforcement via truth-in-advertising legislation: The division of responsibilities could vary, but primary responsibility is a matter of consumer protection.

Overall, countries can address QoS through different means which include:

- development of standards;
- licence regulation;
- monitoring, measurement techniques through survey and test;
- enforcement.

In this fast changing ICT environment, the NRA needs to keep pace with technology, market and business innovations, while ensuring consumers make informed decisions and benefit from reasonable quality services. In most countries, the regulatory framework sets out QoS regulation by setting minimum QoS standards, defining minimum value of QoS parameters, monitoring QoS, defining measurement methods and setting targets, reporting and publication procedures. QoS obligations can be found in different legal forms such as telecommunication laws and consumer protection laws, universal service directives (e.g. in the European Union), licence regulation, QoS regulations, etc.

Analysis of the contributions of QoS monitoring toward achieving regulatory targets is provided in Table 2.3.

Table 2.3: Direct contributions of QoS monitoring to achieving regulatory targets

QoS area	Monitored operators	Regulatory targets							
		Checking claims by operators	Helping customers make informed choices	Improving user experience	Understanding the state of the market	Maintaining or improving quality in competitive markets	Maintaining or improving quality in the absence of competition	Helping operators to achieve fair competition	Making inter- connected networks & platforms work well together
Setting targets	Dominant traditional operators only						+	+	+
	Dominant operators, incl. OTTs/ OSPs						+	+	+
	All traditional operators				+				
	All service providers, incl. OTTs and OSPs				+				
Making measurements	Dominant traditional operators only								
	Dominant operators, incl. OTTs/ OSPs								
	All traditional operators	+			+				
	All service providers, incl. OTTs and OSPs	+			+				
Publishing measurements	Dominant traditional operators only						+		
	Dominant operators, incl. OTTs/ OSPs						+		
	All traditional operators	+	+	+	+	+			
	All service providers, incl. OTTs and OSPs	+	+	+	+	+			

Note: A '+' occurring in an entry in this Table indicates that the activity contributes to achieving regulatory targets. Making measurements is assumed to be required by publishing measurements and setting targets, but making measurements is not awarded '+' just because publishing measurements or setting targets is awarded '+'.

Source: ITU: www.itu.int/ITU-D/treg/Events/Seminars/2006/QoS-consumer/documents/QOS_summary.pdf

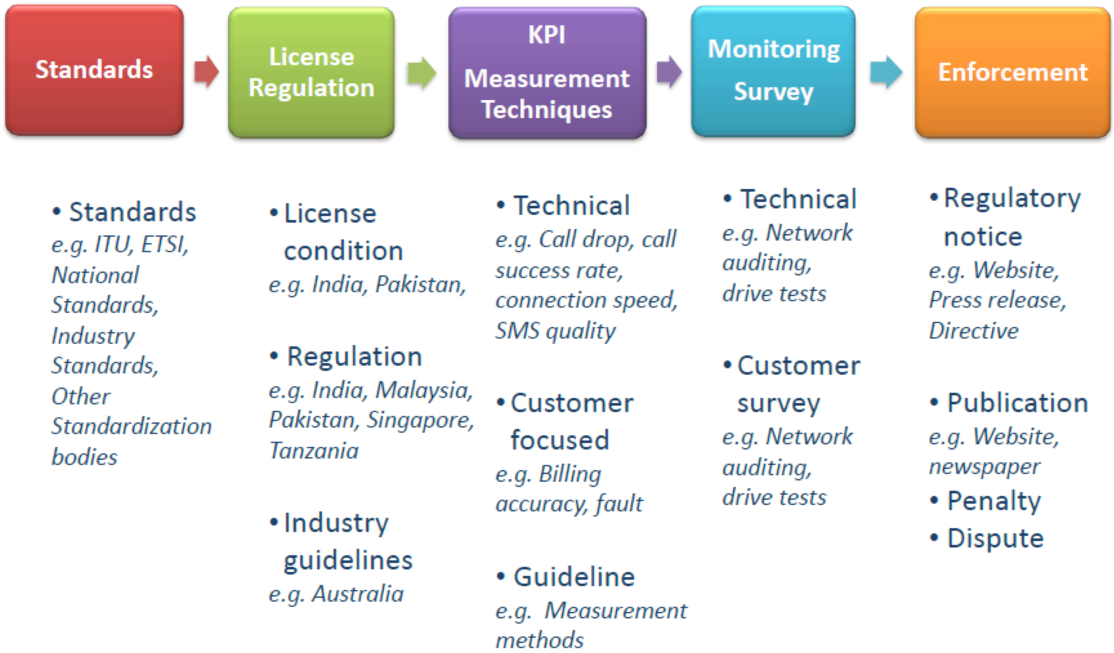
QoS has to be defined based on requirements given to the network and/or service providers. Typically, such a role falls under the jurisdiction of the regulatory authority that implements the QoS regulatory framework; the same can be considered by other authorities in charge of telecommunication/ICT regulations (e.g. NRA, ministry or other government body). The role of NRAs regarding services can be summarized as follows:

- Impose special obligations on operators of publicly available services concerning the provision of availability of services to all users, including users in sparsely populated areas as well as users with disabilities.
- Keep an updated database of prices, conditions of access and use (including limitations), and the quality of public communications networks and services (including voice, messaging, television, data services, etc.). The NRA shall update this data and make it publicly available on its website.
- Monitor, measure and ensure that networks are professionally designed and of a satisfactory quality, and that they provide the desired QoS for different services offered through the given network operator which delivers broadband access.
- Ensure and enforce the quality of the communication services and Internet access service. For that purpose, the NRA should set minimum QoS requirements on Internet access providers and other appropriate measures to enforce QoS to ensure that all end-users enjoy an Internet access service of good quality.
- Ensure and enforce the quality of QoS enabled services (e.g. carrier grade VoIP, IPTV, business services, etc.) according to the service level agreements (SLAs) concluded between the provider and the end-users.

3.1 The quality of service regulatory framework

The QoS regulatory framework is outlined in Figure 3.1. It starts with setting standards, developed by global standard developing organizations (SDOs) such as the ITU-T, as well as by regional SDOs (e.g. ETSI in Europe, etc.). QoS standards can be implemented as part of licence conditions (e.g. India, Pakistan, etc.), ICT regulation (e.g. India, Malaysia, Pakistan, Singapore, Tanzania, etc.), or industry guidelines (e.g. Australia, etc.). QoS is defined through a given set of parameters that are measurable. Such quality parameters that are defined for QoS measurements in a given country (or globally) are referred to as key performance indicators (KPIs.) KPIs can be technical and non-technical. Examples of technical KPIs include call success rate, call drop rate, connection speed (downstream and upstream), SMS delivery time, etc. Non-technical KPIs are customer focused, and may include parameters such as billing accuracy, fault, etc. Once defined, KPIs will serve for monitoring purposes. Different measurement methods can be used; this may differ from one country to another. KPI monitoring is done by the NRA as well as by operators (network providers and/or service providers) or independent organizations. Different approaches exist in the monitoring of technical and customer focused KPIs.

Figure 3.1: QoS regulatory framework



Source: ITU

For example, technical monitoring of KPIs can be performed by network auditing, drive tests (in mobile networks), probe stations on selected locations, etc. The customer focused KPIs are monitored by customer surveys. The purpose of monitoring the values of the defined KPIs (used to define the required QoS in a given country) is to detect degradation of the QoS when it appears, and to apply appropriate actions to enforce QoS. Such QoS enforcement can be performed through a regulatory notice (e.g. publishing KPI monitoring results on a public website, through press releases, via directives, etc.) with the aim of informing customers. However, if such enforcement approaches are not enough to enforce QoS, then more drastic QoS enforcement should be undertaken through financial penalties (to non-conforming telecommunication operators or service providers) or through dispute resolution mechanisms.

The first step of a QoS regulatory approach is to obtain appropriate information on the level of QoS and identify problematic areas. The next step is to publish the information on QoS performances in order to inform customers. The following step is to impose regulations on minimum required performances on a selected set of KPIs (e.g. bit rates). Enforcement measures include imposing fines and compensation for non-conformant operators. Finally, in all steps, constructive dialogue between the authority for ICTs (ministry, NRA, etc.) and the operator concerned is encouraged to foster QoS implementation and improvements.

3.2 Principles for quality of service regulation

As stated in Supplement 9 to ITU-T E.800-series Recommendations, there are four main elements in a regulatory approach to QoS:

1. Obtaining appropriate information on the level of QoS and identifying problem areas. This is essential, without the appropriate information, the other elements cannot be undertaken.
2. Undertaking a constructive dialogue with the operator concerned to encourage and foster improvements.
3. Publishing information on QoS performance so that customers can be better informed.

4. Imposing regulations on performance, such as required minimum levels and fines or compensation.

There are basically two alternative approaches:

1. Regulation-oriented approach, where reporting is to the regulator; performance targets are set in regulations; fines are payable to the regulator if targets are not achieved.
2. Customer-oriented approach, where reporting is to the customer; targets and minimum performance levels are provided in contracts; compensation for poor performance is payable to the affected customer.

QoS regulation has a cost and the costs should be assessed against the benefits. Efforts should be focused where there are known problems. In addition, problem areas can change so there needs to be a degree of flexibility. The following clause provides an overview of the fundamentals of QoS regulation (ITU-T Rec. E.800):

Quality of service regulation is part of customer protection. However, customer protection is broader than quality of service regulation and covers, for example, sales activities, complaint resolution procedures and disconnection policies. Furthermore, as explained earlier, QoS is not the same as network performance, which is concerned with standards for network design.

The main purposes of QoS regulation are (ITU-T Supp. 9 of E.800 Series):

- helping customers be aware of the QoS provided by telecommunication operators/ ISPs through networks (mobile and fixed), so that they can make their own choices;
- checking claims made by operators;
- understanding the state of the market;
- maintaining / improving QoS in the presence of competition;
- maintaining / improving QoS in the absence of competition;
- helping operators to achieve fair competition; and
- making interconnected networks work well together.

QoS regulation is based on a selection of so-called QoS parameters, which can be technical (examples in ITU-T Rec. 804) and non-technical (examples in ITU-T Rec. E.803). Standard developing organizations, such as ITU, standardize QoS parameters for different services. For example, ITU-T Rec. E.804 defines QoS parameters for popular mobile services. ITU-T Rec. 803 defines parameters for supporting aspects of QoS. Not all QoS parameters are subject to regulation. The selected QoS parameters that are important to users, operators and the regulator are referred to as KPIs. Different countries have specific characteristics regarding their QoS parameters and therefore their target values may vary from country to country for a number of reasons (e.g. low penetration of certain services, early years of development of certain services in that country, etc.). Some variations of standard parameters may be necessary, depending on the specific situation in a given country or sector. The measurements of a parameter might need to distinguish between:

- Market segments: QoS may be different for private consumers, small and large businesses or for wholesale and retail offerings.
- Reporting areas: Areas likely to have differences in quality, such as rural and urban areas.
- Operators: Who have few customers, that resell services from other operators, or that are not dominant in the market might be exempted from monitoring parameters or publishing measurements.

- Services: Parameters may be specific to services such as voice, text messages and Internet, television and radio broadcasting, as well as leased lines, as the main services that have most impact on users.

3.3 Service level agreements

This section draws largely from ITU-T Rec. E.860 to describe what a service level agreement is, how it can help enforce QoS, and the role of the regulator.

According to ITU-T Rec. E.860, a service level agreement (SLA) is a formal agreement between two or more entities that is reached after a negotiating activity, with the scope of assessing service characteristics, responsibilities and priorities of each part. An SLA may include statements about performance, tariffing and billing, service delivery and compensations. It is a commercial agreement that is typically monitored by the NRA.

In a multi-provider environment, the relationships that exist between service providers may be very complex. For example, a primary service provider that wants to deliver a service to a customer often uses service elements provided by other service providers, and consequently it becomes much more complex to ensure the QoS level as stated in the SLA. It is therefore necessary to define the responsibilities of all entities involved in service delivery, and, above all, to coordinate all activities in order to reach the agreed QoS levels end-to-end.

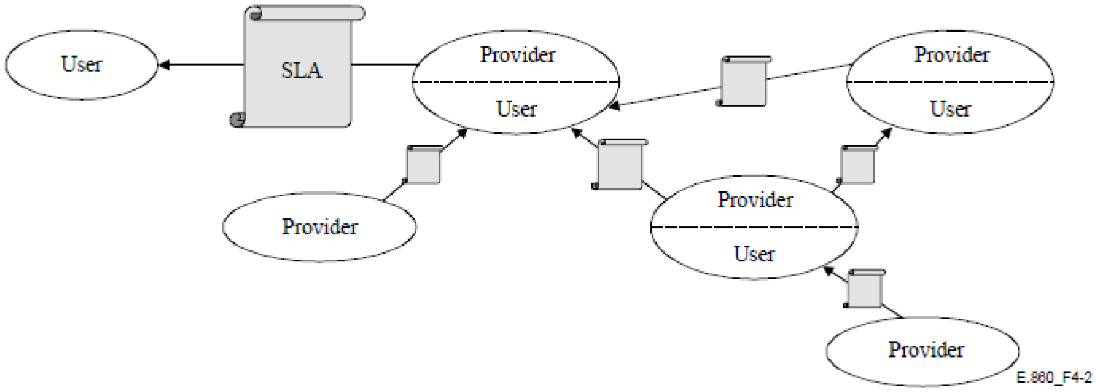
This is when the concept of *one stop responsibility* can come into play. The concept is based on the SLA agreed by two entities that stipulates the QoS conditions, among others. This is called QoS agreement or service quality agreement (ITU-T E.800). An illustration of SLA content is provided in Figure 3.2.

Figure 3.2: SLA between service provider and end-user

Source: ITU

As explained in ITU-T Rec. E.860, one stop responsibility, as agreed between a provider and a customer under an SLA, allows a user to retain a primary service provider, with whom the user signed the SLA, as the sole responsible party for the overall QoS received. In turn, the primary provider can apply the same one stop responsibility to its sub-providers. This however is not obligatory considering the SLA toward the end-user (e.g. there can be peering or transit agreements between the Internet service provider (ISP) i.e. the provider with other ISPs, which are not directly related to the end-user SLA. They can, however, indirectly influence the end-user SLA, as discussed in Chapter 5 on end-to-end QoS provisioning.

Figure 3.3: One-stop responsibility concept for the SLA



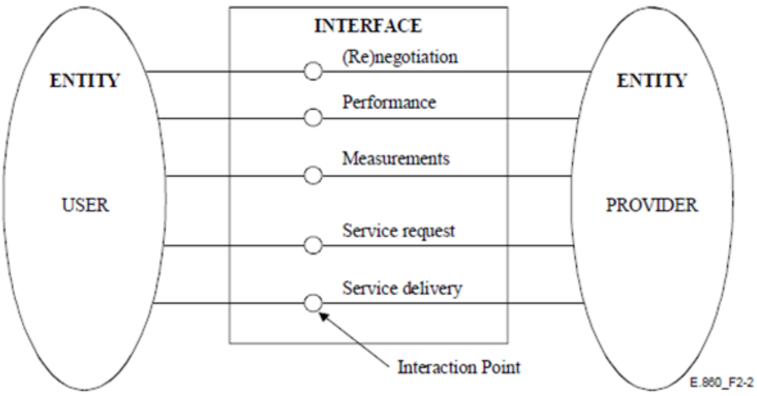
Source: ITU

According to E.860, by applying the one stop responsibility in a recursive manner to all entities (provider and sub-providers) taking part in the provision of the service (Figure 3.3), the service agreed with the end-user is then guaranteed. Again, in practice there are possible variations in this regard since the ISP (i.e. the provider) may use different peering or transit for the traffic to/from the user in different times or locations.

The terms defined in ITU-T Rec. E.860 related to the SLA that are used in the remaining part of this section (Figure 3.4) include the following:

- **Entity** is a generic unit involved in using/delivering a service. It is characterized by its states and its transitions from a state to another. An entity that delivers a service to another entity is called **provider** while the entity that receives the service is called **user**.
- **Interaction point** is where two entities can exchange information. Sometimes an interaction point between user and provider may not belong to their logical interface although this point remains under the control of the provider.
- A group of interaction points at the logical boundary between two entities constitutes an **interface**.

Figure 3.4: Definition of entities and interfaces for SLA



Source: ITU

3.3.1 Quality of service agreement

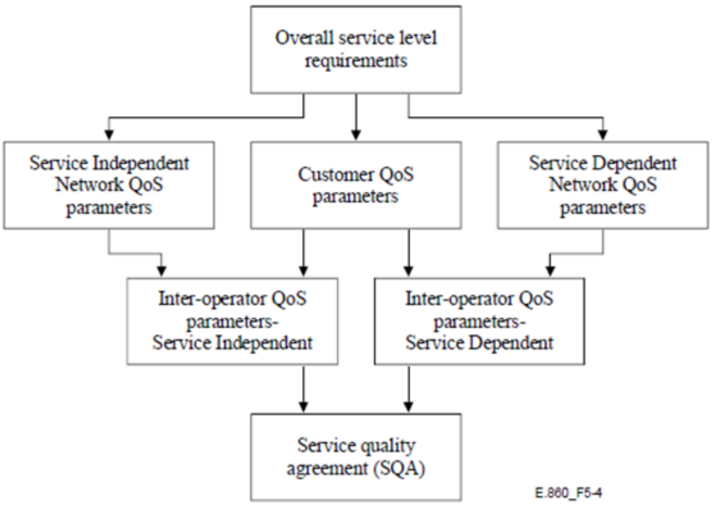
The part of the SLA that refers to QoS is called a QoS agreement and includes a formal programme mutually agreed by the two entities for choosing, measuring and monitoring QoS parameters. The goal is to reach the QoS agreed upon with the end-user and thus obtain end-user satisfaction. The definition of QoS parameters is an essential stage in developing an SLA and, in particular, its corresponding QoS agreement. QoS parameters need to be expressed in a clear and accessible way, in simple language for the end-user and more technical language for service providers. Regarding the type of information exchanged, the following interface descriptions are included in ITU-T Rec. E.860:

- Business interface: This interface is composed of interaction points always located between the user and service provider, used for specific QoS agreement functions as well as (re)negotiation, performance reporting and reaction patterns that are triggered when the agreed QoS level is not provided.
- Technical interface: This interface exchanges service specific information and allows measurements from which QoS parameters are derived.

In order to manage its own resources properly, every entity must know the **characteristics of traffic** that it receives from other entities (traffic at the entry points). Outgoing traffic for one entity is incoming traffic for another entity, for application and management flows.

The conditions (thresholds) that enable the activation of reaction patterns from the receiving entity have to be specified. The description of traffic patterns should be clearly understood by the entities on both sides of the interface. In this way, any possible reaction can be clearly justified to the penalized entity involved in using or delivering a service (e.g. network or service provider). One way to individuate QoS parameters in an interconnection between two entities is provided in ITU-T Rec. E.860, and described in Figure 3.5, where both customer and network parameters are taken into consideration.

Figure 3.5: Determination of QoS parameters for service quality agreement



Source: ITU

A telecommunication service is defined as a group of functions whose realizations are observed through direct or indirect analysis of corresponding events. If we are considering all possible types of functions, a useful categorization of primary QoS parameter is the Timeline Model approach defined by the European Telecommunications Standards Institute (ETSI).

In ITU-T Rec. E.860, the Timeline Model identifies three possible scenarios (levels) on the basis of a temporal scale, and each scenario is then divided into three phases:

- First level: Service scenario, refers to design and realization of a given service by the service provider in a range of years or decades.

- Second level: User scenario, has the focus moved from the totality of the users to the service utilization of each single user (the end points are the start and end of the subscription period) in a range of months or years.
- Third level: Session scenario, attention is focused on the single call/session. End points are the setup and the release of a given call or session, so time intervals are referred to in a range of seconds, minutes or hours.

In all three of these scenarios, quality of service depends on the accuracy of the service functions provided, which is valued on three criteria (I.350):

1. Speed
2. Accuracy
3. Reliability

QoS is assessed by assigning proper values to QoS parameters, which can be divided into two groups:

- Direct parameter refers to a specific service element and is determined by collecting direct observations of events in correspondence with its interaction points.
- Indirect parameter is defined as a function of other direct parameters. Indirect parameters are defined as functions either of values of primary QoS parameters or of decisions taken on the basis of the latter. A good example of an indirect parameter is service availability.

Example from ITU-T Rec. E.860:

Service availability (SA%) is often derived from measurements of service unavailability (UA%) applying the formula: SA% = 100% – UA%

The expression that allows calculating UA% is the following:

UA% = (Σ outage interval / Active time) x 100%

3.3.2 Service level agreements for end-to-end quality of service

To achieve end-to-end QoS, SLA agreements are needed between end-users or end-entities and service providers, as well as between all providers along the path between the end-points of the given call or session. Several service providers are often involved in a service provision and collaborate together in realizing the various service elements forming a multi-provider environment.

Using one stop responsibility, the end-user will rely exclusively on the agreed QoS with the service provider from their negotiated SLA, while the service provider will have to guarantee that QoS by signing, in turn, suitable SLAs with its sub-providers. Such an approach assures that end-to-end QoS of connections, which pass through several service providers, will fulfil QoS agreed with the end-user in the SLA.

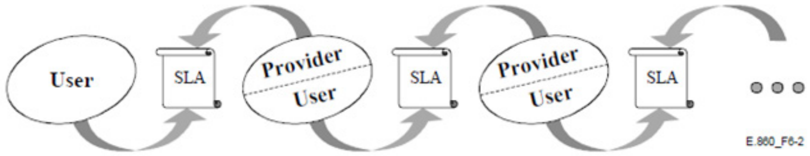
Another method consists in making a chain of SLAs between each user/provider pair involved in the provisioning of the same service. The chain starts with an end-user and primary provider SLA that states the end-to-end QoS. In turn, the primary provider – bearing in mind the promised performance – contracts SLAs with sub-providers recursively to make a chain (as presented in ITU-T Rec. E.860 and reported in Figure 3.6). A general procedure for end-to-end SLA includes:

- The input includes the service description, the entities involved, the description of their roles and their relationships (business model).

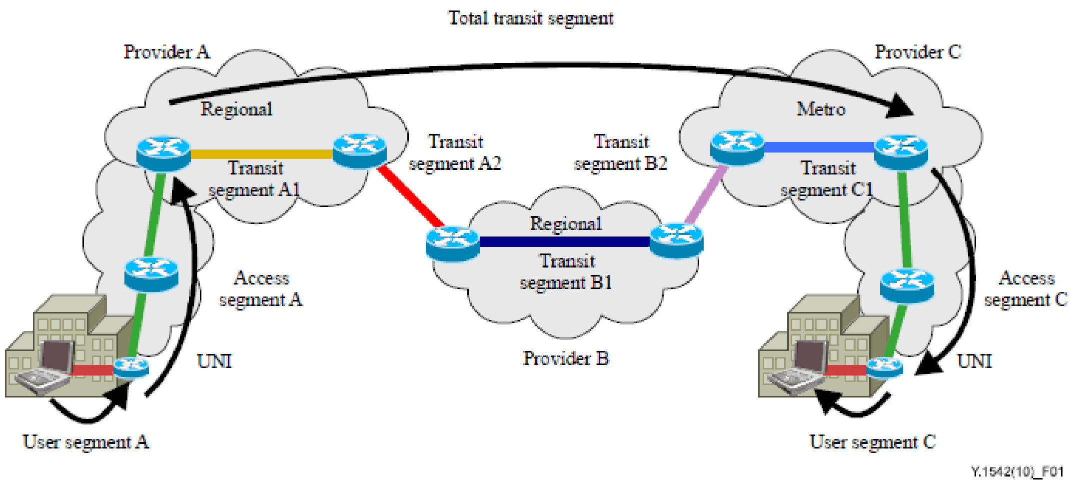
- The procedure individuates the service elements provided to the primary provider by its sub-providers and both business and technical interfaces that will be used.
- The outputs are the service delivery configurations with the description of an SLA for each user/provider pair identified during the procedure.

Figure 3.6: Theoretical chain of SLAs for end-to-end QoS (a) and practical framework for achieving end-to-end IP performance objectives (b)

a) Chain of SLAs for end-to-end QoS



b) Practical framework for end-to-end QoS



Source: ITU

3.3.3 Service level agreements, quality of service regulation and legal aspects

The inclusion of an SLA in contracts has become popular but such agreements are not always effective as their formulation may be vague, and compensation terms may not be stated. Furthermore, the process for claiming compensation may be made excessively complex to deter claims. To be effective, the SLA should state:

- The minimum level of performance offered to the customer, not the average level to be achieved for all customers.
- The compensation payment, if the minimum level is not achieved with the sum at least proportional to the degree of failure.
- The mechanism for claiming compensation. In most cases compensation should be paid automatically and the customer should not be required to make a claim.

It is possible to enforce penalty clauses for failing to meet QoS service levels under relevant domestic laws. Ideally, the goal of the penalty portion of the contract should be oriented less toward punishing the service provider and more toward providing incentives. However, penalties may be charged in a certain amount of money proportional to the interruption period for defined QoS parameters in the SLA. There are cases when penalties are avoided with certain negotiations between the parties (e.g.

the ISP and the client), which may result in the release of the SLA and the option to change providers before the expiration of the SLA.

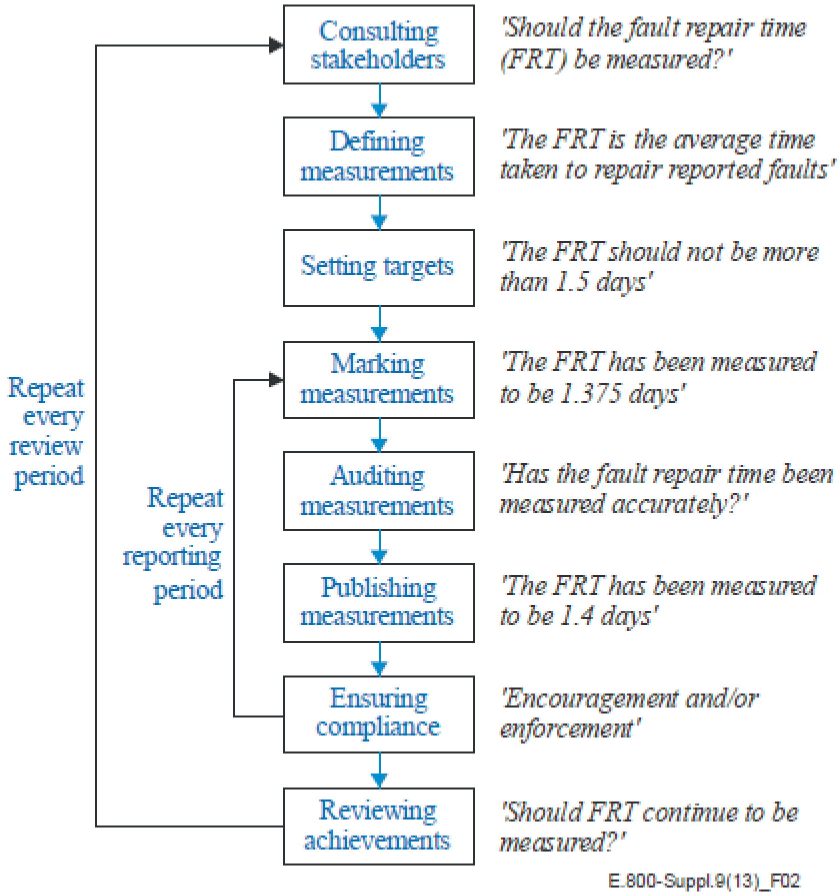
Regarding QoS regulation and especially QoS enforcement, the SLA can play an important role. Typically the NRA is the authority that monitors the format of agreements between telecommunication operators (as service providers) and end-users. Selected QoS parameters as KPIs may be a part of the SLA, such as bit rates in downlink and uplink. For example, by requiring the SLA to specify minimum bit rates in downlink and uplink (where that is technologically feasible, such as in fixed access networks), the NRA can ensure operators provide a certain level of broadband access to the end-users in the country and take enforcement measures if they fail to do so. However, there can be different targets specified for differently priced services, such as different prices for different access bit rates in downlink and uplink direction. The offers for the end-users should be market driven (in mature markets), while the NRA can specify the minimum bit rates that can be offered to the end-users (e.g. to stimulate the uptake of broadband access in the country, which is of higher importance to society in general, and avoid it being just a market battle between telecommunication operators as service providers).

3.4 Activities in quality of service regulation

Quality of service regulation requires the regulator to perform the following activities, as provided in Figure 3.7. Some of these may also be performed by the operator, consumers or even third parties in some cases (contracted or independent). These activities will be examined in greater detail in the following sections:

- defining parameters;
- setting targets;
- making measurements;
- auditing measurements;
- publishing measurements;
- ensuring compliance.

Figure 3.7: Activities in QoS regulation



Source: ITU

3.4.1 Defining quality of service parameters

When defining QoS parameters, the involvement of operators is beneficial and desirable. However, there is a risk that they may exercise undue influence and that the consultation process could be lengthy. The regulator needs to exercise strong leadership while ensuring that stakeholders are consulted. The following factors, among others, should be taken into consideration:

- the practicability for operators to make the required measurements;
- the practicability for regulators or any independent entity to audit the results;
- the measurement being made should retain the customer experience aspect.

QoS regulation is based on the definition of QoS parameters that will be monitored for the purposes of QoS enforcement. A target is defined as a potential value (or a range of values) for a parameter that must be reached if quality is to be regarded as satisfactory. Three classes of parameters determine the user experience:

1. Customer interface parameters.
2. Network infrastructure parameters.
3. Service functionality parameters.

Service functionality parameters are organized according to service type (such as voice, SMS, etc.) rather than by operator type (fixed wireless, wireline, mobile, etc.) to help with comparability between countries and consistency in the treatment of operators.

Parameters are named according to the same conventions irrespective of how they are named in different countries. As such, *rate*, which defines the frequency of actions, *ratio*, which stands for the proportion of actions that succeed, and *time*, which means the average time taken by actions that succeed. A list of proposed QoS parameters is provided in Table 3.1.

Table 3.1: List of proposed parameters

Customer interface	Network infrastructure	Service functionality
1 Customer complaint submission rate	4 Coverage	8 Call set up ratio
2 Customer complaint resolution time	5 Service supply time	9 Call retention ratio
3 Customer service call answer ratio	6 Fault report submission rate	10 Listening voice quality
	7 Fault repair time	11 Value added service call answer ratio
		12 Message transmission ratio
		13 Packet transmission ratio
		14 Packet transmission rate
		15 Data transmission capacity

Source: ITU-T Supplement 9 to ITU-T E.800-series

3.4.2 Setting target levels

Targets are normally set by the regulator based on consultation and prior monitoring of operator data. An operator can also set targets and be required to publish them. Aggregated performance targets, for example, involving a number of different observations can be formulated in two different ways:

1. The percentage of events that exceed or fail to meet a target level of performance (e.g. % lines delivered in more than X days). In this case, X indicates a target level.
2. The number of days within which 90 per cent of lines were delivered. In this case, no target level is indicated.

If compensation is going to be given, then the measure must have a simple pass or fail criterion for each individual customer.

3.4.3 Making measurements

As Table 3.1 shows, for customer interface and network infrastructure parameters, these measurements can be easily made by operators. Many service functionality parameters are best made by external measurement agencies or by use. Measurement methods, if possible, should be objective. For some issues – such as the effectiveness of call centres and help lines – it may not be possible to specify a parameter that can be measured objectively, and subjective user assessments are used, e.g. the caller is asked at the end of the call to assess its effectiveness on a scale of 1-5. While this does give some measure of performance, it is not suitable for the application of penalties or compensation. Measurement may be taken by third parties or reported by the operator itself. They may be based on sampling or include all events. Where measurements can be built into the network or support systems and be automatic, then self-reporting covering all events is normally the best approach. Regarding measurements, there are two methodologies for measuring QoS:

1. Passive measurement (using test packet): Test packets are sent from management systems, and performance metrics such as delay, jitter, and packet loss are measured along the way. This method is also often used for troubleshooting.
2. Active measurement: Probes in the form of software agents or network appliances are deployed on network elements and user devices (for the software agent case). Measurements based on these probes provide a very accurate status of the devices at any time. The sources and sinks of probes may be either dedicated measurement devices, routers that are dedicated to measurement tasks, or routers that support both data traffic and measurement probes. The main drawback of this measurement is that it doesn't scale for large networks.

Regarding international practices, active testing (i.e. active measurement) is the mostly commonly adopted methodology by NRAs to measure QoS of broadband Internet provided by ISPs. Active testing allows regulators to regularly produce benchmarking reports. However, the active testing methodology faces implementation challenges, including:

- The cost of implementing this methodology is high.
- For benchmarking/comparison of QoS performance of various ISPs, the sampling methodology is very critical; therefore, QoS monitoring tools (probes) have to be deployed to replicate a like-for-like QoS performance comparison of ISPs.
- It requires very close collaboration with ISPs and Internet consumers.
- The results from the measurements should be reported for the purpose of auditing the QoS. Reporting normally involves aggregated results. The question is whether they should be aggregated over:
  - all parts of the network or aggregated separately for different areas;
  - all customer types or reported separately for business and residential customers.

This can only be decided on a case-by-case basis taking local circumstances and quality problems into account.

3.4.4 Audit of quality of service

The purpose of QoS auditing is to verify QoS experienced by customers and to compare the results (from audit exercises) against licence obligations. The methods of auditing telecommunication operators include:

- Drive test (performed on a quarterly basis or as required)
- Consumer survey
- Data submitted on a monthly or quarterly basis by telecommunication operators, etc.

For example, consumer surveys can effectively pinpoint the weakest elements of service quality, giving operators good feedback, while allowing customers to compare their views on the various operators with other people. It is also a good addition to the indicator-based method of measurement. Contrasting the two sets of data can determine whether a weakness identified by consumers also falls among the low-levels of relevant indicator data.

3.4.5 Publishing measurements

Measurements should be published by the regulator to help carry out comparisons between operators. To simplify the task, the number of measurements to be published could be reduced. The main purpose of publishing information on QoS is to better inform customers.

Regulators should publish information on performance on their websites and also require operators to send the information periodically to subscribers with their bills. QoS information examples that should be published include the QoS results from the audit campaign (drive test, consumer survey, etc.).

This information should be made available as soon as possible.

3.4.6 Ensuring compliance

Ensuring compliance is highly recommended in QoS regulation. There are two approaches in implementing QoS regulations:

1. The encouragement approach.
2. The enforcement approach.

For the regulator to proceed with the enforcement approach, it may start with recommendations and move towards obligations. The regulator can adopt a range of techniques, starting from naming-and-shaming strategies to tighter regulation, financial penalties and finally more drastic legal enforcements. However, doing so can involve extensive legal processes and may take a long time. A schedule of penalties may be announced publicly to ease implementation.

As a general principle, it is recommended that both encouragement and enforcement should be graduated and proportional. Whenever feasible, the regulator should engage in constructive dialogue with operators on quality problems. This should not be seen as a process of telling the operator how to run their business, but of asking targeted questions that can trigger the operators to review and reconsider their approach in areas with specific problems.

4 Traffic management

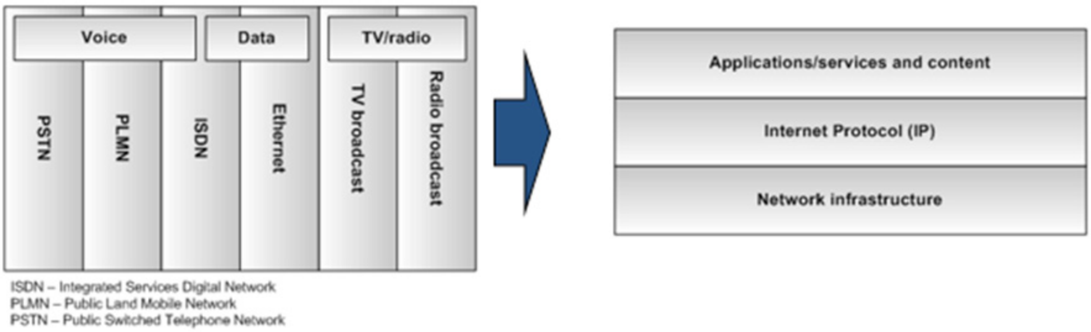
4.1 Convergence of telecommunications and Internet

The network layer of the Internet is the IP (Internet Protocol). Version 4 (IPv4) is currently present in every host, router and gateway of every network. As it stands, it does not contain mandatory QoS mechanisms. However, it does have the ability to identify the type of service field and specify QoS requirements on precedence, delay, throughput and reliability. In a similar manner, IPv6 has a differentiated service code point field and can support QoS per flow on the network layer (e.g. by using flow label and next header options). However, both IPv4 and IPv6 do not guarantee the actual end-to-end QoS as there is no reservation of network resources, something that should be provided by other mechanisms in IP networks. Internet is built on autonomous systems, where each system is identified by a 16-bit or 32-bit number. This number is allocated by the Internet Assigned Numbers Authority (IANA), a department of ICANN (Internet Corporation for Assigned Names and Numbers) that currently governs the Internet in terms of domain naming and IP addressing, as well as other well-known numbers from various standardized protocols for IP networks, such as port numbers used by transmission control protocol (TCP) and user datagram protocol (UDP). The system is autonomous because it can apply traffic management schemes and routing protocols in its administrative domain independently from other systems. Internet and global telecommunication networks are based on IP networks, consisting of 50 000 to 100 000 active systems, which are interconnected between each other. Each system is interconnected with one or more neighbouring systems, not with all of them, thus creating the global telecommunication network of today, completely based on Internet networking technologies. This is crucial in understanding why the traditional way of enforcing QoS (same approach in all countries, e.g. for digital telephony, i.e. PSTN/ISDN) is no longer possible in an IP-based environment due to the heterogeneity of the various IP networks, applied management techniques, and the plethora of services and applications that are constantly being offered (e.g. in OTT applications/services ecosystems). QoS as an end-to-end characteristic is becoming more complex in a telecommunication environment based on Internet technologies.

The traditional telecommunication approach by default includes end-to-end QoS support in the network. The main purpose of the NGN standardization framework is to standardize the end-to-end QoS support in all-IP networks (including all needed functions in transport and service stratums) that is essential for real-time services, such as VoIP and IPTV. Such services have strict requirements regarding QoS (e.g. guaranteed bit rates, losses, delay, and delay variation). Therefore, NGN provides a standardized implementation of QoS (instead of proprietary case-by-case implementation) that is mandatory for the transition from PSTN and PLMN to all-IP networks.

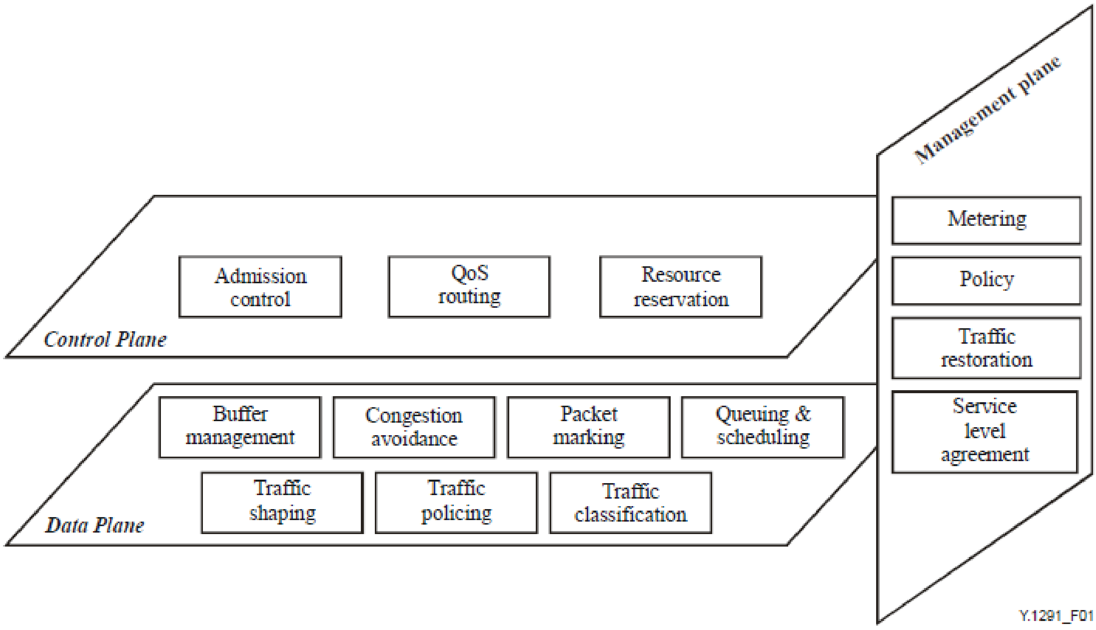
In an all-IP telecommunications/ICT world, Internet technologies should be considered for traffic management and for QoS standardization, monitoring and enforcement. The transition from the vertical silo approach to a horizontal layered approach in an IP environment is illustrated in Figure 4.1.

Figure 4.1: Transition from vertical separation of networks and services (the old way) to horizontal separation of services/applications and broadband IP networks (the new way)



Source: Dr Toni Janevski, NGN Architectures, Protocols and Services, 2014

Figure 4.2: QoS architectural framework



ITU has defined an architectural framework for the support of QoS in packet networks. Although there are unified packet switched networks, different packet switched networks also exist that are standardized, including the SS7 signalling as well as asynchronous transfer mode (ATM). The QoS framework defined by ITU-T (Figure 4.2) is organized into three planes (ITU-T Y.1291):

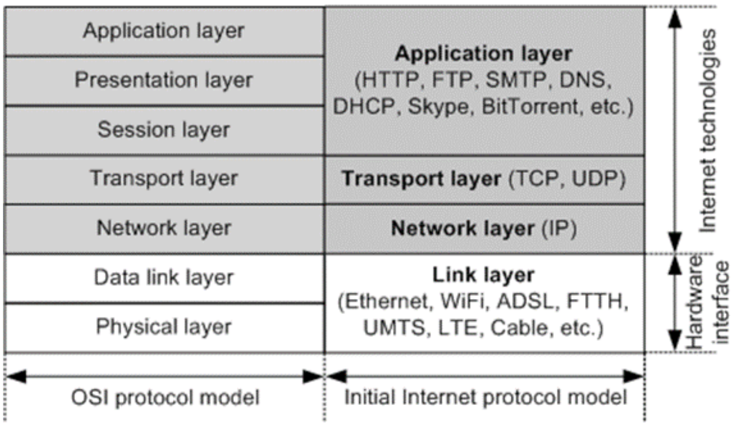
1. The control plane: admission control, QoS routing, and resource reservation.
2. The data plane: buffer management, congestion avoidance, packet marking, queuing and scheduling, traffic classification, traffic policing and traffic shaping.
3. The management plane: SLA, traffic restoration, metering and recording, and policy.

4.2 Internet technologies: the basics

To regulate QoS, regulators need to understand how traffic management applies in telecommunication networks. Because telecommunication networks are becoming all-IP, understanding Internet technologies is key. This section examines the basics of Internet technologies.

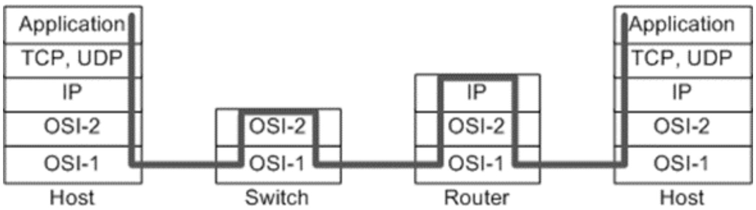
Figure 4.3 shows the Internet protocols layering model mapped with the open systems interconnection (OSI) protocol layering model.

Figure 4.3: Internet protocols mapped to OSI protocol layering model



Source: Toni Janevski, *Internet Technologies for Fixed and Mobile Networks*

Figure 4.4: Comparison of information processing in Internet host, switch and router



Source: Toni Janevski, *Internet Technologies for Fixed and Mobile Networks*

Internet networks consist mainly of two entities: the end hosts (e.g. personal computers, lap-tops, smartphones, modems, etc.) and network elements (switches and routers). The main network elements are the routers that process the network layer packet header (i.e. IP headers), while switches process only protocol layers 1 and 2, and therefore are typically used for the design of IP-based access network architectures, either on the end-users' side or on the servers' side. The end hosts typically have protocols on all layers, from physical layer, at the bottom, up to the application layer, at the top (Figure 4.4).

How packets are classified depends on the approach as different options exist, such as:

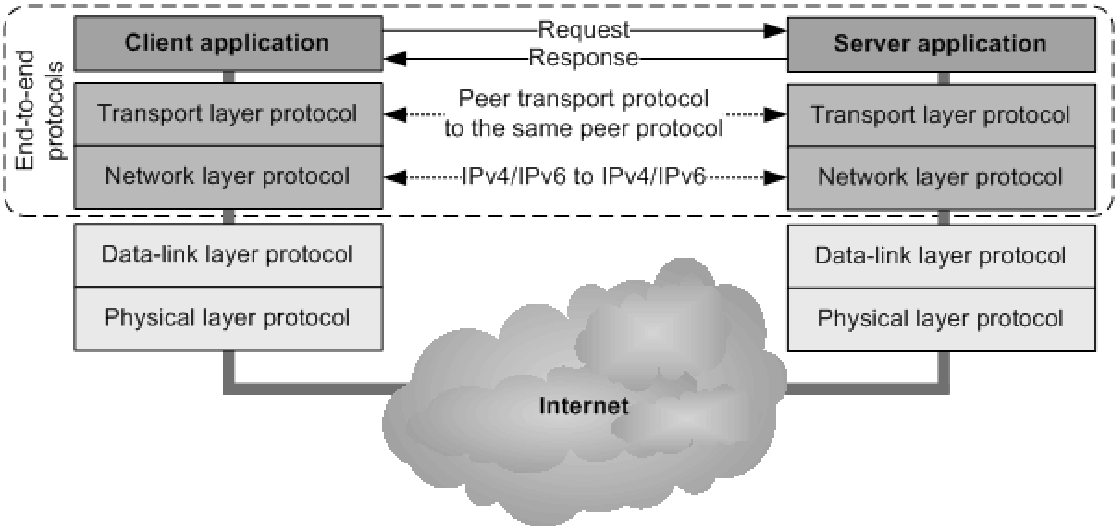
- Classification can be based on ports (ports are used by transport layer protocols such as TCP and UDP to identity applications on the top). For example, port 80 (HTTP, i.e. the web) takes precedence over port 21 (FTP).
- Classification can be based on application type. For example, carrier grade VoIP takes precedence over HTTP, BitTorrent.
- Classification can be based on user type. For example, home and business users get normal service, but hospitals/police/fire departments get highest priority service.
- Classification can be based on subscription. For example, USD 50 for high speed Internet (guaranteed maximum access bit rates in downstream and upstream) compared to USD 10 for fair-usage policy-based Internet (e.g. bit rate is proportionally downgraded with higher usage).

To understand packet classification and traffic management, one needs to know that the main networking principle in the Internet is the client server, where:

- A client requests a service from the server through a well-defined client interface (e.g. web browser).
- The server provides a service through a well-defined server interface (e.g. web server).

Typical examples of standardized client-server protocols are file transfer protocol, hypertext transfer protocol used for the web; all e-mail protocols; video streaming protocols; as well as mainly all non-real-time OTT services (e.g. video sharing such as Youtube, picture sharing such as Instagram, social networking such as Facebook or Twitter, cloud computing (e.g. Google Drive, Amazon cloud, etc.), web search engines (e.g. Google, Yahoo, Bing, etc.), etc.

Figure 4.5: Client server communication



Source: Toni Janevski, *Internet Technologies for Fixed and Mobile Networks*, 2015.

Both endpoints (i.e. hosts) communicating over the client-server network architecture must use the same transport protocol (e.g. TCP, UDP). For each communication, the peer applications on both end hosts must be of the same type (e.g. web clients communicate with web servers, FTP clients communicate with FTP servers, etc.), as shown in Figure 4.5.

When both end host entities (which are also referred to as hosts in Internet literature) can act as both a client and a server, then the communication is referred to as peer-to-peer (P2P). For example, conversational VoIP is an example of peer-to-peer communication – either it is being provided by telecommunication providers with guaranteed end-to-end QoS (i.e. telephony) or it is being provided by OTT voice providers (e.g. Skype, Viber, etc.). Another example of peer-to-peer communication is peer-to-peer file sharing (e.g. BitTorrent).

Packet classification is needed to sort packets into flows (per class). Usually the following fields are used for classification (5-tuple):

- source address (from IP header);
- destination address (from IP header);
- protocol number (from IP header);
- source port (from transport protocol header, e.g. TCP, UDP);
- destination port (from transport protocol header, e.g. TCP, UDP).

In IPv6 networks classification can be performed with 3-tuple (if flow label in IPv6 header is used) source address, destination address, flow label (all from IPv6 header).

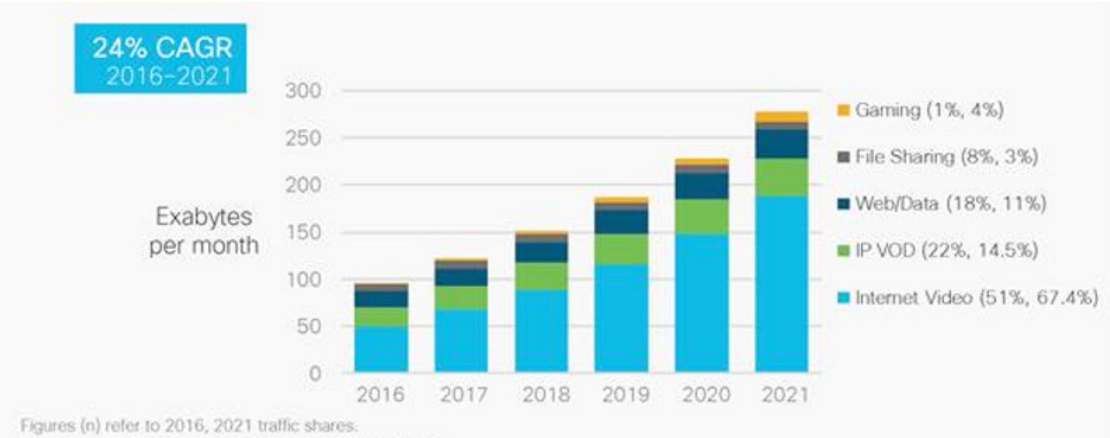
Typically packets are classified at the edge router, then the core routers check the given mark. Due to the autonomous nature of each Internet administrative domain (autonomous system), the marking in one network domain is rewritten at the edge of another network domain. Therefore marking is not the same throughout as the IP packet travels through several different operator networks on the end-to-end path.

4.3 Traffic management aspects

Nowadays, traffic management currently follows a *fair use* paradigm that is intended to limit excessive or unfair use. Until recently, users generating the most traffic have been running P2P applications, and ISPs have therefore mainly targeted P2P in their policies.

With broadband access, users do not need to download a movie to watch it, they can do so online. Today the greatest traffic growth is in video streaming and video is widely expected to grow further as broadband Internet penetration over fixed and mobile networks increases (Figure 4.6).

Figure 4.6: Internet traffic forecast



Source: Cisco VNI Global IP Traffic Forecast, 2016-2021.

Without a managed response (e.g. more capacity, traffic management), there is a risk of congestion and a reduction in many users' QoE. In the future, there will certainly be new killer applications that could put even more pressure on Internet capacity.

Traffic management is therefore targeted to the management of different types of traffic (voice, video, data, messages, etc.) in different parts of the networks (access, core, transit) to ensure the provision of the desired QoS and QoE.

Traffic management is influenced by:

- the type of traffic, such as voice (it is low rate) or video (high bit rates and bursty by nature) or data (variable data rates and bursty by nature);
- the number of users attached to a given network;
- the capacity of the network which is installed (measured in bits per second (bit/s or bps);
- the type of network equipment and its capabilities (e.g. switches, routers, gateways, base stations, etc.);
- business plans (by the ISP, i.e. telecommunication operator) and regulatory legislation (e.g. national regulation);
- capacity of employees at the ISPs and regulators.

4.3.1 The principles of traffic management

Telecommunication operators, i.e. ISPs, may differ in their traffic management practices, however the basic techniques of traffic management are the same. In all cases, a traffic management decision is made that is implemented in the network as an intervention. A traffic management decision can take into account the type of traffic, the user profile and cumulative usage relative to any caps or limits that are in place. A traffic management intervention can either be to modify the traffic priority or to change the bandwidth allocated (e.g. a guaranteed minimum or to impose a maximum speed cap). Traffic management technologies enable the identification of different types of traffic. Two main types of traffic management can be found, implicit and explicit. Explicit traffic management is done through packet prioritization and bandwidth management, and implicit traffic management derives from the network design itself, which affects traffic differentially and can also be regarded as a form of traffic management. The dimensioning of networks, the partitioning of access pipes and the use of content distribution networks all affect QoS, and can do so in ways that discriminate between traffic types. Some of these issues can be resolved through market competition, but others may need regulation.

Traffic management can be viewed in different terms, such as:

- Implementation across different access network types (e.g. xDSL, cable, mobile).
- Where it is controlled and enacted within particular layers of the protocol layering model for ICTs (from the physical layer at the bottom, up to the application layer on the top).
- Where it is controlled and enacted in the physical, geographic network (e.g. core network, access network).
- The impact it has on different traffic types (e.g. voice, peer-to-peer traffic, web browsing, streaming video, etc.).
- The impact it has on different users, or types of users.
- The type of traffic management intervention that is used, and the decision basis for enacting the intervention.

4.3.2 Traffic management: Intervention

While implementation of traffic management is far from trivial, there are relatively few underlying techniques available. All traffic management involves a decision basis and an intervention. For example, exceeding a monthly usage allowance is a decision basis, and the response of cutting the data rate according to policy is an intervention. Three common decision inputs are:

1. The user identity (or profile), specifying a QoS package for that user.
2. Whether or not a usage cap has been exceeded (these caps are often set by the user tariff).
3. The particular traffic type (e.g. VoIP, IPTV, OTT, etc.).

Regarding traffic management interventions, there are two main types:

- Packet prioritization: Wherever queues occur in a network, higher priority traffic will get through whereas lower priority traffic may be delayed or suffer packet loss. This is typically applied today in the core network, but may in future migrate closer to the access network to increase the effectiveness of traffic management in maximizing network utilization while minimizing the effect on most users.
- Bandwidth allocation: The bandwidth (or data rate) offered to a user or a type of traffic can be actively controlled. Users can be offered a minimum guaranteed rate or can be limited or capped at a maximum rate. Bandwidth allocation does not cause packet loss unless it reduces data rate to below that required for a particular application.

Table 4.1 presents a matrix for traffic management approaches, and Table 4.2 provides the characteristics of different intervention types.

Table 4.1: Matrix for traffic management approaches

Decision Input / Intervention type	1. User identity	2. Usage cap	3. Traffic type
A. Packet prioritization	A1	A2	A3
B. Bandwidth allocation	B1	B2	B3

Source: Ofcom, United Kingdom, *Traffic management and quality of experience*, 2011

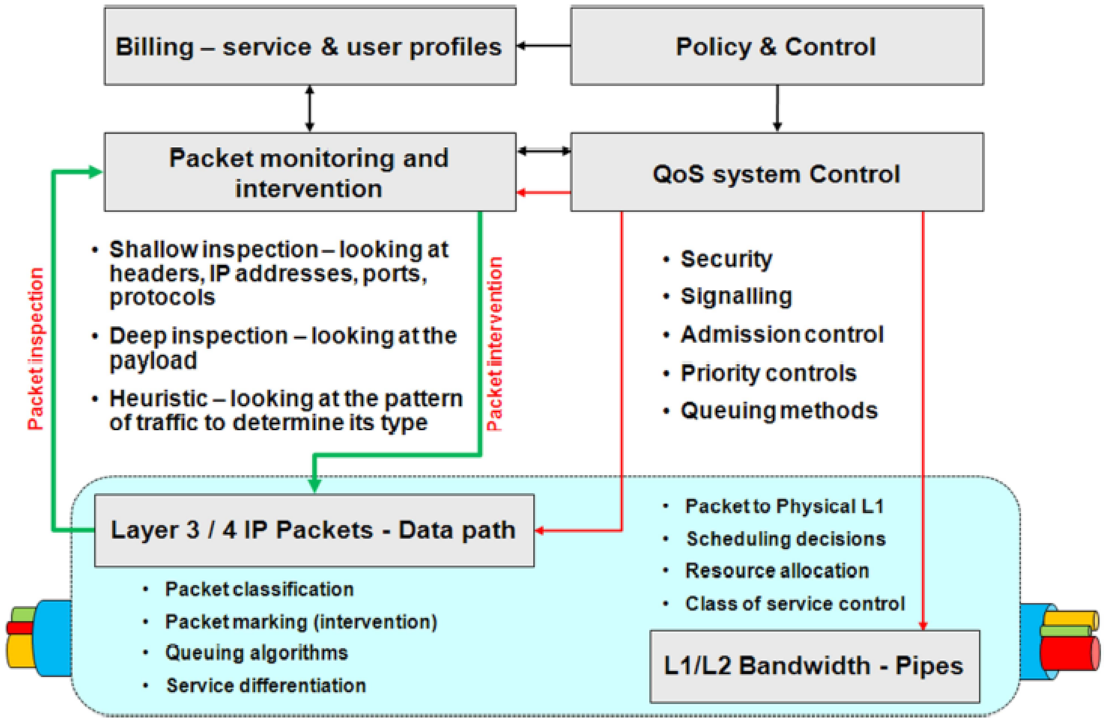
Table 4.2: Characteristics of intervention types

Inter-vention type	Characteristic					
	Possible actions	Applied in	ISO Model Level	Impact of negative intervention on data type		Comments
				TCP/IP FTP	UDP RTP	
A. Packet prioritization	Prioritize or De-prioritize	Core network	Layers 3 and 4	Retransmission of packets	Data loss	TCP/IP traffic can be effectively managed by de-prioritizing this traffic type
B. Bandwidth allocation	Guarantee or Cap	Access network	Layers 2 and 3	Reduced throughput (Service maintained, but at lower speed)	Reduced quality (Codec may drop to a lower rate)	Video is best managed by prioritizing or giving guaranteed bandwidth in the access network

Source: Ofcom, United Kingdom, Traffic management and quality of experience, 2011

The majority of IP interventions are dealt with by inspecting IP packet headers and marking them accordingly for transmission across the network. The inspection equipment will investigate the header information being transmitted across protocol layer 3 and, based on the criteria set in the policy and control unit, will implement IP header manipulation. Generic traffic management architecture is shown in Figure 4.7.

Figure 4.7: Generic traffic management architecture

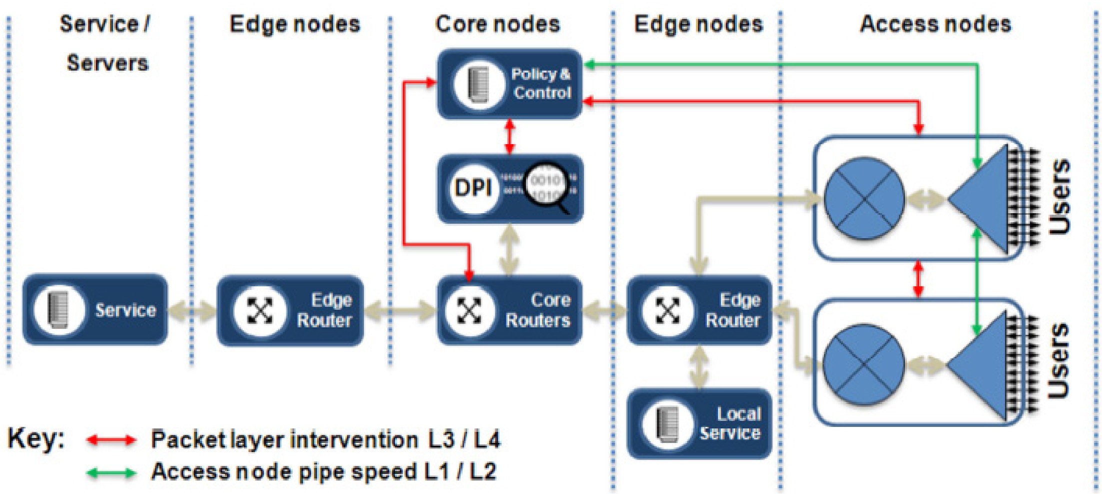


Source: Ofcom, United Kingdom, *Traffic management and quality of experience*, 2011

4.3.3 Network agnostic traffic management example

In telecommunication operator networks, deep packet inspection (DPI) boxes are deployed in the core network nodes to inspect the packets to determine traffic types. The DPI inspects all contents from all headers and information in the packet, which can be done by using the 5-tuple (pairs of source and destination IP addresses, source and destination port numbers, and used transport protocol). An example of how the DPI functions is presented in Figure 4.8.

Figure 4.8: Network agnostic traffic management example



Source: Ofcom, United Kingdom, *Traffic management and quality of experience*, 2011

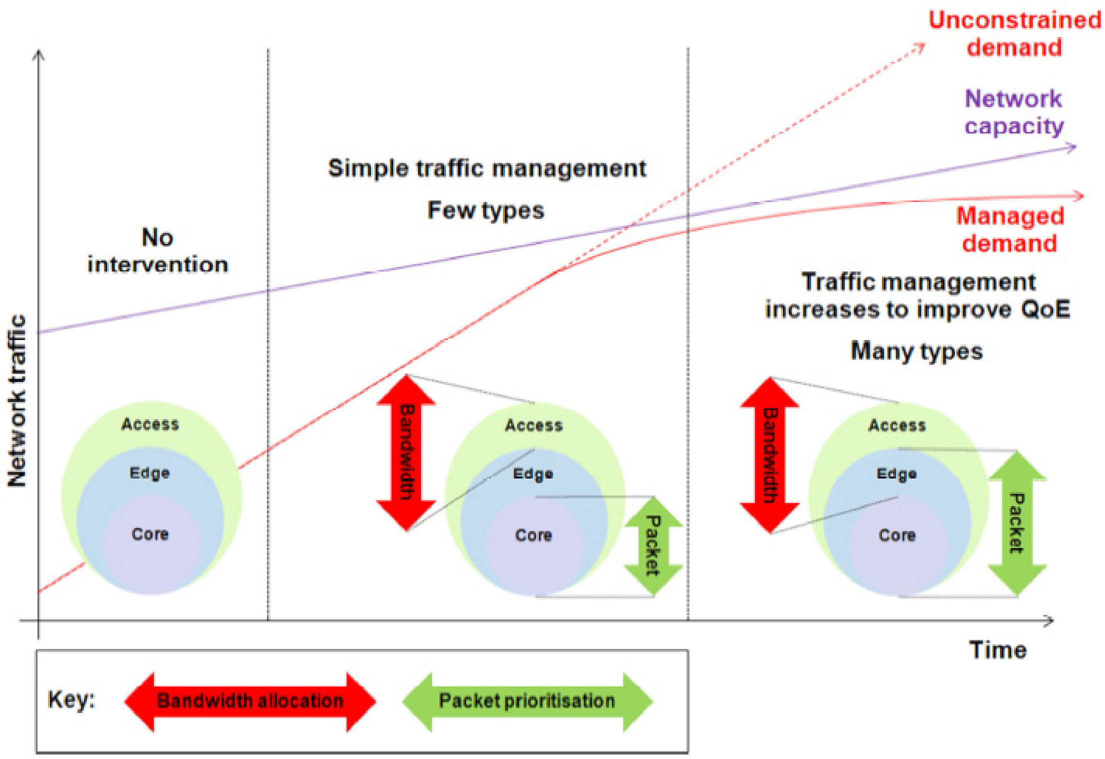
The information from DPI boxes is passed to the policy and control node. The policy and control units typically contain the traffic management policies and, based on the information received from the

DPI box, send control signals to the respective nodes on how to deal with the traffic. The red lines indicate the packet-based intervention where the core nodes re-label packets based on the priority decided by the traffic management policy, and the access nodes then treat them accordingly. The green line indicates control of the access node Layer 1 and Layer 2. For example, the DPI box could monitor a monthly usage cap and when the limit is reached could apply a reduction to the pipe speed by allocating less resource to the end-user in the access node.

4.3.4 Traffic management vs. network capacity

The extent and complexity of traffic management depends on how much congestion is being experienced, or how close network traffic is to the limit of the **network capacity**, as shown in Figure 4.9.

Figure 4.9: Traffic management as a function of network capacity



Source: Ofcom, United Kingdom, *Traffic management and quality of experience*, 2011

When traffic demand is much lower than the installed network capacity then no intervention is needed. When there is moderate space between demand and network capacity, simple traffic management is needed, including bandwidth allocation and packet prioritization. When traffic demand approaches network capacity, the probability for congestion significantly increases. In this case, traffic management is required to improve QoS.

In the future and from a technical point of view, traffic management will remain a response to congestion and a mechanism to maintain the highest level of QoS. The most important changes will be that packet inspection capabilities will migrate out of the core, enabling a more finely graded and user-specific form of traffic management. Table 4.3 illustrates the positive and negative effects of traffic management.

Table 4.3: Positive and negative effects of traffic management

	Positive effects on QoS	Negative effects on QoS
Traffic management applied to a user's own traffic	Can guarantee or prioritize data for sensitive applications	Can restrict or block certain applications
Traffic management applied to other people's traffic	Can reduce congestion to manageable levels, allowing fair use for all	Other people's traffic may take priority

Source: Ofcom, United Kingdom, *Traffic management and quality of experience*, 2011

5 Quality of service parameters and key performance indicators

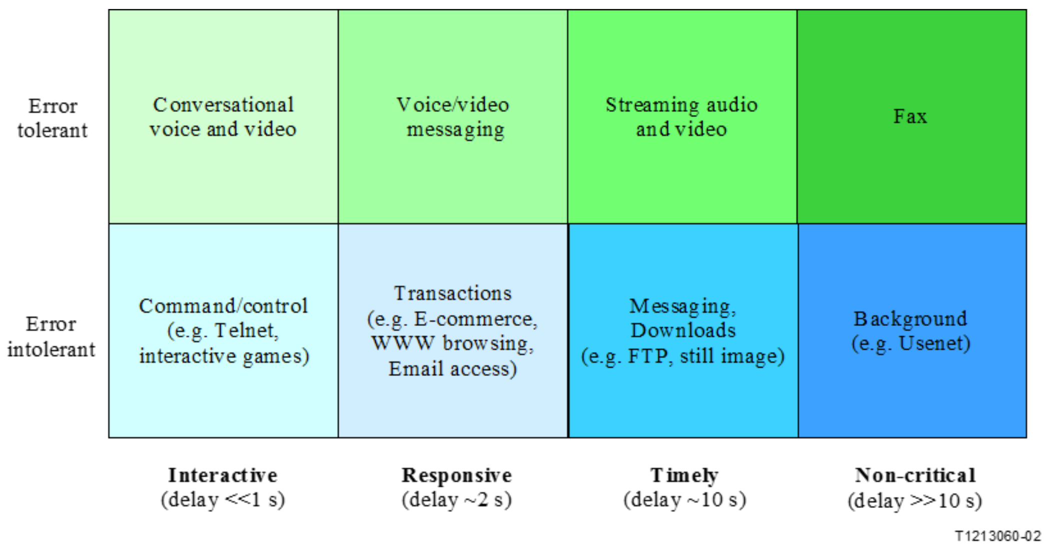
5.1 Quality of service, quality of experience, and application needs

The relationship between **QoS** (at the IP network level) and **QoE** is strongly dependent on the application, for example:

- E-mail is tolerant of high delay or loss as users do not expect instant delivery.
- The QoS of voice conversations (such as in IP telephony) mainly depends on packet delay, delay variation (jitter), and packet loss. In addition to these parameters, QoE of voice is also impacted by terminal capabilities, user-related aspects (e.g. mood, tariffs, etc.) and many more elements that can influence service delivery and the user.

A well-known criterion for ensuring proper experience is that one-way delay through the network should not exceed roughly 150 milliseconds. Longer delays may cause users on both sides of the connection to begin speaking at once (as with telephone conversations using geosynchronous satellites, where round trip delay is 270 milliseconds). For interactive gaming, delay, and delay variation can also be important.

Figure 5.1: Model for user-centric QoS categories



Controlling QoS does not make the transmission links any faster. Network designers and engineers can, however, control:

- the relative priority with which each router processes the IP packets/datagrams waiting to be sent over each transmission link; and
- which packets are to be dropped during periods where more packets are waiting than a given router is able to store or buffer.

Effects similar to prioritization can be achieved by caching (storing frequently used static data close to the user) and by replication (where the same dynamically generated results can be produced in more than location in the network – cloud services can represent an example of this kind of distribution or replication of function). The use of caching content delivery networks represents an increasingly common and important means of improving QoE. For example, locating Youtube video servers closer to the end-users reduces delay and jitter, and hence gives higher QoE. The same approach refers to all services that are based on principle user to content (i.e. Internet native client-server networking approach).

How prevalent is delay sensitive application traffic? It is clear that:

- Real-time bidirectional speech benefits from bounded **delay**. The traffic load associated with VoIP is negligible.
- Real-time bidirectional video (e.g. video conferencing) benefits from bounded delay.
- For streaming one-way speech or video, delay plays a minor role (as long as the user is prepared to accept a second or two of delay at the outset while the jitter buffer is filled). Streaming video is a huge and growing segment of Internet traffic.

5.2 Quality of service parameters

Quality of service parameters (alternatively called QoS metrics, QoS indicators, QoS measures or QoS determinants) characterize the quality level of the service being offered and the level of customer satisfaction. QoS parameters represent subjective and abstract user perception of quality in terms of numeric (quantified) values. QoS parameters can be obtained from objective and/or subjective measurement methods. QoS parameters may also be interrelated.

If QoS parameters characterize the quality level of a certain aspect of a service being offered, then this should lead to customer satisfaction. QoS parameters can be used by service providers to manage and improve how they offer their services, as well as by customers (end-users or partner providers) to ensure that they are getting the level of quality that they are paying for. They have now been used to support commercial contracts such as service level agreement formulation and verification.

QoS parameters can be obtained from objective or subjective measurement methods:

- Objective QoS parameters are obtained from measurement of physical attributes of circuits, networks and signals.
- Subjective QoS parameters are obtained by conducting well-designed customer opinion surveys.

QoS metrics can be primary parameters that are determined by direct measurement of call characteristics or events, such as circuit noise, echo path loss, or signalling release cause. QoS metrics can also be derived from a collection of primary parameters such as:

- statistical calculation (e.g. call completion rate for calls to a given destination for a day);
- rating factor to estimate customer opinion (e.g. E-model rating according to ITU-T Rec. G.107); and
- decision thresholds.

Specific QoS metrics can be defined to serve different applications and service types, such as:

- QoS metrics for different signal types, e.g. voice, fax, video;
- QoS metrics for one signal type (voice), but different service types, e.g. telephony conversational voice, voice-mail and streaming audio, which have different requirements for delay;
- QoS metrics for the same signal type and service type, but different classes of commercial offering, e.g. premium-price high-quality telephone voice service, as opposed to toll-free best effort telephone service with advertisements.

5.2.1 Comparable performance indicators

Comparable performance indicators refer to agreed QoS values that enable customers to be aware of the actual variety of service quality so that they can make informed decisions when choosing a service provider. Examples of comparable performance indicators are provided in Table 5.1.

Table 5.1: Comparable performance indicators

Telecommunication activities	Objective QoS Indicator	Subjective QoS indicator
Service provision	Supply time for initial network connection, percentage of orders completed on or before the date confirmed	Satisfaction with this parameter
Restoration/repair	Fault-clearing of reported faults on or before the date confirmed	Satisfaction with this parameter
Service reliability	Number of reported faults, number of customers touched by a cut connection	Satisfaction with service reliability
Billing	Number of billing complaints received per 1 000 units	Satisfaction with this parameter
Complaint handling	% Complaints, resolved within 20 working days	Satisfaction with this parameter

Source: Geza Gordos et al, Telecommunication Networks and Informatics Services

5.2.2 Survey of ITU standardized quality of service parameters

Quality of service parameters or metrics are essential for effective QoS management. They should be simple to use, provide accurate representation of customer perception, and be commonly accepted as standards. It is possible to distinguish between parameters for specific service types. For example, there are a number of standards that relate to conversation or voice quality (ITU-T Recs. G.107, G.108.2, G.109 and P.862/P.863).

- Subjective evaluation of voice calls is dealt with in ITU-T Recs. P.800, P.800.1, P.831 and P.832 that provide specifications on a 5-point mean opinion score (MOS) for voice quality assessment (1 = bad, 2 = poor, 3 = fair, 4 = good, 5 = excellent).
- ITU-T Rec. G.109 defines five categories of speech transmission quality that can be used as guidance in establishing different speech transmission quality levels in telecommunication networks.
- ITU-T Rec. P.561 In-service non-intrusive measurement device – voice service measurements, defines the scope of measurement and accuracy objective of voice grade parameters, such as

speech level, noise level, echo path loss and echo path delay, based on non-intrusive monitoring of live calls.

- Call clarity index (CCI) uses a two-way conversational opinion model and maps measured INMD parameters for a given call based on predictions of customer perceived mean opinion scores (1 to 5), as detailed in ITU-T Rec. P.562.
- The E-model provides a scalar rating of transmission quality, but this can be transformed to provide estimates of customer opinion (ITU-T Recs. G.107, G.108, P.833, and P.834). The E-model requires knowledge of the end-to-end configuration, i.e. networks and terminals, and is intended for network planning purposes.

Perceptual evaluation of speech quality (PESQ) is a one-way listening model. It estimates user-perceived MOS by comparing the transmitted reference speech signal and the received degraded signal. The model takes into account impairment effects due to voice compression and IP network parameters (e.g. jitter and packet loss), in addition to conventional circuit switched network impairments, such as noise and echo (ITU-T Rec. P.862). ITU-T Rec. P.863 (also known as perceptual objective listening quality assessment (POLQA)) incorporates current industry requirements and allows for assessment of super-wideband speech, as well as networks and codecs that introduce time warping. It includes different test factors and different existing coding technologies for voice such as G-series ITU voice codes, 3GPP codecs such as GSM and AMR, Skype codecs, etc.

In addition to voice, other standardized QoS parameters are referred to in this section.

- Fax transmission quality is covered in ITU-T Rec. E.437.
- Comparative metrics for alternate routes are part of ITU-T Rec. E.437, which recommends these metrics in comparing the performance of different routes from one origin to the same destination, as well as in assessing the effectiveness of services being offered on direct or alternative routings.
- Video transmission quality is mainly covered by the ITU-T recommendations currently being developed by ITU-T SG 12. The main ITU-T recommendations on video quality belong to the J-series (J.140-series, J.240-series, and J.340-series for measurement of QoS for multimedia video including television and HDTV); the P.900-series on audio-visual quality in multimedia services; and the P.1200-series covering models and tools for quality assessment of streamed media.
- The recent list of QoS parameters is provided in ITU-T Rec. E.803, which lists 88 different QoS parameters (see the 2011 version), while QoS parameters for popular mobile services are defined in ITU-T Rec. E.804.

Below are different types of QoS parameters defined in ITU-T Rec. E.803:

- **Preliminary information on ICT services** (Parameter 2) Pricing transparency: is characterized by clarity, conciseness and unambiguity in every tariff structure for all usage conditions for every service provided by the service provider. Measured as: opinion rating.
- **Contractual matters between ICT service providers and customers** (Parameter 5) Integrity of contract information: true and fair view of pertinent information on supply, maintenance and cessation of a telecommunication service provided by a service provider. Measured as: opinion rating.
- **Provision of services** (Parameter 9) Meeting promised provisioning date: successful completion of provisioning of service on the date promised in the contract in relation to the total number of signed contracts with promised service provisioning dates. Measured as: ratio or percentage.
- **Service alteration** (Parameter 17) Time for alteration of service: time elapsed from the instant alteration notification is received by the user to the instant the alteration is completed. Measured as: time.

- **Technical upgrade of ICT services** (Parameter 26) Time for technical upgrade of a service: time elapsed from the instant the technical upgrade period was announced to the user to the instant the technical upgrade was carried out. Measured as: time.
- **Documentation of services** (operational instructions) (Parameter 36) Documentation of delivery time: time taken from the instant a service is provided to the instant documentation for the commissioning and use of the service is delivered to the customer. This parameter measured as: time.
- **Technical support provided by service provider** (Parameter 42) Accessibility to technical support: ratio of the number of successful attempts to technical support to the total number of attempts to reach this support. Measured as: ratio or percentage.
- **Commercial support provided by service provide** (Parameter 49) Commercial solution delivery time: time elapsed from the instant the customer raised a problem with commercial support to the instant a solution was achieved. Measured as: time.
- **Complaint management** (Parameter 54) Accessibility of the complaint management: ratio of the number of successful attempts to the total number of attempts to reach complaint management (CM) in a specified period. Measured as: ratio or percentage.
- **Repair services** (Parameter 62) Successful repairs carried out within a specified period of time: ratio of the number of repairs successfully carried out to the total number of repair requests accepted by the service provider within a specified period. Measured as: ratio or percentage.
- **Charging and billing** (Parameter 68) Accessibility of tariff information: ratio of the number of successful attempts to the total number of attempts to reach this facility located as indicated in the contract or regulations (access details to this facility to be provided by the service provider). Measured as: ratio or percentage.
- **Network/Service management by customer** (Parameter 78) Outage duration: the total time a network/service management facility is not accessible to the customer during a specified reporting period. Measured as: time.
- **Cessation of service** (Parameter 85) Cessation acknowledgement time: time elapsed from the instant of sending the cessation request to the instant of receipt by the customer of the acknowledgment from the service provider. Measured as: time.

5.2.3 End-to-end network performance parameters for IP-based services

The characteristic of telecommunication/ICT services is the end-to-end QoS. With the transition of telecommunication networks and services from PSTN to IP network and IP-based services, the most important QoS metrics (for any service) for the provision of traditional telecommunication services (voice, TV and leased lines) along with traditional Internet services (web, e-mail, FTP, and all other OTT services) are the end-to-end QoS parameters in IP-based networks.

ITU-T Rec. Y.1540 defines network parameters that may be used in specifying and assessing IP network performance. The most important performance parameters are:

- IPTD (IP packet transfer delay): The time difference between the occurrences of two corresponding IP packet reference events (an IP packet reference event is a packet transmission via a given measurement point in the network). There are several types of IPTD, such as:
  - minimum IPTD (smallest IP packet delay among all IP packet transfer delays);
  - median IPTD (50^{th} percentile of the frequency distribution of IP packet transfer delays);
  - average IPTD (arithmetic average of IP packet transfer delays).
- IPDV (IP packet delay variation, or jitter): The difference between the one-way delay of IP packet and reference IP packet transfer delay (e.g. average IPTD as a reference delay).

- IPLR (IP packet loss ratio): The ratio of total number of lost IP packets to the total number of transmitted IP packets in a given measurement.
- IPER (IP packet error ratio): The ratio of the total number of errored IP packets to the total number of transmitted IP packets in a given measurement.

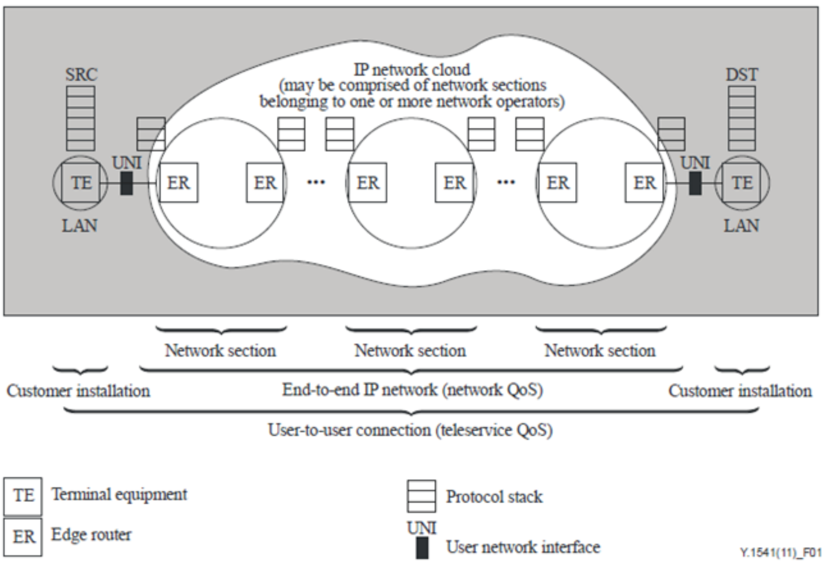
The values of the defined performance parameters vary, depending upon different so-called network QoS classes. The classes might not be used in certain network environments.

Transfer capacity (in bit/s) is the performance parameter that has the highest impact on the performance perceived by the end-user. Higher bit rates (i.e. broadband access and transport) are normally better for all services, including real-time and non-real-time. However, the theoretical capacity of a given system (e.g. xDSL, WiFi, GPON, LTE, etc.) is always larger than the bit rate perceived by end-user applications. In practice, the error ratio is not constant, congestion may occur, terminal equipment may have different processing and storage capacities, as well as a different operating system (where network and transport layer protocols are implemented at the end hosts).

ITU-T Rec. Y.1541 provides target values for different QoS classes, where these network performance parameters are useful for supporting SLA management at the wholesale level as well as at the end-user level.

The end-to-end network model is also referred to as UNI-to-UNI (user network interface). IP clouds may support user-to-user connections, user-to-host connections, and other endpoint variations. Network sections may be represented as clouds with edge routers on their borders, and a number of interior routers with various roles. The number of network sections in a given path may depend upon the class of service offered, along with the complexity and geographic span of each section. The scope of ITU-T Recommendation Y.1541 allows one or more network sections in a path. The network sections supporting the packets in a flow may change during its lifetime. IP connectivity spans international boundaries but does not follow circuit switched conventions (e.g. there may not be identifiable gateways at an international boundary if the same network section is used on both sides of the boundary).

Figure 5.2: UNI-to-UNI reference path for network QoS objectives



The UNI-UNI performance of a path can be estimated if the performance of sub-sections is known, covered in ITU-T Y.1541 (Figure 5.2). The main standardized QoS parameters for IP-based services include:

- Mean transfer delay (ITU-T Y.1541): For the mean IP packet transfer delay (IPTD) performance parameter, the UNI-UNI performance is the sum of the means contributed by network sections.
- Delay Variation (ITU-T Y.1541): The relationship for estimating the UNI-UNI delay variation (IPDV) performance from the network section values must recognize their sub-additive nature. It is difficult to estimate this accurately without considerable information about individual delay distributions. This detailed information will occasionally be shared among operators, and may not be available in the form of continuous distribution. Therefore, the UNI-UNI IPDV estimation may have accuracy limitations.
- Error packet ratio (ITU-T Y.1541): For the IP packet error ratio (IPER) performance parameter, the UNI-UNI performance may be estimated by inverting the probability of error-free packet transfer across *n* network sections loss ratio (ITU-T Y.1541): For the IP packet loss ratio (IPLR) performance parameter, the UNI-UNI performance may be estimated by inverting the probability of successful packet transfer across *n* NS, as follows:

$$IPER_{UNI\text{-}UNI} = 1 - \{ (1 - IPER_{NS1}) . (1 - IPER_{NS2}) . (1 - IPER_{NS3}) . \dots . (1 - IPER_{NSn}) \}$$

- **Loss ratio (ITU-T Y.1541)**: For the IP packet loss ratio (**IPLR**) performance parameter, the UNI-UNI performance may be estimated by inverting the probability of successful packet transfer across *n* NS, as follows:

$$IPLR_{UNI\text{-}UNI} = 1 - \{ (1 - IPLR_{NS1}) . (1 - IPLR_{NS2}) . (1 - IPLR_{NS3}) . \dots . (1 - IPLR_{NSn}) \}$$

The units of IPLR values are lost packets per total packets sent, with a resolution of at least 10^{-9}.

5.2.4 ITU quality of service classes

Network QoS classes are specified by ITU-T (Rec. Y.1541), based on the requirements of key applications – conversational telephony, reliable data applications based on TCP (e.g. WWW, e-mail, etc.), and digital television. They are shown in Table 5.2.

Table 5.2: ITU QoS classes

QoS Class	Upper bound on IPTD	Upper bound on IPDV	Upper bound on IPLR	Upper bound on IPER
Class-0	100 msec	50 msec	10^{-3}	10^{-4}
Class-1	400 msec	50 msec	10^{-3}	10^{-4}
Class-2	100 msec	Unspecified	10^{-3}	10^{-4}
Class-3	400 msec	Unspecified	10^{-3}	10^{-4}
Class-4	1 sec	Unspecified	10^{-3}	10^{-4}
Class-5	Unspecified	Unspecified	Unspecified	Unspecified
Class-6	100 msec	50 msec	10^{-5}	10^{-6}
Class-7	400 msec	50 msec	10^{-5}	10^{-6}

QoS classes specified in ITU-T Y.1541 define upper bounds on key performance parameters (besides the transfer capacity) for end-to-end IP services (end-to-end means from one UNI to another UNI, i.e. UNI-UNI performance is defined for each class). For example:

- Class-0 and Class-1 are targeted to real-time jitter-sensitive applications (e.g. VoIP, video conferences) where class-0 provides higher interactions due to a lower bound on the IPTD parameter.
- Class-2 and Class-3 are targeted to transaction data, from which class-2 is intended for signalling traffic, while class-3 is for interactive applications.
- Class-4 is targeted for short transactions, video streaming or bulk data.
- Class-5 is unspecified (regarding all performance parameters) and is targeted to traditional best effort Internet applications.
- Class-6 and Class-7 are provisional in the given table. However, such QoS classes are needed for new emerging applications with strict performance parameters. They also introduce in their definition a new parameter named IP packet reordering ratio (IPRR) that has the same upper bound as IPER for these two classes.

The specified upper bounds on IP-network performance parameters refer to end-to-end QoS provisioning – not an easy task to implement in the existing Internet.

5.3 Interconnection and quality of service regulations

Interconnection is an important part of QoS. Interconnection for voice traffic over PSTN and PLMN networks is based on traditional QoS voice parameters, such as limited end-to-end delays, bit rates guarantees for each direction of the voice connection, etc.

Interconnection is also important for best effort Internet traffic. This type of interconnection is harder to consider than traditional interconnection for voice traffic due to the fact that bit rates, end-to-end, are more variable and depend on different network segments over which best effort traffic travels end-to-end.

5.3.1 Quality of service norms for TDM interconnection between telecommunication networks

Although the ICT world is progressing toward all-IP networks, there are still many TDM (time division multiplexing) telecommunication networks that use circuit-switching for voice (i.e. telephony) and therefore SDH (synchronous digital hierarchy) in the transport networks with which they interconnect for such legacy (i.e. TDM) voice services.

To ensure effective TDM interconnection between networks, the network-related parameters to measure the quality of telecommunication services relate to (ITU-T E.847):

- network availability;
- connection establishment (accessibility);
- connection maintenance (retainability);
- optimal point of interconnection (POI) capacity provisioning and its effective utilization;
- POI congestion (number of POI not meeting the benchmark).

Interconnection in TDM networks can be considered relatively simple and well established since all legacy telephone networks usually use the same signalling system (i.e. SS7 signalling), media transport as in TDM, and numbering scheme (such as that of ITU-T Rec. E.164). Interfaces such as E1 and T1 links are also well used depending on the region or network equipment provider.

From a regulatory point of view, the purpose of interconnection is to ensure end-to-end network service connectivity and enable consumers of interconnected operators to establish connections with one another. Access also enables service providers to utilize facilities of other providers to further influence their own business plans for providing service to customers.

Table 5.3 shows some parameters and their thresholds that aim to help network operators set measurable and realistic KPIs to ensure effective compliance of regulations and help them in negotiating interconnection agreements to mitigate unforeseen disputes. An interconnection agreement should ensure fair, reasonable and non-discriminatory terms and conditions of interconnection between telecommunication service providers, and take into consideration technological, market, licensing, regulatory and legal developments in the telecommunication sector.

While interconnection is purely a matter of mutual agreement between interconnecting parties, any interconnect capacity creation, augmentation and/or disconnection of the interconnect capacity may have to be mutually agreed upon. However, it is desirable for administrations to have ex-ante regulatory guidelines for establishing a proper environment to facilitate effective and expeditious interconnection in the interest of consumers. For this purpose, they may prescribe broad guidelines based on fair, reasonable and non-discriminatory principles and leave the details of the interconnection agreement to be mutually decided by the interconnecting telecommunication operators (i.e. telecommunication service providers) in a time-bound manner. Alternatively, if they are unable to mutually agree upon terms and conditions of the interconnection agreement between themselves in a specified time-frame, a standard interconnection agreement – which must be entered into between interconnecting telecommunication service providers – may be prescribed.

Table 5.3: QoS norms for TDM interconnection between telecommunication networks

Key Performance Indicators (KPI)	Benchmark threshold and/or KPI information
Subscriber attempt success ratio for a POI	It should discourage intentional deterioration in QoS of a particular POI.
POI congestion	This refers to failed total number of call requests over a POI. The benchmark threshold for POI congestion may be set at <0.5%.
Subscriber attempts-seizure success ratio	This is the ratio between actual seizures at the POI and the total call attempts meant for that POI. It reflects the performance of a particular POI.
Inter-operator POI efficiency	Gives comparative performance of any particular inter-operator POI with respect to the other inter-operator POIs.
Time-frame for activation of a new POI	The prescribed time limit benchmark for providing POI connectivity is 90 days, counted from the date of confirmation or acceptance of demand for POI connectivity.
Time-frame for POI capacity enhancement	Where POIs between networks already exist, POI capacity enhancement may be possible within 60 days from the date of acceptance or confirmation of demand.
Interconnection route utilization parameter	The prescribed benchmark for the route utilization parameter is 70 per cent.
Mean time to repair for POI ports	POI port failure should not be greater than 72 hours.
Time to repair interconnection route	Interconnection route should not be more than one hour from the time the fault occurred.
Dual seizure ratio	This should not exceed 40 per cent of handling capacity in case of a failure condition (ITU-T Q.780).

Key Performance Indicators (KPI)	Benchmark threshold and/or KPI information
Signalling link utilization	This should not exceed 40 per cent of handling capacity in case of a failure condition (ITU-T Q.780); and sufficient number of signalling links provided between POIs to avoid any signalling congestion.
Unit of time measurement and recordings in CDRs (call data records)	The unit of time measurement should either be in seconds or milliseconds in CDRs in order to avoid any inter-operator billing disputes.
Clock synchronization and accuracy of switch time	Synchronization with reference to the clock of the interconnection provider or another operator is recommended.
Acceptance testing and monitoring	A uniform testing procedure (which should be reviewed from time to time) with a regular monitoring mechanism, by a governmental agency or accredited third-party is recommended.

Source: ITU-T Rec. E.847

The broad guidelines suggested above (describing, among other things, the technical and commercial conditions for interconnection) are a sort of model Reference Interconnect Offer (RIO), which may form the basis of all interconnection agreements.

In order to resolve problems relating to bilateral interconnection issues and to ensure effective interconnection, one option is to establish an interconnect exchange. The interconnect exchange could provide interconnection ports to all types of telecommunication service providers and, in turn, it could reduce the number of POIs. Under such a scenario, the existing peer-to-peer interconnection may continue as before; however, any increase in the number of ports would be carried out through the interconnect exchange. There is a need to establish a framework and explore options on operating such an interconnect exchange.

5.3.2 Internet interconnection and quality of service

The majority of Internet traffic exchange is carried-out under peering and transit agreements. Peering is an agreement in which two interconnecting ISPs carry each other's traffic. Peering does not include the obligation to carry traffic of third parties. Transit is an agreement where an ISP agrees to carry traffic on behalf of another ISP or end-user. Transit is usually a bilateral business and technical arrangement, where one provider (the transit provider) agrees to carry traffic to third parties on behalf of another provider or an end-user (the customer). In most cases, the transit provider carries traffic to and from its other customers, and to and from every destination on the Internet, as part of the transit arrangement.

Peering thus offers a provider access only to a single provider's customers. Transit, by contrast, usually provides access at a predictable price to the entire Internet. Historically, peering has often been done on a bill-and-keep basis, without cash payments.

There are credible claims that new forms of peering and transit are emerging that are making the Internet vastly more complex. Many of these claims emphasize the emergence of paid peering and partial transit. While it may be true that these forms are becoming more common than in the past, these claims should be interpreted with caution.

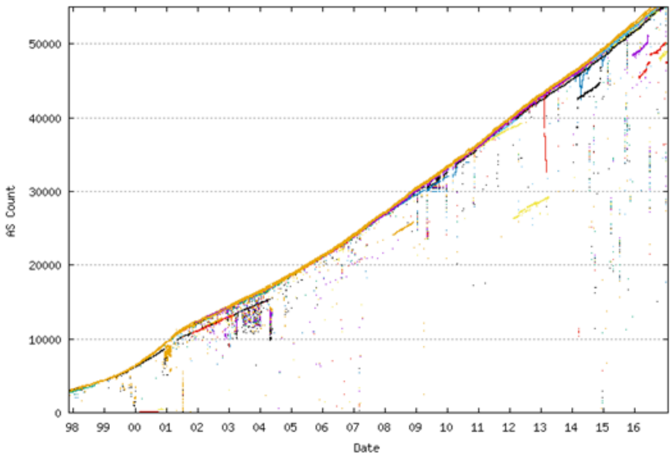
Paid peering is not technically different from settlement-free peering. Both paid peering and partial transit were already well established when the Internet was privatized in the 1990s – they are not new. There is little or no publicly available data on the prevalence of paid peering, partial transit, mutual transit, or other variants of peering and transit.

The Internet has become more widespread, intricate and interlinked over time, while dependence on the largest ISPs has decreased. The number of independent IP-based networks (autonomous systems) continues to grow (Figure 5.3); the average path length, expressed as a number of autonomous system hops (not router hops), is stable (Figure 5.4). This implies that the autonomous systems are more richly connected than in the past.

In 2017, the entire Internet consisted of approximately 55 000 active autonomous systems with the average path length (end-to-end) span across three to five such systems. Each autonomous system on the path of the IP packets (i.e. the traffic) adds more delay and a higher probability of bottlenecks somewhere on the path between the two end points of a communication call/session. This shows that Internet has good scalability, despite its increase in size, the number of autonomous systems that the traffic passes end-to-end remains almost the same, which directly influences the end-to-end QoS is a positive manner.

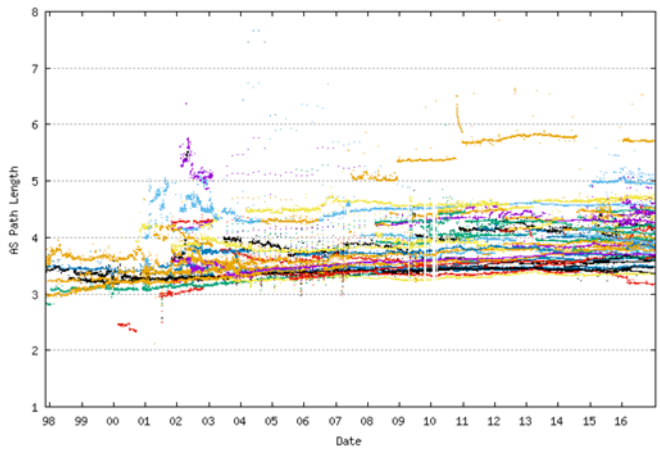
Large network operators typically exchange traffic with comparably large network operators through private peering arrangements that are direct connections between network operators. Generally, they are subject to contracts and to nondisclosure commitments. In terms of the amount of Internet traffic carried, these connections are highly significant, both individually and collectively.

Figure 5.3: Number of active autonomous systems in the world (1998-2016)



Source: http://bgp.potaroo.net/

Figure 5.4: Average autonomous system path lengths (1998-2016)



Source: http://bgp.potaroo.net/

Two significant interconnection trends are:

1. the growing importance of content delivery networks; and

2. the growing tendency of large content and application providers to operate their own global networks and their own content delivery systems.

Traffic forecasts in the Cisco VNI (2017) claim that 71 per cent of all Internet traffic will cross content delivery networks by 2021 globally, up from 52 per cent in 2016. Meanwhile large content and application providers such as Google and Apple operate some of the largest data networks in the world (although they typically lack local distribution), and negotiate peering arrangements in their role as network operators.

5.3.3 End-to-end quality of service in an IP environment

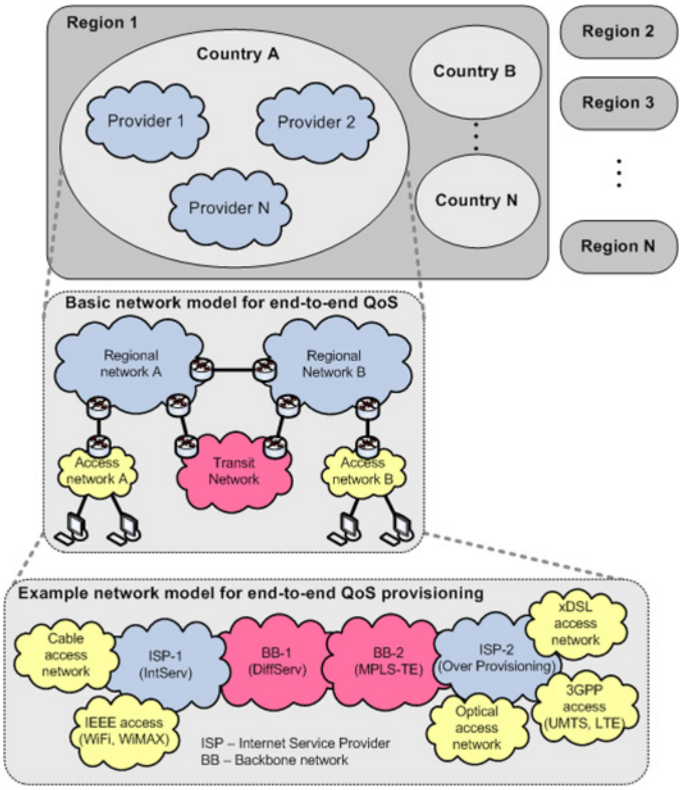
The whole concept of QoS is attractive to the end-user if the presentation at the user interface satisfies their needs and expectations. This means that an overall approach to QoS provisioning is necessary (i.e. end-to-end QoS provisioning).

As previously mentioned, in the end-to-end network model across the Internet (UNI-to-UNI), IP network sections may be represented as clouds with edge routers on their borders, and a certain number of interior routers with various functionalities. Such IP clouds may support user-to-user connections, user-to-host connections, and other variations of the endpoints. In general, there can be one or more network sections in a path. Also, network sections that support the packets in a flow may change during its lifetime. Additionally, IP connection may span national or regional boundaries. In all cases, UNI-UNI performance of a given path can be estimated knowing the performance of its sub-sections across different networks.

Generally, providing end-to-end QoS in IP-based platforms and networks is difficult due to their heterogeneity. In other words, using IP as a transport technology does not mean networks and platforms are the same or compatible. An extreme case of configuration among different IP networks is a scenario where each network has a different mechanism, level of performance control and QoS provision (e.g. ISP-1 uses IntServ, Backbone-1 uses DiffServ, Backbone-2 uses MPLS-TE, ISP-2 uses over provisioning, as shown in Figure 5.5). In this case, it is hard to provide services with guaranteed end-to-end QoS level because each network has a different QoS mechanism.

A basic network model (consisting of access, backbone and transit networks) should be applied commonly by providers, but the technologies that compose such a network model would be different depending on the providers and countries. In addition, differences exist between national regulatory frameworks and how they address SLAs, as well as QoS and QoE frameworks (Figure 5.5).

Figure 5.5: End-to-end QoS provision and basic network model

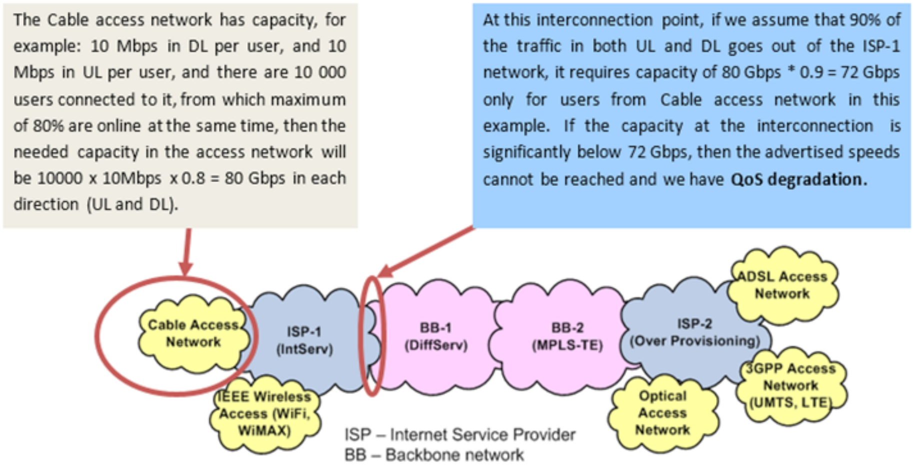


Source: ITU-T, *How to increase QoS/QoE of IP-based platform(s) to regionally agreed standards*, March 2013

Finally, end-to-end performance assessment and evaluation are essential in order to provide end-to-end QoS for fixed and mobile networks.

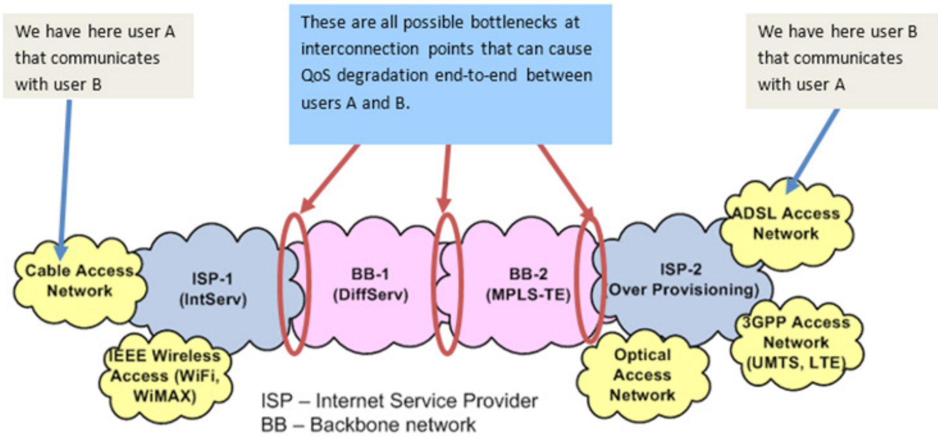
Issues of QoS and interconnection points are shown in Figures 5.6 and 5.7. As illustrated, interconnection points are possible bottlenecks for end-to-end traffic. The interconnection points of a given operator (i.e. ISP) should be able to transfer the demanded traffic in all access networks (of the given ISP) during peak time (e.g. the time of the day with the highest volume of traffic to/from end-users). In this regard, peering and transit agreements of a given operator (i.e. ISP) influence end-to-end QoS and may require regulatory attention to ensure end-to-end QoS performance of services.

Figure 5.6: Interconnection and QoS: required bit rates at the interconnection point dependent upon the aggregate access bit rates from/to end-users



Source: ITU-T, *How to increase QoS/QoE of IP-based platform(s) to regionally agreed standards*, March 2013

Figure 5.7: Interconnection and QoS: possible bottleneck at interconnection points in end-to-end view



Source: ITU-T, *How to increase QoS/QoE of IP-based platform(s) to regionally agreed standards*, March 2013

5.3.4 Interconnection, quality of service and end-to-end regulation

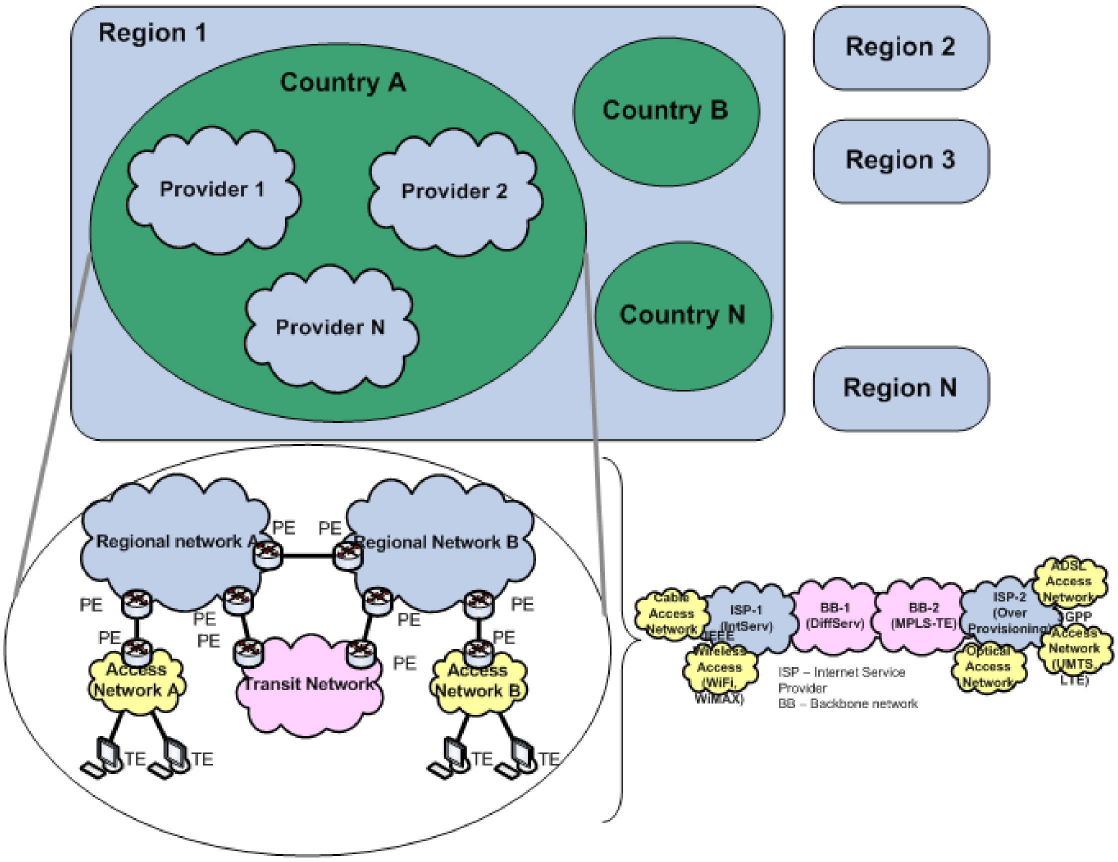
Interconnection is well regulated for carrier grade telephony. There are now IP exchanges (IPXs) in many countries. However, QoS regulation at the interconnection points is typically not present. The QoS parameters for the interconnection points can be regulated within a country by the NRA (e.g. interconnection bit rates) and monitored at IPXs. End-to-end QoS/QoE provisioning can be achieved only through regional and global harmonization, which must include QoS regulation between each pair of IPXs and the networks attached to them.

In the telecommunication world, PSTN and PLMN interconnection has been easier to implement because circuit switched voice uses 64 kbit/s in each direction (globally). Interconnection today is also related to peering and transit in IP networks:

- IP networks carry heterogeneous traffic, put more simply, this consists of QoS-enabled VoIP (including signalling) and IP traffic from/to Internet access service (IAS) as well as to/from content delivery networks.

- IP packets are transferred via interconnection points aggregated in VPN (virtual private network) tunnels established between the two peers (peers are the gateway nodes/routers on the border of each of the two networks that interconnect).
- There are different VPNs for QoS-enabled traffic such as operator provided VoIP (as PSTN/ISDN replacement), for signalling traffic (e.g. Session Initiation Protocol (SIP)), for network neutral traffic (traffic from IAS and content delivery networks).

Figure 5.8: End-to-end QoS regulation



Source: ITU-T, *How to increase QoS/QoE of IP-based platform(s) to regionally agreed standards*, March 2013

For end-to-end QoS, interconnection (Figure 5.8) should be regulated at the national and international levels, currently, this is not the case. In IP-based networks, the most appropriate place to enforce end-to-end QoS is at the interconnection points (e.g. IPXs). Of course, the need for QoS encouragement and enforcement at the broadband access level remains.

5.4 Key performance indicators

Key performance indicators are based on network counters and are essential for operation and maintenance, and for business models, and which can help in other actions such as reporting and auditing. QoS is experienced, required or expected by end-users. The QoS level planned by service providers may not always match the delivered level of QoS, and despite efforts from service providers to provide higher QoS levels, the level experienced by end-users may still be low, even much lower than expected. From the end-user point of view, QoS depends a combination of indicators ranging from network and terminal performance, to retail channels and customer care.

5.4.1 Key performance indicators, targets and measurement methods

KPIs can be formulated with *implied* targets, for example, the percentage of faults repaired in one day. This implies that one day is the target. This approach has been discussed in depth by standard developing organizations with the conclusion that it is better to formulate parameters without implied targets, but to set a target level separately, if appropriate. For example, a formulation without an implied target would be the time within which the fastest 80 per cent of faults are repaired. A target could then be two days. Generally, such parameters without implied targets are preferred.

How to set targets varies very much from one parameter to another. The performance level achievable may be affected by the type of access. It may be necessary to specify different target values for the same service over fixed access and over mobile access. The level of performance considered to be minimally acceptable may increase over time as technology develops and users demand more. Past practice has been to treat fixed and mobile services as distinct services. Hence fixed voice telephony was a separate service to mobile voice telephony, although only if viewed from the perspective of the calling party.

With the development of next generation networks (NGNs), however, there has been a change in the approach. Fixed and mobile are viewed as different forms of access to a common core network. This is the objective behind the IP multimedia subsystem (IMS) standardization, which is being followed by many traditionally mobile and some traditionally fixed service providers. It is also the approach taken by some countries in moving towards unified licensing, where services are provided over both fixed and mobile networks under the same licence.

In order to make formulation of QoS parameters as future proof as possible, the parameters have been grouped in accordance with their usage domains. This means that wherever possible the parameter definition applies to services over both forms of access (mobile or fixed). In terms of measurement and targets, however, there may be differences because of differences in access.

It is possible to measure mobile access using drive tests from stationary or moving vehicles. For fixed access, such tests would require either connection to the local loops at the roadside cabinet or access to the subscriber premises, which is less practicable. Consequently, for measurements over fixed access, techniques that can run from distribution frames or exchange sites have been developed to assess the performance that is being delivered to the subscriber. As a result, and in most cases, different measurement methods have had to be specified for the same service provided over fixed and mobile access, but they are, wherever possible, measurements of the same service parameter.

5.4.2 Key performance indicators for data services

Data includes all Internet-based services that are provided through Internet access, based on the network neutrality principle and by applying a best effort approach for packet delivery. Over-the-top (OTT) service may be treated equally with the term data. Both terms are used interchangeably in this manual.

What belongs to the OTT service space?

It covers all data services as everything that a telecommunication operator charges as data is in fact Internet traffic due to OTT services. OTT services include (but are not limited to):

- FTP (file transfer protocol) standardized by IETF (Internet Engineering Task Force www.ietf.org).
- E-mail, with standardized protocols by IETF.
- Web services, which use HTTP as the communication protocol, standardized by IETF, and above HTTP is typically HTML (HyperText Markup Language). Web services offered through open Internet access are considered as data (i.e. OTT) services. For example, all public websites on

the Internet (e.g. www.itu.int, etc.) are data services (either provided by a third party or hosted by the same operator which provides Internet access to the user).

However, HTTP can also be used in the provisioning of certain QoS enabled services (as enabler, e.g. for IPTV) by the telecommunication operator, and in such a case it is not considered as data (i.e. OTT) service:

- Proprietary (not standardized) services and applications, such as Skype, Viber, BitTorrent, etc.
- Web-based proprietary services, such as video sharing and streaming (e.g. Youtube, Netflix), social networking services (e.g. Facebook, Twitter), cloud computing services (e.g. Google docs), etc.
- Everything else that uses network neutral Internet access, either through fixed or mobile/ wireless network.

All services provided via network neutral Internet access service (IAS) are referred to as data services.

What are the requirements of different data services offered through IAS?

As defined by the Body of European Regulators for Electronic Communications (BEREC): "*Internet access service means a publicly available electronic communications service that provides access to the Internet, and thereby connectivity to virtually all end points of the Internet, irrespective of the network technology and terminal equipment used.*"[3]

Data services are provided by using the network neutrality principle (see Chapter 8). Network neutrality refers to the way that Internet service providers manage the data or traffic carried on their networks when data is requested by IAS subscribers/end-users from various providers of content, applications or services available on the Internet (e.g. YouTube, various websites, Instagram, Facebook, Twitter, BitTorrent, Google Docs, various cloud services, video streaming and sharing sites, and so on), including traffic exchanged between end-users (e.g. VoIP using Skype, Viber, WhatsApp, etc., or file sharing with BitTorrent, etc.). The best effort Internet is about the equal treatment of data traffic being transmitted over the Internet, i.e. that the best efforts are made to carry data, no matter what it contains, which application transmits the data (application-agnosticism), where it comes from or where it goes. The benefits of best effort Internet notably include the separation of applications running over the Internet and underlying access and transport technologies (either via copper, fibre or wireless/mobile). This separation enables innovation of applications independent of the ISP, enhancing end-user choices.

In the context of network neutrality (net neutrality), the performance of individual data applications is also important as it can be used to detect potential degradation of individual applications. Table 5.4 illustrates popular applications by non-professional users and the relevance of quality parameters on the performance of those applications. In Table 5.4, the relevance goes from "–" (less relevant) to "+++" (very relevant). When evaluating quality aspects of IAS in the context of net neutrality, it is essential to evaluate potential degradation of individual applications based on such considerations.

Table 5.4: Popular types of OTT applications and quality parameters

Application	Data transmission speed		Delay	Delay variation	Packet loss
	Downstream	Upstream			
Browse (text)	++	-	++	-	+++
Browse (media)	+++	-	++	+	+++

[3] BEREC, *Guidelines on the Implementation by National Regulators of European Net Neutrality Rules*, http://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/guidelines/6160-berec-guidelines-on-the-implementation-by-national-regulators-of-european-net-neutrality-rules

Application	Data transmission speed		Delay	Delay variation	Packet loss
	Downstream	Upstream			
Download file	+++	-	+	-	+++
Transactions	-	-	++	-	+++
Streaming media	+++	-	+	-	+
VoIP	+	+	+++	+++	+
Gaming	+	+	+++	++	+++

Source: ITU-T Rec. G.1011, and ITU-T Rec. E.800

What are the main parameters that define QoS for data services?

First is the bit rate of the IAS, which provides access to data services. Second is the availability of the given data service. Third (when service is available), the QoS for data is influenced by the delay experienced for the data services by the end-users. Based on this discussion, if the given data service is available, then the KPIs for each hop of an IP-based network will be:

- Bandwidth: The maximum number of bits that a transmission path can carry.
- Propagation delay: The time that a packet requires, as a function of the combined length of all transmission paths and the speed of light through the transmission path.
- Queuing delay: The time that a packet waits before being transmitted. Both the average delay and variability of delay (jitter) matter, since the two together establish a confidence interval for the time within which a packet can be expected to arrive at its destination.
- Packet loss: The probability that a packet never reaches its destination. This could be due to transmission errors, but errors are quite rare in modern fibre-based fixed networks. More often packets are lost because the number of packets waiting for transmission is greater than the available storage capacity (buffers).

These KPIs correspond closely to parameters defined by ETSI, and they are recommended by BEREC[4]:

- Upload / download speed
- Delay
- Jitter (variability of delay)
- Packet loss ratio
- Packet error ratio

However, individual data applications may have a specific set of KPIs that are dependent on the functional definition. For example, the web is the most used best effort service, which is standardized by the IETF. Standardized QoS parameters in ITU-T E.804 (popular mobile services) for web browsing are:

- HTTP service non-accessibility (%) is the probability that a subscriber cannot establish a PDP (packet data protocol) context and access the service successfully.
- HTTP set-up time(s) is the time period needed to access the service successfully, from starting the dial-up connection to the point of time when the content is sent or received.

[4] BEREC: *Monitoring quality of Internet access services in the context of net neutrality* http://berec.europa.eu/eng/document_register/subject_matter/berec/reports/4602-monitoring-quality-of-internet-access-services-in-the-context-of-net-neutrality-berec-report

- HTTP IP-service access failure ratio (%) is the probability that a subscriber would not be able to establish a TCP/IP connection to the server of a service successfully.
- HTTP IP-service set-up time(s) is the time period needed to establish a TCP/IP (transmission control protocol/Internet Protocol) connection to the server of a service, from sending the initial query to a server to the point of time when the content is sent or received.
- HTTP session failure ratio (%) is the proportion of uncompleted sessions and sessions that were started successfully.
- HTTP session time(s) is the time period needed to successfully complete a PS (packet switched) data session.
- HTTP mean data rate (kbit/s): After a data link has been successfully established, this parameter describes the average data transfer rate measured throughout the entire connect time to the service. The data transfer shall be successfully terminated. The prerequisite for this parameter is network and service access.
- HTTP data transfer cut-off ratio (%) is the proportion of incomplete data transfers and data transfers that were started successfully.

Example of QoS parameter definition (for HTTP) – HTTP mean data rate (kbit/s)

Abstract definition: After a data link has been successfully established, this parameter describes the average data transfer rate measured throughout the entire connect time to the service. The data transfer shall be successfully terminated. The prerequisite for this parameter is network and service access. Trigger points (for the HTTP mean data rate) are provided in Table 5.5.

Abstract equation:

$$\text{HTTP mean data rate}\,[\text{kbit/s}] = \frac{\text{user data transferred}\,[\text{kbit}]}{\left(t_{\text{data transfer complete}} - t_{\text{data transfer start}}\right)[\text{s}]}$$

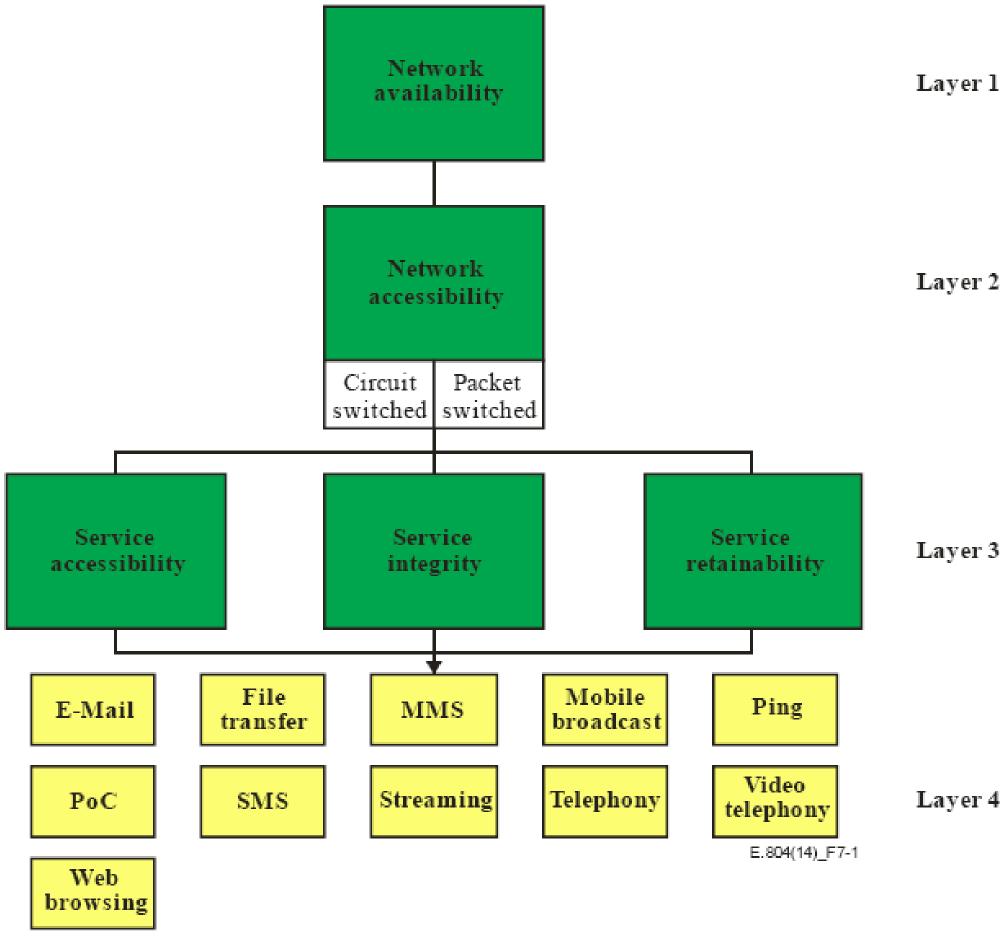
Table 5.5: Trigger points for HTTP mean data rate

Event from abstract equation	Trigger point from user point of view	Technical description/ protocol part
tdata transfer start: Time of successfully started data transfer.	Start: Web page download starts.	Start method A: Reception of the first data packet containing the content. Start method B: Sending of the first GET command.
tdata transfer complete: Time when data transfer is complete.	Stop: Web page download successfully completed.	Stop: Reception of the last data packet containing the content.

5.4.3 Key performance indicators for mobile services

Figure 5.9 shows a model for quality of service parameters in mobile networks. This model includes four layers. The first layer, network availability, defines QoS from the viewpoint of the service provider rather than the service user. The second layer, network access, is the basic requirement for all other QoS aspects and parameters from the service user point of view. The third layer contains the other three QoS aspects, service access, service integrity, and service retainability. The different services are located in the fourth layer. Their outcomes are the QoS parameters.

Figure 5.9: QoS aspects and the corresponding QoS parameters



QoS for mobile services is covered in ITU-T Rec. **E.804** and explained below.

Direct mobile services

QoS parameters are defined for the following direct services:

- FTP (file transfer protocol)
- Mobile broadcast
- Ping
- Push-to-talk over cellular (PoC)
- Streaming video
- Telephony
- Video telephony
- Web browsing (HTTP)
- Web radio
- WLAN (wireless local area network) service provisioning with HTTP-based authentication
- Wireless application protocol (WAP)
- IMS multimedia telephony

- E-mail
- Group call

Each of these direct mobile services is defined with a set of QoS parameters similar to the example for QoS parameters for HTTP mean data rate (provided above).

Store and forward mobile services

These QoS parameters can generally be divided into four groups of parameters:

1. Generic parameters
2. E-mail parameters
3. Multimedia Messaging Service (MMS) parameters
4. Short Message Service (SMS) and Short Data Service (SDS) parameters

Overall, store-and-forward services are typically messaging services that have less stringent demands on QoS parameters.

There are service independent QoS parameters that may be dependent upon mobile or wireless network technology, or may be relevant to all IP-based services (e.g. domain name system (DNS) parameters). Service independent QoS parameters (as defined in ITU-T Rec. E.804) are:

- radio network unavailability
- network non-accessibility
- attach failure ratio
- attach set-up time
- PDP context activation failure ratio
- PDP context activation time
- PDP context cut-off ratio
- data call access failure ratio
- data call access time
- DNS host name resolution failure ratio
- DNS host name resolution time

Regarding service independent QoS parameters that are dependent upon the mobile network, the PDP (Packet Data Protocol) context is used in UMTS/HSPA (Universal Mobile Telecommunications System/high speed packet access) mobile networks (i.e. 3G) and in GPRS/EDGE (General Packet Radio Service/Enhanced Data rates for Global Evolution – i.e. 2.5G), while in 4G mobile networks (e.g. LTE/LTE-Advanced) it is being replaced with EPS (evolved packet system) bearer. Both types of parameters are related to maintaining user call/session information in the mobile core and access network for all data services (provided through mobile Internet access).

For service independent QoS parameters, the DNS parameters refer to all IP-based services, including fixed networks. The DNS connects the two name spaces in the Internet, they are IP addresses (including IPv4 and IPv6) on one side and domain names on the other side. Without the functioning of the DNS, there would be in practice no access to data services over Internet access service, whether the connection is going through fixed or mobile access. DNS QoS parameters are therefore fundamental for all IP-based services, as are their KPIs.

Regarding mobile broadband QoS parameters, currently 3G and 4G mobile networks are typically considered as mobile broadband access. All testing principles and QoS parameters are provided in ITU-T Rec. E.804. A subset or all of them may be chosen as KPIs for mobile services.

From an end-user perspective, there is no difference between a mobile broadband connection with a smartphone and a fixed broadband connection from a laptop. Therefore the same indicators apply, which include (but are not limited to) the following:

- web browsing (HTTP QoS parameters);
- voice-over-IP (both signalling and voice data parameters are important);
- download speed (kbit/s, Mbit/s);
- upload speed (kbit/s, Mbit/s);
- UDP latency (important for real-time services, such as VoIP and IPTV, which typically use RTP/UDP/IP, where RTP is the real-time transport protocol);
- UDP packet loss (important for real-time services, such as VoIP and IPTV, which typically use RTP/UDP/IP);
- DNS resolution (important for all IP-based services, either real-time or non-real-time);
- video streaming (video is one of the most demanding services regarding the bit rates in downlink, where the demands increase with the resolution of the video content).

5.4.4 Key performance indicators for voice over LTE

Regarding voice over LTE (VoLTE), the relevant KPIs are specified in ITU-T Rec. G.1028 on end-to-end quality of service for voice over 4G mobile networks. VoLTE is a managed voice service that benefits from prioritization over the other traffic. OTT applications do not use session initiation protocol/IP multimedia subsystem (SIP/IMS) signalling and are delivered in best effort manner through the Internet access service (with no prioritization). This section examines VoIP over LTE/LTE-Advanced according to ITU-T Rec. G.1028. The quality classification identifiers (QCIs) in use for VoLTE are shown in Table 5.6.

Table 5.6: LTE Quality Classification Identifiers (QCIs) in use for voice over LTE

QCI	Resource type	Priority level	Packet delay budget	Packet error loss rate	Example services
1	GBR	2	100 ms	10^{-2}	Conversational voice
5	Non-GBR	1	100 ms	10^{-6}	IMS signalling

Source: ITU-T Rec. G.1028.

Figure 5.10: Typical degradations of VoLTE communications

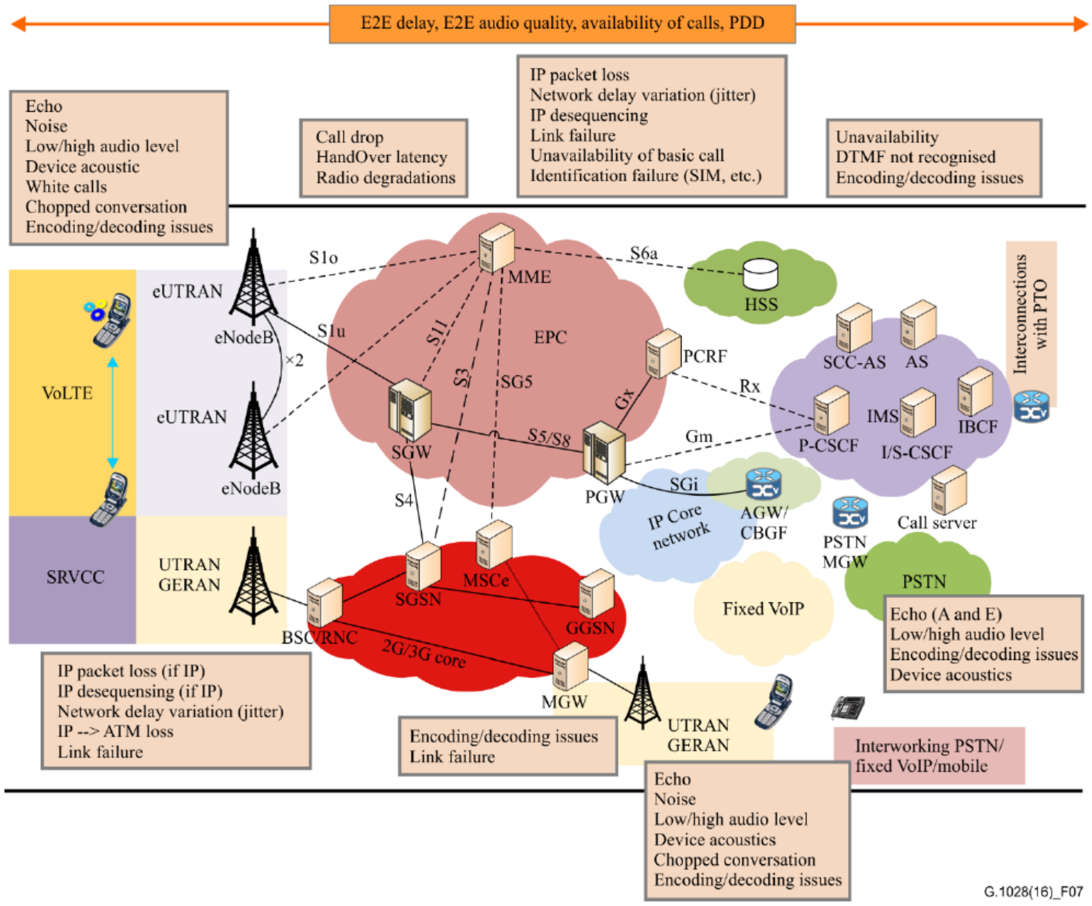


Figure 5.10 shows the QoS degradations that can typically be encountered on a VoLTE call. QoS is understood here as defined in ITU-T Rec. E.800. The main elements of the network are depicted to show the signalling and media elements, as well as connections with PSTN or mobile platforms.

Table 5.7: End-to-end quality indicators and corresponding network KPIs

End-to-end indicators	Definition	IP network KPIs
Registration success rate	Rate of successful registration attempts in the VoLTE service. Equivalent to IMS registration success ratio as defined in (ETSI TR 103 219).	Registration success rate. KPI related to IMS and based on P-CSCF counters. Equivalent to 1 – ineffective registration attempt (IRA) ratio, as defined in (IETF RFC 6076).
Service availability	End-to-end service availability in terms of capacity to establish calls from, and to, a VoLTE customer. Equivalent to 1 – VoLTE session set-up failure ratio as defined in (ETSI TR 103 219). Equivalent to 1 – telephony service non-accessibility as defined in (ITU-T E.804) (clause 7.3.6.1).	Network efficiency ratio. Measures the ability of network, from the service platform point of view, to deliver calls to the VoLTE customer. Based on SIP protocol, network error rate (NER) is equivalent to session establishment effectiveness ratio (SEER), as defined in (IETF RFC 6076).

End-to-end indicators	Definition	IP network KPIs
Post dialling delay	Time interval (in seconds) between the end of dialling by the caller and the reception back by user of the appropriate ring tone or recorded announcement. Equivalent to call set-up time, as defined in (ITU-T E.800). Equivalent to telephony set-up time as defined in (ITU-T E.804) (clause 7.3.I.1).	SIP session set-up time. Interval between sending INVITE message (with SDP) and ACK (180 or 200) message by the originating side. Equivalent to successful session request delay (SRD), as defined in (IETF RFC 6076).
Voice quality (MOS-LQ)	Equivalent to speech quality as defined in (ITU-T P.10). Models like those defined in (ITU-T P.862) and (ITU-T P.863) provide an objective view on the quality of the voice signal as it may be perceived by the customer. Can be seen on a call basis or on a sample basis (see (ITU-T E.804) clauses 7.3.I.2 and 7.3.6.4).	Network quality index ((ITU-T G.107), (ITU-T P.564).) IP packet loss ratio (see definition of Internet packet loss ratio (IPLR) in (ITU-T Y.1540)): several possible measurement points.
Mouth-to-ear delay	The time it takes for the speech signal to go from the mouth of the speaker to the ear of the listener.	IP packet transfer delay (see definition of Internet packet transfer delay (IPTD) in (ITU-T Y.1540)). Round trip time Corresponds approximately to twice the end-to-end delay. Can be measured based on RTCP protocol messages.
Call drop rate	Service continuity in terms of capacity to maintain calls to their normal end. Equivalent to telephony cut-off call ratio as defined in (ITU-T E.804) (clause 7.3.6.5).	Session completion rate KPI related to IMS and based on P-CSCF counters. Equivalent to session completion ratio (SCR), as defined in (IETF RFC 6076).
Speech bandwidth (NB, WB or SWB)	Measurement of the bandwidth used (normal NB or WB, or even partial and unwanted bandwidth limitation).	Codec statistics. Information related to the selection of (AMR and AMR WB) codec and codec modes, as well as switch between them, accessible on SIP protocol messages.

Source: ITU-T G.1028.

From a customer point of view, these degradations are divided into categories based on QoS required and perceived, as defined in ITU-T Rec. G.1000.

Call session performance:

- problems of registration to the service (IMS/SIP);
- call set-up issues (bad accessibility);
- failed continuity (or retainability), including impact of mobility (radio handovers and SRVCC (single radio voice call continuity) events).

Perceived speech quality during the call (integrity):

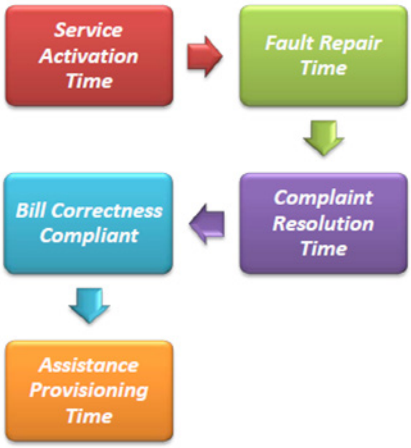
- Frequency content: This refers to the speech spectrum of signals presented to end-users (NB, WB, or SWB) and its potential distortions.
- Interruptions: Concerns all events resulting in clipping of the speech signal during the conversation:
  - end-to-end delay (impact on conversation interactivity);
  - presence of unwanted noises, from whatever origin.

End-to-end quality indicators and corresponding network KPIs are provided in Table 5.7. All target values for managed VoIP (that is, with QoS guarantees, as replacement of circuit switched telephony in mobile networks) for different scenarios, such LTE-LTE, LTE-3G, and LTE-PSTN, are specified in ITU-T G.1028.

5.4.5 Non-technical key performance indicators

In addition to technical QoS parameters, non-technical QoS parameters are also defined (see ITU-T E.803). Those QoS parameters that are considered as the most important can at certain times become KPIs.

Figure 5.11: Non-technical key performance indicators



Source: ITU

Currently the most commonly used non-technical KPIs include (but are not limited to) the following (Figure 5.11):

- Customer satisfaction
- Service quality
- Service availability
- Provision of service
- Service activation / de-activation / restoration time
- If target value is not reached, further analysis might be necessary
- Network availability
- MDT (mean down time)
- MTTF (mean time to failure)

- MTBF (mean time between failures)
- Billing information
- Clarity of tariff plans
- Ease of switching between plans
- Ease of getting billing information
- Ease of bill payments
- Ease of getting refunds
- Billing accuracy

5.5 QoS measurement

To measure QoS as an end-to-end characteristic of services, the following types of measurements can be used: PE-PE measurements (PE – provider edge router) and CE-CE measurements (CE – customer edge router), even when the PEs or CEs are contained in, or attached to, the networks of different providers. Measurement of QoS along the path between end-to-end customers should be an essential part of monitoring and troubleshooting SLAs. ITU-T introduces objectives, considerations, methodology and protocols for QoS measurement in the case of inter-provider through ITU-T Rec. Y.1543, and Supplement 8 to ITU-T E.800 series of recommendations.

End-user aspects of QoS including QoE should be a set of QoS and performance measurements. The measurements will be taken from each of the segments of the measurement network model and may be combined to form multi-segment, site-to-site, edge-to-edge or terminal-to-terminal metrics. Enhancement of QoS contributes to increasing the level of confidence in the expected service characteristics of the networks. This will enable new applications, services and revenue streams.

The objective of QoS measurements is to provide information to customers, potential customers and service providers, including:

- For **customers** and potential customers:
  - reports to customers of what service has been delivered;
  - reports to potential customers to support marketing claims on service characteristics.
- For **service providers** and third-party delivery assurance entities:
  - reports to design service offerings;
  - reports for troubleshooting;
  - data for marketing collateral;
  - reports to enable capacity planning and service development.

5.5.1 Quality of service measurement system

The QoS measurement system and the statistics obtained from the measurement should:

- be well defined (non-ambiguous) and easily understood by service providers and customers; be relevant to customer applications;
- enable service providers to diagnose issues and anticipate capacity requirements;
- be independently repeatable, that is, multiple service provider measurements over the same time get the same result;

- be independently verifiable by customers, i.e. customer measurements should be close to service provider estimates;
- be widely applicable regarding traffic type, link size, load independent, any IP network;
- be appropriately sensitive to distance and path;
- not significantly impact the forwarding of other data;
- be sufficiently scalable to support enough (e.g. millions) customer sites;
- be sufficiently reliable and accurate to enable SLAs with financial penalties to be administered.

5.5.2 Quality of service measurement methodologies

Two types of methodologies exist for measuring QoS:

- Passive measurement (using test packets): Test packets are sent from management systems, and performance metrics such as delay, jitter, and packet loss are measured along the way. This method is also often used for troubleshooting.
- Active measurement: Probes in the form of software agents or network appliances are deployed on network elements and user devices (for the software agent case). Measurements based on these probes provide a very accurate status of the devices at any time. The sources and sinks of probes may be either dedicated measurement devices, routers that are dedicated to measurement tasks or routers that support both data traffic and measurement probes. The main drawback of this measurement is that it doesn't scale for large networks.

To enable measurement of QoS parameters across multiple provider networks, one of the following methods can be used:

- Each provider agrees to use a common measurement protocol and to make probe points available to other providers, enabling measurements to be made along the end-to-end path.
- Each network provider uses its own methods and probe devices to collect measurements on a per-provider basis, with these measurements being combined to estimate the concatenated end-to-end performance.

In some cases, for example in the Africa region where the level of competition in the communications market is not high enough to influence a significant change in the QoS achieved/delivered, regulatory authorities may find themselves having to enforce specified levels of QoS parameters (see ITU-T E.802 Amendment 1: New Annex A on guidelines on selection of representative samples). To be able to do this, the specified QoS parameters need to be monitored within a legal framework where QoS measurements can be used to hold a service provider accountable for performance.

This may lead to the specification of QoS parameters and the desired targets being tied to penalties, where a service provider may be sanctioned accordingly for failure to comply with such specifications. There is then a need to carry out these measurements in such a way that they reflect a service provider performance. Truly representative QoS measurements are not only critical for regulatory purposes. It is also important for all users of these measurements – be they consumers of telecommunication services or service providers themselves – to have confidence in the accuracy of measurements. Annex A of ITU E.802 recommends that, where samples instead of real traffic are used, QoS measurements should provide a precision of ±10 at a maximum, with a confidence level of 95 per cent. For example, if 96 sample measurements are carried out, there is a 95 per cent confidence level that the true value of the QoS parameter lies within a range of ±10.

5.5.3 Basic network model for measurements

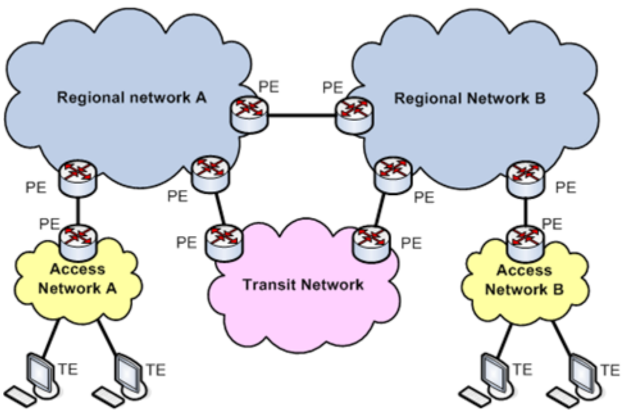
Ideally, measurements would be made between the same endpoints for each customer's traffic. These endpoints are the customer terminal (TE – terminal equipment), customer edge router (CE – customer equipment) or provider edge router (PE – provider equipment).

Providers offer assured delivery services between different endpoints as per the following cases:

- Edge-edge: extend to the edge of a provider's network;
- Site-site: extend to the edge of a customer's premises (also called end-to-end);
- TE-TE for a managed customer network service: extending to a customer's terminal.

To position the measurements points, the network model is partitioned into segments (Figure 5.12), each being monitored independently which is according to the three cases listed above (i.e., edge-edge, site-site, and TE-TE).Typically, there may be a backbone service provider providing transit services between the regional service providers. A specific service provider may act as either, or both, an access provider for some traffic and as a transit provider for some traffic.

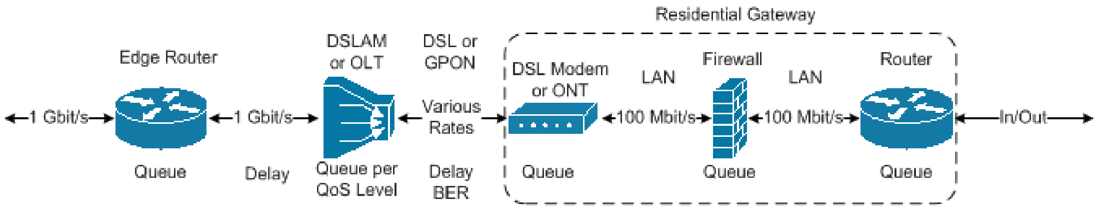
Figure 5.12: The basic network model for QoS measurements



Source: based on ITU-T Y.2173.

Access networks can be fixed or mobile access networks. Examples of fixed access network model with xDSL (digital subscriber line), such as ADSL (asymmetric DSL) and VDSL (very high bit-rate DSL), and FTTH (fibre-to-the-home) technologies are provided in Figure 5.13. In the downstream direction, from the core to the customer premises, a series of network elements and wires are connected: edge router, DSLAM – digital subscriber line access multiplexer (or OLT – optical line terminal for GPON – gigabit-capable passive optical networks), DSL modem (or ONT – optical network terminal for GPON), firewall, and router. This model is bidirectional, so upstream traffic traverses the same elements in reverse order.

Figure 5.13: Access network model



Source: ITU-T, *How to increase QoS/QoE of IP-based platform(s) to regionally agreed standards*, March 2013

5.5.4 Quality assessment methodologies

There are two methodologies for quality assessment:

1. Subjective assessment: With this method, the quality of audio and visual media is evaluated in subjective terms. However, subjective quality assessment, in which human subjects evaluate the quality of various testing conditions, is time-consuming and expensive. In addition, special assessment facilities – such as professional audio-visual devices and soundproof chambers – are required. Thus objective quality assessment is defined as a means for estimating subjective quality solely from objective quality measurement or indices. Mean opinion score is used as a measure of a subjective opinion.
2. Objective assessment: The assessment of QoE must be performed using subjective tests with metrics such as MOS. However, it is also possible and sometimes more convenient to estimate QoE based on objective testing and associated quality estimation models. Objective measurement and automatic calculation using appropriate quality estimation models are generally much faster and cheaper (ITU-T G.1011).

There are three modes of objective testing to evaluate QoE:

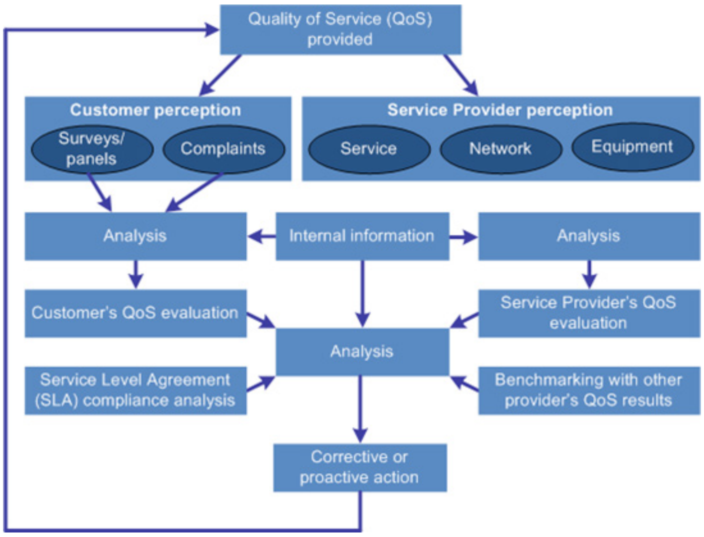
1. Intrusive mode: In this case the quality assessment system requires that a signal be injected into the system under test in order to generate a degraded output signal.
2. Non-intrusive mode: In this case the quality assessment system can be used whilst live traffic is carried by the channel, without the need for any active test signals. This measurement is performed on real customer (live) traffic.
3. Planning mode: It is not used in a real-time environment, but as a tool for the design of systems, and hence does not require any real-time inputs. This type of measurement is performed on artificially generated traffic (established test calls), such as phone calls, fax transactions, videoconference sessions, ISDN calls, website connections, etc., and by measuring relevant end-to-end parameters such as accessibility, transmission reliability, call clarity, etc. To obtain a global view of the service, a large number of connections are needed at different time periods and between several end-to-end points. Exhaustive measurements can only be obtained by using the same measurement unit at each point, since in general these two units need to know the measurement protocol used in the session (e.g. PESQ (perceptual evaluation of speech quality) measurements). Intrusive methods can typically achieve very high correlation with subjective tests. The drawback, however, is the usage of network resources for the assessment.

Criteria like call set-up time, call failures, or interruptions can quite easily be measured via adequate probes in appropriate locations. Measurements can be made either on real traffic or on artificially generated traffic. This can be done either on public traffic or private networks. Intrusive and non-intrusive methods are useful and can be combined.

Another approach in order to assess the quality of a service from a user perspective is through the QoS parameters. These parameters consist of definitions and measurement methods for specific user-perceivable aspects of QoS. However, there are also specific parameters that are strictly related to specific networks and transmission technologies. The main purpose of these parameters is to inform the user on the QoS of the market and to publish QoS statistics. The parameters are therefore defined in a way that is understandable to the average, inexperienced user.

The same service provided by a telecommunication operator can be measured by the service provider and perceived by the customer (two views), as shown in Figure 5.14.

Figure 5.14: QoS perceptions (customer perception and service provider perception)



Source: Author

5.5.5 Quality of service measurement considerations

In addition to definitions and standards regarding QoS parameters and their assessments via measurements, measurements to be defined should be:

- Practical for operators**:** The measurements defined for QoS monitoring by the NRA need to be feasible for implementation by operators at reasonable cost in a reasonable time-frame using consistent measurement and audit procedures. If possible the measurements should be the same as or similar to ones that operators already make for their own purposes.
- Important to customers**:** Measurements must be carried out for the most popular services used by customers. These measurements should be reviewed to see whether they need to be changed as the market evolves and different aspects of services become more important.
- Comparison between operators**:** The details of measurement methods may need to be discussed between operators before they can be settled. The measurement methods should be precise enough that differences in interpretation and implementation should not lead to differences in measurements.

Figure 5.15: Internet (resources) access speed tests

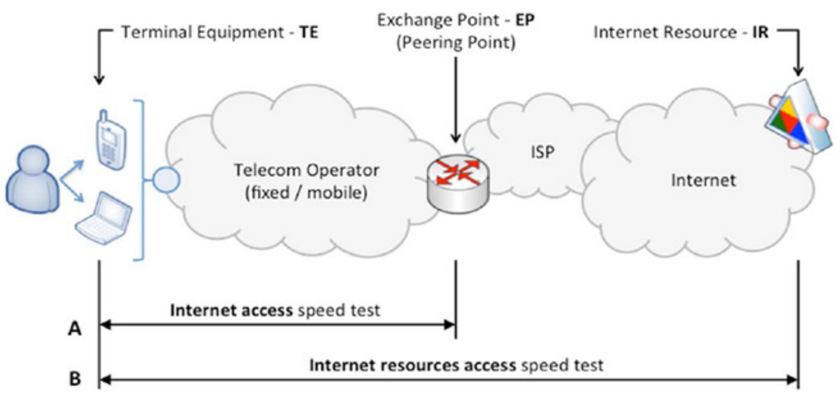


Figure 5.15 presents typical scenario for measurements of the bit rates (i.e. speeds) via Internet access. The OECD categorizes the types of clients that initiate each performance test on the end-user side and examines their characteristics as follow[5]:

- end-user application measurement (EAM);
- end-user device measurement (EDM);
- project self-measurement (PSM); and
- PSM by Internet service provider (PSM-ISP).

Selected examples from the OECD report on Internet access speeds are described in Table 5.8 to illustrate the types of metrics measured and their purposes in different parts of the world. The categories of metrics are the following: DATA, also referred to as Internet speed, is the amount of data transferred within a certain time between a client and a server; DNSR is DNS response time; WEB is length of time to load an webpage from a certain major website to a client; LT is latency; JT is jitter; PL is packet loss.

Table 5.8: List of examples for official measured metrics and their purposes

Country	Client type	Purposes	Measured metrics
Austria	EAM	Consumer protection, competition enhancement, network development (information on network quality), net neutrality (planned)	DATA, LT, JT, PL (DNSR and WEB are planned)
Chile	PSM-ISP	QoS indicators	DATA, DNSR and aggregation rate. (parameters informed by operators, not necessarily verified by SUBTEL)
France	PSM	Verification of licence obligations; consumer protection; competition enhancement; network development	Voice quality, SMS, MMS, data rates (DL and UL), web surfing, video service quality
Germany	EAM and PSM	Consumer protection; net neutrality	Platform measurement: DATA, DNSR, WEB, LT, HTTP response time End user measurement: DATA
Korea	EAM for fixed, PSM for mobile	Consumer protection; network development	Fixed : DATA, WEB Mobile: WEB, rates of successful download and upload that were faster than certain speed, web loading time, (calling quality)
Mexico	EAM	N/A	DATA, LT
Norway	EAM	Consumer protection	DATA, LT

[5] OECD, *Access Network Speed Tests*, www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/ICCP/CISP(2013)10/FINAL&docLanguage=En

Country	Client type	Purposes	Measured metrics
United States	Fixed EDM, Mobile EAM	Consumer protection	DATA, WEB, LT (UDP and ICMP), PL(UDP and ICMP), video streaming, VoIP, DNS R, DNS failures, latency under load, availability of connection, data consumption

Source: OECD, Access Network Speed Tests, 13 January 2015

6 Broadband quality of service measurements

In general, QoS measurement methodology, the protocol used – including reporting – should be capable of estimating at least the set of QoS parameters based on packets transmitted between specified measurement points. It is important to know the characteristics of a connectionless service – such as IP and NGN – that deliver user data via standalone packets (IP packets, i.e. datagrams) in each direction. As outbound and inbound traffic routes may differ, targets and measurements for all QoS attributes are in this case practically one-way, reflecting the connectionless nature of the service. Measurement probe packets should traverse as much as possible the same path as customer packets having the same QoS service class and the same QoS mechanisms in routers along the path. The value of probe packets should be appropriately set for the QoS class to be measured. This chapter examines concrete measurement tools and platforms for broadband QoS measurement, and presents selected country case studies on broadband QoS measurement, while tools for measurement are provided in annex to this manual.

6.1 Quality of service measurement system requirements

Requirements identified for quality monitoring systems, as defined by BEREC[6], include:

- Accuracy: The achieved measurement results should be reliable, reproducible and consistent over time. These measurements can be technical indicators characterizing both QoS and QoE. Margins of error should be known and published.
- Comparability: This includes 'plain' comparability of individual sample measurements, as well as comparability at higher levels, depending on the goals set by the NRA, such as comparability between Internet access services. Comparisons of measurements should always be put into context with a wider analysis to clarify the cause of any differences observed.
- Trustworthiness: The system components must be robust and protected against security attacks. They should also ensure availability, integrity and confidentiality. Measurement data must be secured during storage and transmission.
- Openness: Details about the measurement methodology should be made available, and open source code should be considered an option to achieve this requirement. Transparency of collected data (open data) should also be sought, with due respect for the limitations of national legislation. As far as possible, a quality measurement system should be based on state-of-the-art specifications, standards, recommendations and best practices.
- Future-proofness: The system design should ensure flexibility, extensibility, scalability and adaptability. This implies cost-effectiveness. These requirements contribute to the overall accountability of the quality monitoring and should therefore be taken into account when the

[6] *Monitoring quality of Internet access services in the context of net neutrality*

NRA designs a quality monitoring system. The technology chosen and the tools available on the market should also be taken into account when choosing the governance approach.

Regarding Internet access service, which is used for all OTT services, various approaches are taken by different stakeholders. In many European countries, regulators have either suggested or used certain tools that are available, or have engaged certain institution to develop such tools. All measurement tools provide information on the RTT (round-trip time), downlink (DL) and uplink (UL) bit rates (in kbit/s, Mbit/s) averaged over a given time interval of downloading and uploading files.

6.2 Broadband quality of service measurements: Case studies

This section presents country case studies on broadband QoS measurement. Tools used for broadband QoS measurement are provided in the annex to this manual.

6.2.1 Canada

In Canada, the Canadian Radio-television and Telecommunications Commission (CRTC) launched a project to create a community of broadband consumers across Canada. Data is gathered from *Whiteboxes* installed in the homes of participants who expressed an interest in measuring the performance of their broadband Internet services (Figure 6.1). CRTC is collaborating with major ISPs on this project. The data being gathered provides useful insight into network performance, including actual connection speeds, and provides a better understanding of whether certain Internet services from participating ISPs are delivering speeds as advertised. These results also provide data that will enable CRTC to improve its broadband policy-making.

Figure 6.1: Canadian campaign for QoS measurements with *SamKnows*

Source: CRTC

The results of the campaign conducted between March and April 2016 showed that among ISPs, download was consistent between peak and off-peak hours. A majority of ISPs delivered speeds above their advertised rates, regardless of the access technology they used. ISPs also largely met or exceeded their advertised upload speeds. All access technologies met or exceeded the advertised download speed on average. Packet loss was generally very low with some exceptions. All access technologies (FTTH, Cable/HFC, DSL) met or exceeded the advertised download speed on average, demonstrating that the access technologies themselves are capable of supporting the advertised services. Regulators are increasingly providing broadband speed testing open to all on their websites to enable consumers to test their broadband connection and monitor changes.

6.2.2 France

In November 2016, ARCEP (*Autorité de Régulation des Communications Électroniques et des Postes*) submitted a draft proposal and subsequently launched a public consultation in December 2016 for a complete overhaul of its fixed Internet access and telephone service QoS indicators.

To reflect user experience as accurately as possible, ARCEP is proposing to move towards crowd-sourcing and make use of new digital tools for the user to obtain a reliable, objective and reproducible measurement of how their individual access is performing. This approach will enable ARCEP to gather a wealth of information collaboratively produced to identify any market failures and to make information transparent. ARCEP also plans to carry out a comparative analysis of the existing different crowdsourcing tools available in the marketplace to better understand these tools and the methodological approaches to best address regulatory objectives. As stated by ARCEP, the objective over time is to reflect the user experience as accurately as possible, as part of a data-centric approach to regulation. This new approach would require an adjustment to be made to the current regulatory framework. Currently ARCEP publishes *scoreboards*, which include:

- Internet access: bit rates, latency, web browsing, streaming video;
- telephone calls: call completion success rate, call set-up time, speech quality;
- customer service: line set-up, reliability, technical support.

Provisions regarding the quality of fixed Internet access and telephone services that have become superfluous will be removed starting in the second half of 2017. Internet access and telephone service scoreboards have been based on tests performed in a controlled environment. ARCEP wants to move to a system that is based on the experience of the user and is as accurate as possible.

6.2.3 Germany

The Federal Network Agency launched its broadband measurement on 25 September 2015. End users can quickly and easily determine the speed of their Internet access using broadband measurement, thereby determining the performance of their fixed and/or mobile broadband connections. A test can be performed free of charge for stationary connections under *breitbandmessung.de*. For mobile connections, a measurement with the free broadband measurement app was made possible with applications for Android and iOS (as the two most used operating systems for smartphones today) in the respective stores.

With this test, customers had the possibility to independently check the performance of their broadband Internet access. Broadband measurement makes it possible to compare the actual data transmission rate of the respective broadband connection with the contractually agreed data transmission rate. Measurement is made to be independent of the provider and the technology. The individual measurement results are electronically storable. This allows customers as end-users to perform various measurements and compare them with each other.

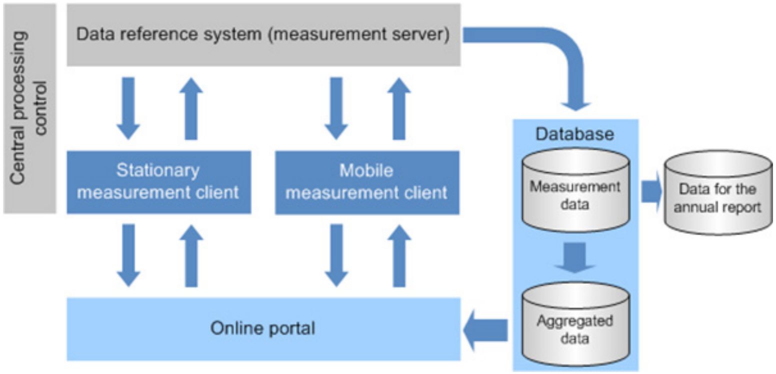
On 27 March 2017, the Federal Network Agency published its first annual report on its broadband measurement, which covers the period from 25 September 2015 to 25 September 2016. For fixed broadband connections, 106 159 valid measurements were taken, while for mobile broadband connections, it numbered 53 651.

Overview of the measurement concept and system

The measuring concept underlying the broadband measurement consists of a measuring system and a measuring method. The measuring system means the combination of measuring point (measuring client) and counter-measuring point (data reference system) and the measuring process in use. The measurement of stationary broadband Internet access services is done on a browser-based basis at https://breitbandmessung.de.

The customer survey was carried out in the reporting period by means of a client measurement using a Java plug-in in the browser of the end-user. An application-based measurement client allows the measurement of mobile broadband Internet access services by end-users via smartphones or tablets, supporting Android (Java) and iOS (ObjectiveC). Measurements were made on the end-user device for all technologies, such as GPRS, UMTS, LTE, and WiFi. The reporting period covers September 2015 to September 2016. At the beginning of the second reporting year, a changeover from Java Plug-in to HTML5 with WebSockets took place.

Figure 6.2: Overview of the measurement concept



Source: Based on Federal Network Agency in Germany, *Broadband measurements - Annual report 2015/16*

The remote end for the measurements consists of the measurement servers (data reference system), as shown in Figure 6.2. A central processing control ensures a controlled sequence of the measuring procedure. In the case of the actual measurement (measuring method), the technical sequence is identical in both cases (stationary and mobile). All measured data are stored and processed in a central database. The data are then validated and processed for a timely, aggregated presentation. On the other hand, a detailed evaluation is carried out for the annual report (Figure 6.2). The data transfer rates as the main KPI in broadband measurements in Germany were split into seven bandwidth classes, as shown in Table 6.1.

Table 6.1: Bandwidth categories for broadband measurements in Germany

Bandwidth classes	Data transfer rates
Class 1	2 Mbit/s to less than 8 Mbit/s
Class 2	8 Mbit/s to less than 18 Mbit/s
Class 3	18 Mbit/s to less than 25 Mbit/s
Class 4	25 Mbit/s to less than 50 Mbit/s
Class 5	50 Mbit/s to less than 100 Mbit/s
Class 6	100 Mbit/s to less than 200 Mbit/s
Class 7	200 Mbit/s to less than 500 Mbit/s

Source: Zafaco GmbH on behalf of Federal Network Agency in Germany

In order to avoid manual entry, the tariff types of the providers (where available) were called up from the provider database of the broadband measurement on the basis of the specified provider and the contractually agreed maximum data transmission rate. In total, more than 130 providers in Germany provided their tariff information during the reporting period, which represents more than 90 per cent of the market volume in the fixed networks segment.

For mobile networks, the measurement was performed by using applications based on Java (Android) or ObjectiveC (iOS) on the end-user device. However, various factors can influence the test result in mobile environments, including tariff-related limitations of the data transmission rate (throttling after exceeding a monthly volume included), the utilization of the Internet access provider and the number of active users in the same mobile cell or the same network segment. In addition, the terminal itself, the mobile radio technology used in the measurement (GPRS, UMTS, LTE), as well as the network coverage and supply quality at the measuring site, can play a role. This also includes the question of whether the mobile radio measurement has taken place inside or outside a building, or in motion (e.g. during a car or train journey).

In all cases, the end customer had to accept the provisions on data protection and the conditions of use before measurement. In particular, consent to the use of the data collected during the measuring procedure should be confirmed.

If it was determined before the start of the measurement that the device would be connected via wireless local area network (WLAN i.e. WiFi), the end customer was informed about this. The subsequent measurement was then recorded as WLAN measurement. The following data, on the connection to be measured, was determined by user dialogue: location (in a building, outdoors, moving), provider, contract-agreed maximum data transmission rate, tariff type, customer satisfaction. During measurement in all environments (fixed and mobile), the following steps were performed:

- querying additional parameters from the router (at the customer end);
- execution of the run-time measurement;
- carry out the download measurement;
- carry out the upload measurement.

At the end of the measurement, tariffs were provided, according to the customer data base or tariff database. Such information is required to determine any limitation of the data transmission rate or throttling after exceeding a monthly data volume included, to check whether the *inclusive volume* had already been exceeded during the measurement.

Mapping the broadband bandwidth across the country

In June 2016, the Federal Network Agency published a map function as part of its broadband measurement. The mapping contains the results of broadband measurements carried out over the tests so far. With the help of the map, anyone can access information on the results achieved, in a given region, in Germany.

The broadband map (https://breitbandmessung.de/) shows the measured data transmission rates as well as the percentage of measured rates compared to the contractually agreed maximum data transmission rate for individual providers. It is possible to use the results according to specific criteria, for example, by provider and/or bandwidth class. The measurement results are displayed in different grids according to the zoom level.

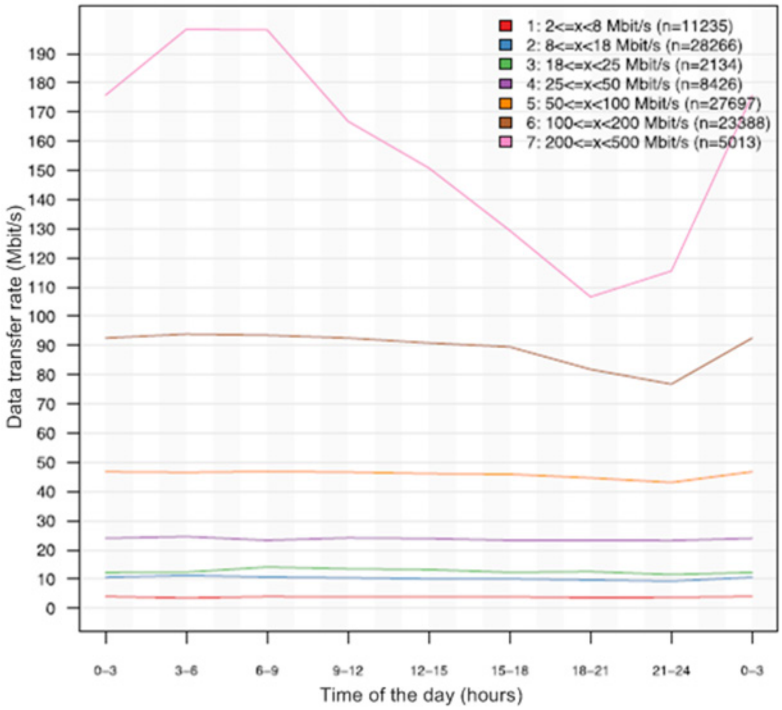
The publication of the measurement results is in accordance with data protection regulations. At least four measurements from different connections in a grid are summarized as a median before the values are displayed in the map. A reference to the respective person cannot be established.

Results in the fixed networks

Depending on the bandwidth class, 4 to about 25 per cent of end-users reached 100 per cent of the agreed maximum data transfer rate. The lowest value was achieved in the bandwidth class of 8 to <18 Mbit/s, which is predominantly characterized by ADSL connections. There were also differences between the providers with regard to reaching the agreed maximum data transmission rate. With regard to providers, the range ranged from 1 to around 35 per cent of the end customers.

For bandwidth class 200 to <500 Mbit/s, the performance fell sharply during evening peak time (as shown in Figure 6.3). This bandwidth class was characterized by products of cable network operators.

Figure 6.3: Download transfer rates in fixed networks in Germany by bandwidth class



Source: Based on Federal Network Agency in Germany, *Broadband measurements - Annual report 2015/16*

Measurement of customer satisfaction was surveyed. About 65 per cent of the customers were satisfied with the performance of their suppliers and rated them: very good, good, or satisfactory. Results also showed that satisfied end-users achieved a better ratio of the actual measured data transmission rate compared to the agreed maximum data transmission rate.

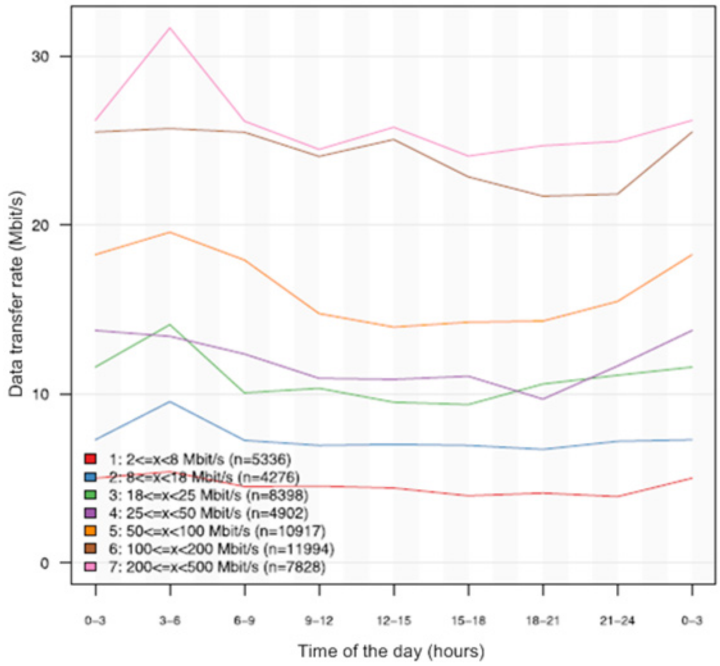
Results in the mobile networks

For mobile broadband connections, the ratio between actual and agreed maximum data transfer rate was below that of stationary connections. The share of end-users reached at least half the maximum transmission rate in the fixed network (just over 70 per cent), however, this figure was only reached by mobile subscribers with less than 30 per cent of users.

However, end customers also rated the very good, good or satisfactory scores (82.8 per cent), even for mobile broadband connections. This suggests that end-users in mobile broadband connections are more likely to rate mobility and availability as performance, rather than reaching expected maximum data transfer rate.

In particular, in bandwidth classes 6 (100 Mbit/s to less than 200 Mbit/s) and 7 (200 Mbit/s to less than 500 Mbit/s), only a small part of end-users reached the corresponding threshold of at least 100 per cent of the contractually agreed maximum data bit rates (as shown in Figure 6.4 for bit rates in the downlink direction).

Figure 6.4: Download transfer rates in mobile networks in Germany by bandwidth class



Overall, the German regulator stated that the measurements do not allow for any conclusions to be drawn regarding broadband supply because the results of broadband measurement depend on the tariff that the user has agreed with the provider. In this respect, no statements can be made on the basis of broadband measurement on the supply situation, or availability of broadband Internet access services.

6.2.4 Italy

The Italian regulator AGCOM (Autorità per le Garanzie nelle Comunicazioni) has an on-going project called *QoS Internet broadband fixed access*. The project seeks to address the issue of misleading Internet offers where ISPs provided only the theoretical maximum speed without providing any minimum guaranteed speed; there is no possibility to withdraw from the contract without penalty; and it is not possible to compare ISP performances because of the lack of transparency.

The AGCOM approach to Internet measurements builds on:

- ISP measurements based on dedicated probes located in the main towns, able to measure performance related to the two most sold offers for each ISP.
- End-user measurements to allow users to measure their own fixed line performances by software called Ne.Me.Sys. The end-point is located in end-user homes. There are four sub-options for the end-user regarding the measurements:
    1. Issue of a complete certificate.
    2. Release of a certificate as soon as 5th percentile target value is violated.
    3. Speed test with registration.
    4. Speed test without registration (one-shot).

All such measurements employ the same network measurement system, based on a software agent running on a standard personal computer.

AGCOM selected the following QoS parameters to measure Internet access performances (Figure 6.5):

- data transmission speed;
- packet delay (RTT);
- packet loss ratio;
- unsuccessful data transmission ratio.

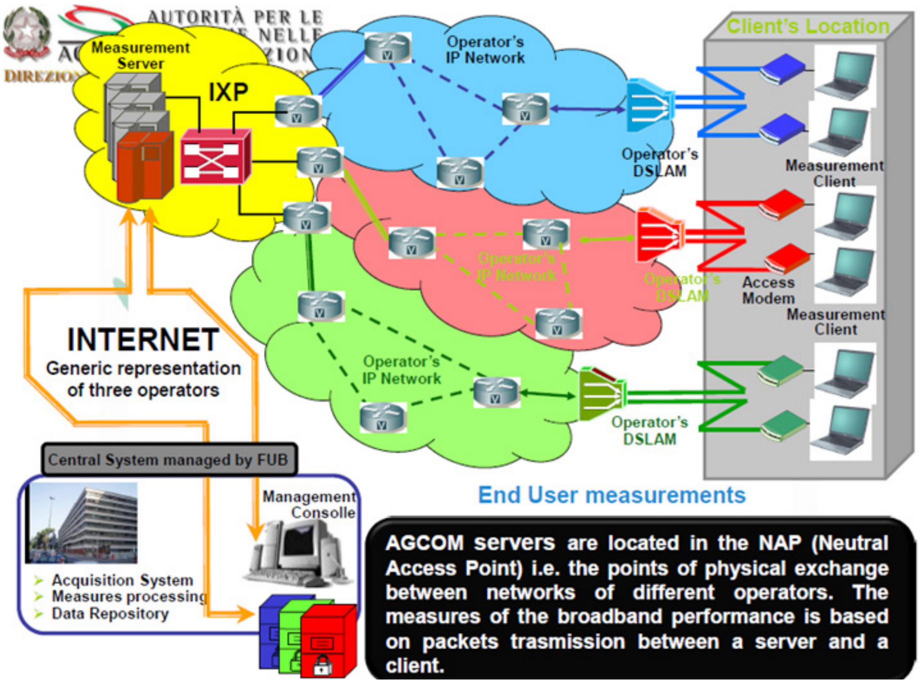
The following four values relevant to data transmission speed are computed for both download and upload direction:

1. 95th percentile in kbit/s;
2. 5th percentile in kbit/s;
3. mean value in kbit/s;
4. standard deviation in kbit/s.

The following two values relevant to delay are computed:

1. mean values in milliseconds;
2. standard deviation.

Figure 6.5: End-user measurement process



Source: AGCOM

The **Ne.Me.Sys**. tool (https://www.misurainternet.it/nemesys.php) measures the quality of the line, making at least one measure per hour throughout the day. To fully characterize the line, the software has to make a measurement in each time slot. This is necessary to evaluate the performance as a function of network load. The evaluation of the line is made by at least 24 independent measurements taken in each time slot. Each measurement is made with: 20 FTP download sessions, 20 FTP upload sessions, and 10 ping sessions. HTTP measurements, instead of FTP, were used in the period 2015-2017.

The outcomes of broadband measurements done by Ne.Me.Sys., and the results obtained, can be used by customers to terminate their contract without penalties, to freely downgrade to a cheaper profile, or to demand that QoS parameter levels be restored.

The results reported in the final certificate, in fact, can be compared with QoS KPI promised values, indicated by the operator for each Internet offer, and will be published on the *misurainternet* site.

If the results are less than the promised values, the user may submit a claim to the operator. If the operator does not improve the quality within 30 days, the user, after a second claim, may terminate the contract without penalties.

Regarding the KPIs for mobile broadband measurements, and in accordance with ETSI technical specifications TS-102-250 and TS-202-057, the following KPIs have been chosen to assess the network performance and quality of mobile broadband service:

- data transmission (DL/UL) throughput;
- data transmission (DL/UL) unsuccessful rate;
- web page download time (HTTP/HTTPS);
- web page download unsuccessful rate (HTTP/HTTPS);
- packet delay;
- packet loss;
- jitter.

For the period 2015-2017, AGCOM has defined measurements for mobile networks that include both static measurements (with probe stations) and dynamic tests (drive tests) for all mobile networks in Italy. These tests include:

- Fixed duration test: DL/UL transfer tests of very large files (e.g. 2 GB), limited to 30 seconds.
- Video streaming test with two possible approaches that have both advantages and disadvantages:
    1. A streaming service could be developed and located at the regulator premises. The advantage is that the test activity is kept within the mobile network under test. The disadvantage is that advanced real-world streaming techniques can hardly be replicated.
    2. The measurement is done using one of the most diffused video streaming service, YouTube. The advantage is that advanced streaming techniques, as experienced by the users, can be taken into account. The disadvantage is that the tests involve sections of external networks.

An example of an AGCOM measurement loop for the measurement of FTP and HTTP (for file download and upload) and ping (for measuring RTT) is presented in Figure 6.6. Figure 6.7 shows the type of tests performed by AGCOM in test campaigns for broadband QoS measurements in the period 2012-2017. HTTP has been the preferred application protocol for file upload and download since 2015 as the majority of Internet users are accessing the web through web browsers, where the web is based on HTTP over a TCP/IP protocol stack. The older FTP is now rarely used by end-users.

Figure 6.6: Measurement loop example

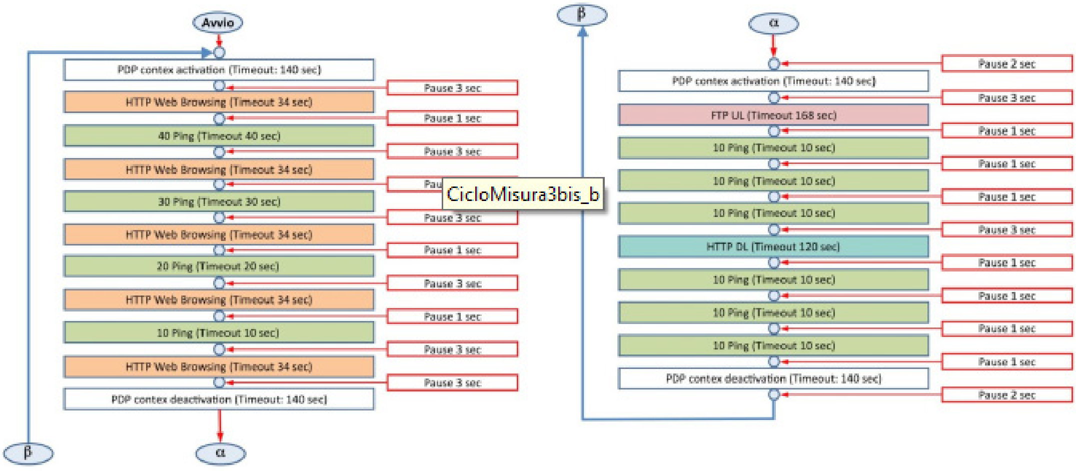


Figure 6.7: AGCOM comparison table for campaigns

AGCOM Deliberation			154/12/CONS				580/15/CONS			
Drive Test Campaigns			2012	2013 - 1	2013 - 2	2014	2015	2016 - 1	2016 - 2	2017
Type of tests: Data download	HTTP	FIXED FILE	E	x	x	x	x			
		FIXED DURATION					x	x		
Data upload	FTP	FIXED FILE	E	x	x	x				
	HTTP	FIXED DURATION					x	x		
Web page download	HTTP		E	x	x	x	x	x		
	HTTPS			E	x	x	x	x		
Packet TX/RX			E	x	x	x	x	x		
Videostreaming							x	x		
Test devices		USB dongle	E	x	x	x				
		Smartphone					x	x		
Technology		3G-2G	E	x	x	x	x	x		
		4G-3G-2G					x	x		
Test scenario		Static	E	x	x	x	x	x		
		Dynamic	R	R	R	R	x	x		
		N. of cities	20	20	20	40	40	40		
		N. of static points	1013	1013	1013	1202	1202	1202		

x Official tests for publication
E Experimental test/campaign
R Reserved to AGCOM/FUB

In 3G sub-campaign the fixed-file DL test is carried out for comparison with previous campaigns (historical series)

FTP UL tests are replaced with HTTP UL tests (ref. ETSI ES 202 765-4 V1.2.1)

3G-limited and 4G sub-campaigns (in selected cities) are carried out

6.2.5 New Zealand

Gaming is becoming a popular OTT service which is widely used around the world and has strict delay requirements (on delay and jitter), more stringent than OTT VoIP. Game site latency has been measured by TrueNet commercial measurement tools and platforms in Australia and New Zealand. These results, as illustrated in Figure 6.8, may serve others who do not perform such measurements. RTT delay measurement results on the most popular online games over fibre and cable Internet access (from October 2016) are provided below.

Figure 6.8: Latency measurements on gaming

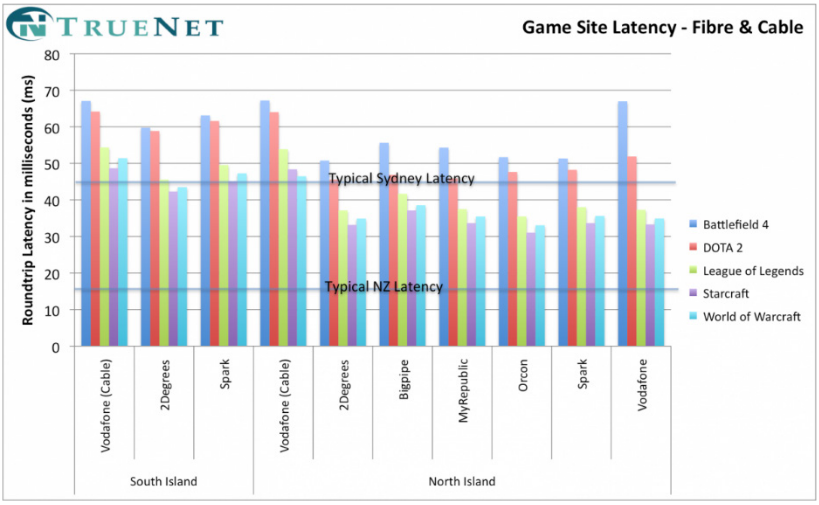
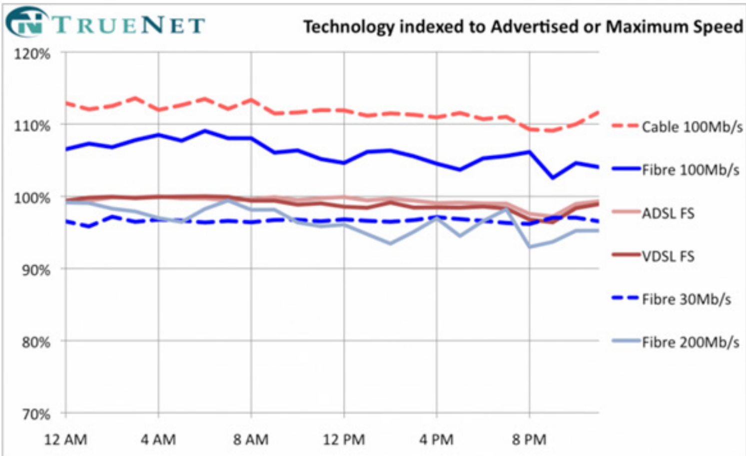


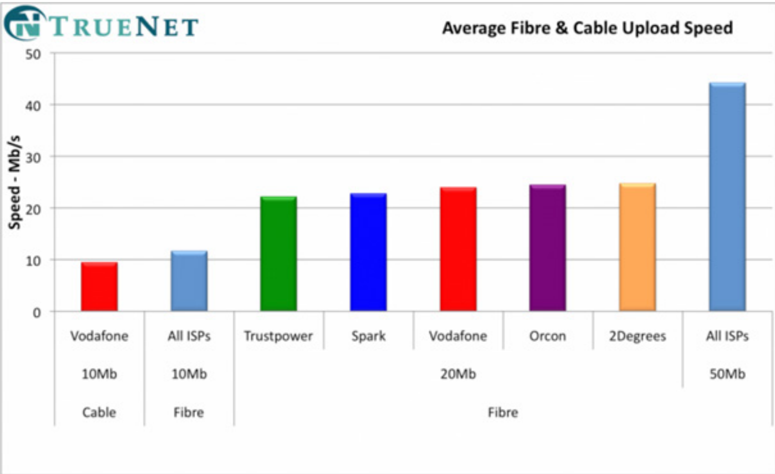
Figure 6.9: TrueNet New Zealand file download speed (measured vs. advertised)



Source: TrueNet. https://www.truenet.co.nz/story/2016/11/october-2016-urban-broadband-report

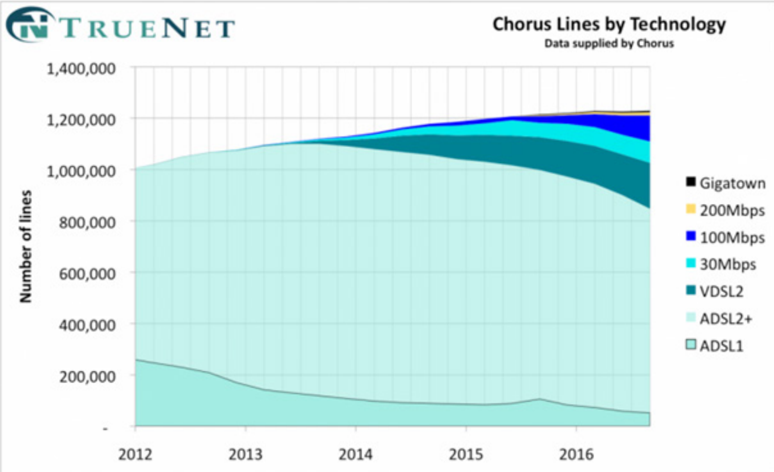
Comparing performance of these OTT services provided via Internet access service by time-of-day (Figure 6.9) is important as it shows service degradation when everyone is using the Internet during the evening peak hours of 8 pm to 10 pm. A poor result typically shows the line drops below 90 per cent, which usually occurs in the busy period between 7 pm and 10 pm, i.e. if this is true, the average customer of that ISP is getting less than 90 per cent of their line capability.

Figure 6.10: TrueNet New Zealand file upload speed (measured vs. advertised)



Source: TrueNet. https://www.truenet.co.nz/story/2016/11/october-2016-urban-broadband-report

Figure 6.11: New Zealand fixed broadband Internet access per technology



Source: TrueNet. https://www.truenet.co.nz/story/2016/11/internet-price-trends

Upload speed (Figure 6.10) is important to users sending large amounts of data through the Internet, or uploading files to the cloud. The TrueNet upload test sends a 1 MB file to the Wellington server and records the results using a similar method to download tests. The penetration of fixed broadband access in New Zealand is shown in Figure 6.11.

6.2.6 Poland

In accordance with the provisions of the Universal Service Directive of the European Union, the Memorandum of Cooperation to improve the quality of services provided to users in the telecommunication market was proposed in May 2012 by the President of the Office of Electronic Communications (UKE), the regulatory authority in Poland, and signed in October 2012, includes:

- contracts for services should be structured in a clear, understandable, easily accessible form;
- published information on the quality of services provided by telecommunications undertakings should be comparable, relevant and up to date;
- the user shall have access to comprehensive, comparable, reliable information presented in a friendly form;

- measurable indicators of quality of service shall be identified, as well as the content, form and method of providing information to be published;
- minimum quality requirements shall be identified in order to prevent deterioration of the quality of service in public networks.

UKE imposed the following technical and administrative QoS indicators (see Table 6.2) as defined in the ETSI Guide (EG 202 057-2, EG 202 057-3 and EG 202 057-4):

- Fixed and mobile services: successful call ratio.
- Mobile services: speech quality ratio, dropped call ratio.
- Internet access (fixed and mobile) services: data transmission speed, delay.
- All telecommunication services: average response time for operator services, bill correctness rate.

Table 6.2: QoS indicators in Poland

Indicator	Range for good quality	Range for satisfactory quality	Range for poor quality
Average response time for operator services	<= 60 s	Longer than 60s but shorter than 120s	120s or more
Bill correctness rate	Above 97.5%	from 95.1 to 97.5% inclusive	Below 95.1%
Efficiency of telephone calls	Above 98%	from 95 to 98% inclusive	Below 95%
Interrupted calls rate	Below 2%	from 2 to 5% inclusive	Above 5%
Quality of speech	Above 90%	from 80 to 90% inclusive	Below 80%

Source: UKE

UKE has concluded that consumers should have the possibility to check the quality of this service for the applications they are using as part of Internet access. The list of services, with assigned threshold values for data transmission speed and delays (according to UKE), is shown in Table 6.3.

Table 6.3: UKE measurements of data transmission speed

Group of applications	Transmission speed not lower than	Delay not greater than
WWW browsing	1 Mbit/s DL	200 ms
SD videos watching	2 Mbit/s DL	200 ms
HD videos watching	6 Mbit/s DL	200 ms
HD videos talks	1.5 Mbit/s DL and UL	150 ms
VoIP telephony	64 kbit/s DL and UL	150 ms
multiroom services (3 x HD video)	18 Mb/s DL	200 ms
On-line real time games	2 Mb/s DL and 1.5 Mb/s UL	30 ms

Group of applications	Transmission speed not lower than	Delay not greater than
Other on-line real time games (chess, ...)	1 Mbit/s DL and UL	200 ms

Depending on the percentage share of samples complying with the minimum criteria of applications, Internet access service is classified by UKE in Table 6.4.

Table 6.4: UKE classification of the quality of Internet access

Result of classification of samples for applications	Quality of IAS
Below 70%	Poor quality
From 70 to 90%	Satisfactory quality
Above 90%	Good quality

Source: UKE

UKE has applied specific rules for measurements in mobile networks as mobile users may be at different locations in the network at different times. The same users may therefore experience different levels of quality within the same network. One of the objectives defined in the Memorandum is to ensure comparability of the measurement results. For this purpose the following rules on mobile network measurements were adopted:

- simultaneity tests (measurements) are conducted at the same time, using the same measurement unit or units in parallel for all operators and all measured services;
- area and time of measurements is the same for all operators;
- measurements will be conducted by an independent entity;
- measurement campaigns will be conducted periodically, in accordance with the adopted reporting period;
- the UKE has monitoring and supervisory functions.

The choice of a measurement route should take into account population distribution patterns, traffic patterns and the area of service provision. The minimum duration of the measurement campaign is 800 hours. At least 80 per cent of the measurements are conducted in motion, with measurements conducted for the following categories of areas: large urban areas; towns with at least 50 000 inhabitants excluding large urban areas; and domestic highways outside administrative borders of large urban areas and towns.

Regarding the publication of measurement results, the telecommunications undertakings have the obligation to publish up-to-date results of QoS measurements for their networks. UKE should publish the summarized benchmarks of QoS indicators for particular reporting periods on its website as submitted by telecommunications undertakings. The first measurement campaign started in 2015 and service providers who have signed the Memorandum must submit the results of their QoS measurements to UKE twice a year.

The Memorandum is open to all interested parties and is unlimited in time. Any telecommunication undertaking in Poland can join the initiative at any time by committing to apply the solutions and standards agreed for the benefit of subscribers and their own companies.

The final report is addressed not only to the Memorandum signatories but is also a public document. The solutions presented in the report may also be used by other telecommunication undertakings when elaborating their own QoS measurement systems.

6.3 Toward the future: Mapping broadband quality of service

Mapping of the existing infrastructure and the broadband QoS allows public authorities to identify the investment gap. It allows for the monitoring of progress towards NGN targets. Mapping is therefore a key element of national broadband plans and of state aid assessment in the European Union. Mapping of broadband QoS helps in reducing investment costs by facilitating higher re-use of existing passive telecommunication infrastructure, avoids duplication of civil engineering works, prevents damages while performing civil engineering works, and facilitates co-investment among sectors.

For example, in Europe, the planned EU integrated monitoring platform will aggregate and benchmark mapping measurements of services through four main steps:

1. Design, development and maintenance of the integrated platform.
2. Two sets of data: quality of service and quality of experience.
3. An interface enabling the pulling/entry, data conversion.
4. A certification and benchmarking function for crowdsourcing apps that comply with a set of qualification criteria.

The final version of the EU broadband measurement platform is expected by December 2017 and will include important QoS and QoE aspects:

- QoS aspects include data based on marketed speeds/quality criteria (on a basis of a number of pre-defined parameters/metrics) gathered within existing national mapping initiatives. Data entities include Ministries/agencies, network operators and National Regulatory Authorities;
- QoE aspects refer to data on actual user experiences pulled from crowdsourcing applications. The qualification process for the data is set by pre-defined parameters/metrics. Data sources include BEREC and the following platforms: M-LAB, Akamai, Ookla, Netradar, Opensignal, Specure, RIPE, PERSOFAR, as well as data collected by consumer organizations, etc.

Regulatory authorities play a key role in promoting competition in the provision of electronic communications, primarily by ensuring the highest benefits for service users in terms of choice, price and QoS; promoting innovation; and encouraging efficient investment in electronic communications infrastructure and associated facilities. Based on this, an operator is entitled to request shared use (including physical co-location) of network elements and associated facilities of another operator or a third party, where necessary, where it is impossible or when it does not make economic sense to construct or install a new electronic communications network and associated facilities. The NRA shall establish and keep an updated database on the type, availability, QoS information, and geographic location of capacities which may be requested for shared use or access. The database has to be made publicly available on the NRA website, offering comprehensive browsing capacity.

Infrastructure mapping enables policy-makers, regulators and operators to identify network availability. Mapping further enables the identification of gaps (underserved areas), supports investors in their planning and decision-making, and helps identify potential areas for infrastructure sharing within the sector and with other utilities. Mapping is also a tool to improve the QoS of communication networks and can provide consumers with access to network availability, coverage and even speeds.

Mapping is therefore a key element of next generation networks (NGN) planning and provides, for example, the basis for state aid assessment in the EU. The results of the EU study on the mapping of broadband and infrastructures (SMART 2012/0022)[7] will help public authorities in Europe to adopt similar criteria to ensure the credibility and reliability of their mapping, thereby helping to speed up the process of planning public interventions under EU funds. The mapping concept is presented in Table 6.5.

[7] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=8455

During Phase 1, the study reviewed mapping initiatives in Europe and around the world and developed a methodology based on four types of mapping:

1. Infrastructure mapping: Geo-referenced and structured data of physical infrastructure, e.g. ducts/fibre/nodes, antenna towers/masts, and other relevant infrastructures (energy, transport or water supply). A number of European countries perform infrastructure mapping initiatives: Austria[8], Belgium[9], Denmark[10], Estonia[11], France, Poland[12], Switzerland[13], and the United Kingdom[14].
2. Quality of service (supply) mapping: Maps information on the supply side of broadband service provision, including the available bandwidths and the quality of service, technologies, operators/service providers. A number of European countries perform service mapping initiatives: Belgium, Denmark[15], Finland[16], Germany[17], Greece[18], Hungary[19], Ireland[20], Norway[21], Poland[22], Spain[23], Sweden[24], Switzerland[25], and the United Kingdom[26].
3. Demand and quality of experience (demand) mapping: Data on actual latency/speeds experienced by users; data usage (per household); expectations regarding quality of service and experience and willingness to pay by different user groups. Two European countries perform demand mapping initiatives: Sweden[27], and the United Kingdom[28].
4. Investment mapping: Information related to prospective public and private investment of high speed broadband during the next three years (in line with EC broadband state aid guidelines).

In Phase 2, the EU integrated monitoring platform will aggregate and benchmark mapping measurements of services as part of the following steps:

1. design, development and maintenance of the integrated platform; this will include two sets of data: quality of service and quality of experience;
2. development of an interface enabling the pulling/entry, data conversion;
3. inclusion of a certification and benchmarking function for crowdsourcing apps that comply with a set of qualification criteria.

8 www.senderkataster.at/
9 www.bipt.be/
10 http://mastedatabasen.dk/VisKort/PageMap.aspx
11 http://ela12.elasa.ee/elakaart/
12 http://www.uke.gov.pl/mapa/?map_tab=1
13 http://map.geo.admin.ch/?topic=funksender&lang=de
14 http://maps.ofcom.org.uk/broadband/
15 http://dba.erhvervsstyrelsen.dk/file/348160/broadband_mapping_2012.pdf
16 www.ficora.fi/attachments/englantiav/6HdjnUV00/Toimialakatsaus_2012_EN.pdf
17 www.zukunft-breitband.de/DE/Breitbandatlas/breitband-vor-ort.html
18 http://mapsrv1.terra.gr/eettutilities/mapnew.aspx
19 www.vus.sk/broadband/nbbs/hu_nbbs.pdf
20 www.dcenr.gov.ie/Communications/Communications+Development/National+Broadband+Scheme/National+Broadband+Scheme.htm
21 https://www.regjeringen.no/no/dokumenter/bredbandsdekning-2014/id2356922/
22 http://en.uke.gov.pl/report-on-the-coverage-of-poland-with-telecommunications-infrastructure-751
23 http://bandaancha.eu/analisis/mapa
24 http://bredbandskartan.pts.se/
25 http://map.geo.admin.ch/?topic=nga
26 http://maps.ofcom.org.uk/broadband/
27 http://bredbandskartan.pts.se/
28 www.samknows.com/broadband/exchange_mapping

Table 6.5: Mapping concept

Service mapping		Infrastructure mapping	
National level		National level	
Demand mapping		Investment mapping	
Demand for broadband	Quality of service	Rolled-out investments	Planned private investment
According to the national guidelines to justify State aid	Depending on initiative requirements	Integration into service and infrastructure mapping	According to the national guidelines to justify state aid

The national mapping process is very important as it establishes a single information point for broadband service, infrastructure, demand and investment. Infrastructure mapping is the detailed, geo-referenced and structured gathering, processing and visualization of data on infrastructure, which creates transparent access to relevant information. Service mapping describes systems that gather, analyse and present information on the supply of broadband services available in a specific area, and hence provides an insight into the current state of broadband availability in order to assist in decision-making processes. Both service and infrastructure mapping may use several publication formats, such as static or interactive maps in public and other more restricted formats. In both cases the authority in charge should be the NRA.

6.4 ITU framework for monitoring quality of service of IP network services

Through Y.1545.1 (March 2017), ITU has specified a framework for broadband QoS monitoring, i.e. a framework for QoS of IP network services. The rapid increase in the use of the Internet has changed the way we live, and has become an important factor in people's daily life. ITU-T Rec. Y.1545.1 highlights the necessity of testing the QoS of network services offered by ISPs (e.g. fixed and mobile operators), from diagnostic and regulatory points of view. The recommendation also addresses QoS evaluation scenarios, sampling methodology and testing tools for regulators. It also provides guidance to regulators on minimum QoS parameters for evaluating the quality of Internet services.

The minimum set of parameters for evaluating the quality of IP network service, according to ITU-T 1545.1, is defined in Table 6.6. Methods of measuring IP network services provided by ISPs are categorized as active and passive methods of measurement (according to RFC 7799). The advantages and disadvantages of both methods are shown in Table 6.7.

Table 6.6: Minimum set of parameters for evaluating the quality of IP network service

Parameter	Definition
1 IP network service activation time	These parameters apply to a set of individual attempts to access and utilize IP network services, and in one case are supplied by the DHCP server of the service provider. (See Annex A of Y.1546.)
2 DNS response time	Defines a round-trip delay metric for IP networks. (See RFC 2681.)
3 Number of IP network interconnection points	This metric is a count of the number of interconnection points to other autonomous systems (AS), based on creating a diagram of the network being measured according to the procedures specified in RFC 7398.

Parameter	Definition
4 Round-trip delay (RTT to IP network interconnection points)	This metric measures the round-trip delay between subscriber service demarcation points and the interconnection points to ASs. Sometimes these interconnections occur at public Internet exchange points (IXP). (See RFC 2681 for the round-trip delay.)
5. IP delay variation (one-way delay variation to IP network interconnection points)	The one-way delay variation performance parameter is defined in Y.1540.
6 IP packet loss (one-way packet loss to IP network interconnection points)	The one-way packet loss performance parameter is defined in Y.1540.
7 Data rate (download and upload)	Defined with 7.1 and 7.2 in this table.
7.1 Mean data rate achieved: is the average of the data transfer rate achieved for a given number of samples [1]	This is the average of the data transfer rate achieved for a given number of samples, i.e.: $\text{Mean Data Rate achieved} = \frac{\sum_{i=1}^{N} H_i}{N}$
7.2 Percentage of the mean data rate: denotes the deviation between the data rate contracted / advertised to the achieved data rate [2]	Denotes the deviation between the data rate contracted / advertised to the achieved data rate, that is equal to: $\frac{\text{Mean Data Rate achieved}}{\text{Data Rate contracted}} \times 100\%$
8 Internet IP network service availability	Represents the fraction of time probability that the end-user is able to access IP Network packet transfer Internet services via his/her access to Internet connection. (See Y.1540, Section 7.)
9 Radio coverage availability	Not defined in Y.1545.1 (further study is required).

[1] The payload stream should consist of incompressible data. This is normally achieved by generating a sequence of random numbers. Another practical solution can be to use a stored stream that is already compressed, e.g. from a zip or jpg file, or to use the digits of the number Pi. The payload stream should have at least twice the length (in kbit/s) of the theoretically maximum data transmission rate per second (in kbit/s) of the Internet access under consideration.

[2] In this case, a given regulator can set a target of for example 70 per cent, 80 per cent, etc. of the maximum data rate contracted by the subscriber, depending on the country's ICT Market.

Table 6.7: Advantages and disadvantages of active and passive methods of measurements

Measurement method	Advantages	Disadvantages
Active methods	The data (probing packets) is originated from a controlled source with predefined settings and therefore types of services can be fully controlled Easy benchmarking / comparison between measurements obtained from different internet connections provided by different ISPs	– Requires that the line under testing be fully available – Test design must be sure the line is idle before testing

Measurement method	Advantages	Disadvantages
Passive methods	The probe only needs one connection point to the network which means less hardware Does not *take over* the line under test, so it is never an inconvenience to end-users	– Unknown traffic type makes it difficult to test maximum line capability – Difficult to average different tests as the data traffic is not consistent

Source: ITU-T Rec. 1545.1

6.4.1 Testing tools classification by ITU

According to Y.1545.1, testing tools can be hardware-based or software-based. Hardware-based tools can have at least the following options of implementation:

- Option 1: Probes replace completely the end-user equipment and no other equipment can be connected to the Internet access while the probe is performing measurements. This is applicable for both fixed and mobile Internet access.
- Option 2: Probes share the Internet access with ordinary traffic. For example, probes can be connected to the customer residential gateway. Appropriate probes can monitor the end-user traffic behaviour and perform the tests only when there is no traffic being transferred.
- Option 3: A testing application programming interface (API) is embedded into the customer residential gateway, through a firmware update, in order to act as a probe and test the fixed Internet connection.

On the other side, there are at least three kind of software based tools:

- Web-based tool: Download and execution of measurement software is initiated via the end-user web browser by accessing a specific web page.
- Dedicated software client: Measurement software is permanently installed on the end-user terminal equipment. In this case, different versions of software are needed to support different operating systems and terminal equipment.
- Testing API: An API can be included into the code of one popular website in order to perform the test transparently each time users access the website.

No matter what type of test tool is chosen, test tool specifications should be sufficiently detailed so that two independent implementations of the tools should measure statistically equivalent performance (with high confidence) when measuring the same network path under the same conditions.

6.4.2 Quality of service evaluation scenarios by ITU

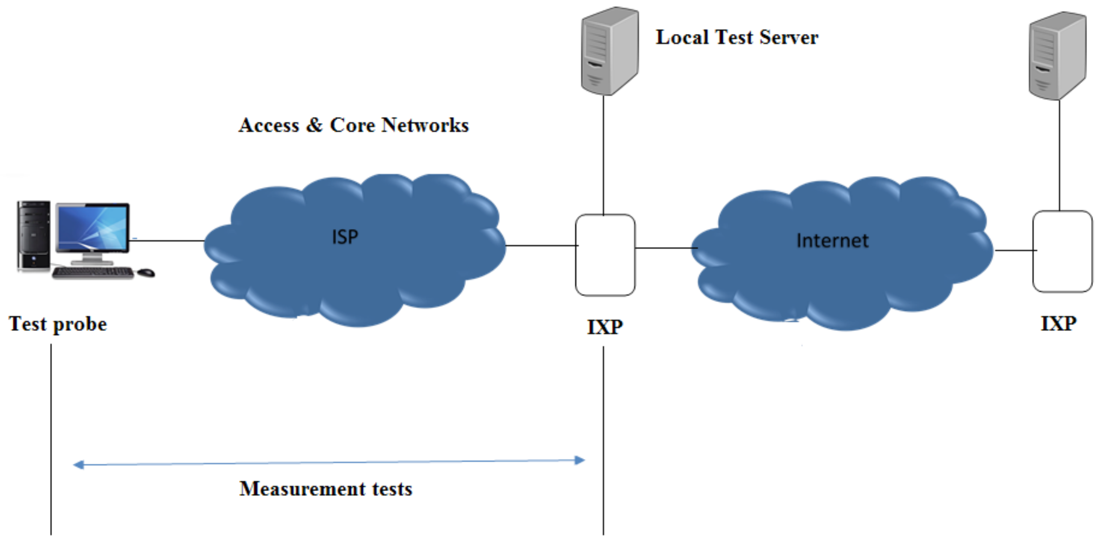
Scenarios usually applied in order to evaluate the QoS of IP network service (i.e. Internet access services) can be classified into two main types:

- evaluation scenario at national level (test server located at local IXP);
- evaluation scenario at international level (test server located at an international IXP).

Measurements are conducted on the selected QoS parameters that have an impact on the user experience when utilizing IP network service.

In the evaluation scenario at national level, the test server is located at the local IXP and probes are installed at the end-user point of view. Measurements are carried out by regulators with or without the involvement of ISPs, and the measurement path includes a complete Internet connection from customer to the test server located at the local IXP. ISPs or regulators can use standardized hardware or software-based probes (when they are available). In this evaluation scenario, tests initiated by probes are directed to the local IXP when testing local KPIs (such as download/upload mean data rate, latency), as illustrated in Figure 6.12.

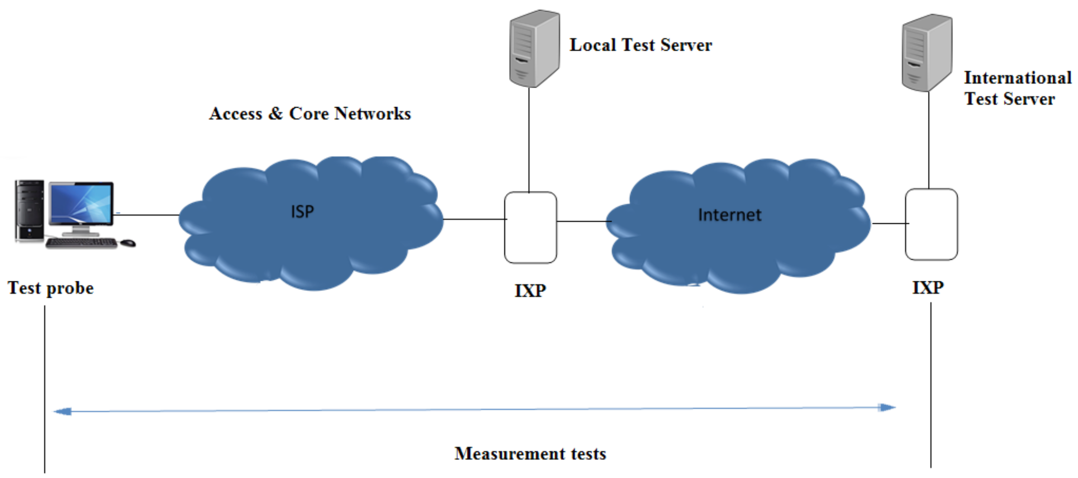
Figure 6.12: Set-up of measurements of Internet QoS at national level



Source: ITU-T Rec. 1545.1

In the evaluation scenario at international level (illustrated in Figure 6.13), the test server is located at an international IXP (e.g. may be installed in another country or even another continent). Usually, the Internet connection that ISPs provide to customers is to the entire Internet. Therefore, the more bandwidth capacity in the ISP connections, the better the quality of Internet connection provided by ISPs will be. This scenario allows regulators to test international data transmission KPIs (such as download/upload data rate, delay). This further allows the comparison between the connectivity of IP-based services inside and outside the country (different countries/continents).

Figure 6.13: Set-up of measurements of Internet QoS at international level



Source: ITU-T Rec. 1545.1

6.4.3 Important considerations about the sampling methodology

The number of probes to be used in testing the QoS of Internet measurements should be enough to guarantee that the data collected are representative for that region and sufficient from a statistical perspective. Further, the data collection plan should be designed in order to ensure that the results sufficiently reflect the QoS as perceived by the user.

It is recommended that the selection of panellists (end-user access points, where to install probes) should take into consideration various factors such as technologies (e.g. xDSL, fibre optic, wireless/mobile networks), Internet data rate packages (depending on popularity), location, and be based on a voluntary process in order to avoid ISP traffic prioritization for those users being tested (which could lead to unrealistic results in favour of ISPs).

Detailed post-processing and statistical methods can be found in ITU-T Rec. E.804 (Chapter 11).

Important considerations regarding Internet QoS measurements include the following:

- Selecting access lines for each speed package: The sampling methodology should have a stable level for the confidence intervals obtained in different regions and for different ISPs. If the final results of the access lines per ISP correspond almost to the market share of the ISP, it is likely to mean that the sampling criteria followed by the national measurement campaign are representative. However, there is a difference between fixed and mobile access to Internet in selecting the access point:
  - *Mobile Internet*: It is possible to measure QoS only where coverage is ensured by selecting a number of hotspots for measurements across the country. This can be calculated depending on the size of the country, geographic coverage percentage, and classification of rural, urban and suburban areas.
  - *Fixed Internet*: Selection of access points for fixed ISPs is quite challenging as in order to perform the measurements, it is necessary to enter the consumer's premises in most cases. This problem is faced by both regulators and ISPs. However, this obstacle may be overcome through the development of cooperation between regulators, consumers and ISPs. Experience in this regard shows that in order to develop cooperation and attract sufficient numbers of volunteers, each attempt should be led by an appropriate advertising campaign and publication of information using different media channels.
  - Selecting the measurement moments: The moments for the measurements should in principle cover high and low traffic, including peak hours. However, for simplicity, the measurements may cover only high traffic, including peak hours. If the IAS is working properly in peak hours (or at least in high-traffic hours) the conclusion could be made that quality in low-traffic hours should be even more acceptable. The frequency of the measurements should be based on the number of users participating in the campaign, the option(s) taken for the overall set of measurements, and the level of statistical error and confidence intervals acceptable for the project.

6.5 Issues for consideration

What happens with multiple flows over the same Internet access?

Well, different services or applications that are provided via public Internet access toward end-users share available bandwidth (i.e. bit rates) in the uplink (UL) and downlink (DL). For example, if you have 10 Mbit/s bandwidth in DL, and you download with HTTP or FTP ten files in parallel over that bandwidth, then each connection (download) will have less than $1/10^{th}$ of the DL bandwidth. That means congestion also occurs on the user side. Most of the non-real-time applications use TCP/IP, where TCP is designed to provide congestion control on the two ends (client and server) by adapting its speed to the available bandwidth and by sharing the available bit rate equally with other TCP flows over the same connection. However, it is possible (even in the above example) that some TCP flows will have lower bit rates due to some other bottleneck from end-to-end between the client and server, which can be anywhere on the path.

Real-time services (services sensitive to delay) such as VoIP (e.g. Skype, Viber) use RTP over UDP/IP for transfer of the user data (that is voice in the case of VoIP). In such cases, retransmission does not fill the lost packets as TCP does, but results in losses in the given flow (e.g. in VoIP flow). Each user can see the download or upload speed (e.g. via web browser or FTP client software for download/upload). Each user has a certain experience regarding Internet access services (bit rates, delay) at a given time.

Can the end-user be trusted regarding the measurements?

It depends…. If it is about the availability/unavailability of an Internet access, or about significant decrease in the bit rates or increase in the delay, then it may trigger an action toward operation and maintenance on the ISP side (e.g. to repair broken Internet access links or equipment). But, if it is about Internet access QoS on average, then the user cannot make valid measurements by himself/herself (e.g. doing speed tests at certain times). Measurement must be made through certain software (or hardware) installed as an agent (or probe) on the end-user side (with user agreement on that), which will provide periodical measurements on the specified QoS parameters (RTT delay and jitter with ping, downlink and uplink speed with HTTP), taking into account background traffic over the same Internet access and capabilities of the user equipment (e.g. memory, processor, etc.).

Other issues for considerations include the following:

- **Traffic management** is being applied and should be applied in the operator networks, such as ISPs.
- The **network neutrality** based Internet access service must have QoS guarantees on given parameters, such as bit rates in UL and DL, RTT delay, jitter and packet losses (all dependent upon services).
- **QoS for the Internet access service** provided by the ISP should be measured on the end-user side. That requires Internet measurement tools and platforms. There are free available measurement platforms (e.g. M-Lab, RIPE Atlas), and free measurement tools (e.g. SpeedTest, Glasnost, NDT). Many NRAs (e.g. in Europe) have their own tools for Internet QoS measurements on the end-user side.
- **Many factors influence the measured data**, such as other networks on the end-to-end path, background traffic from other applications, type of network (fixed, mobile, and which technology 3G, 4G, etc.), user equipment, traffic management techniques applied by the ISP for the given tariff package, etc. So, this is not a *linear game*. Much knowledge is needed to understand how broadband works in order to regulate it.

7 Economic principles of quality of service regulation

For the purposes of this manual, QoS is directly related to the pricing of services in commercial environments. The focus here is on pricing in an IP environment.

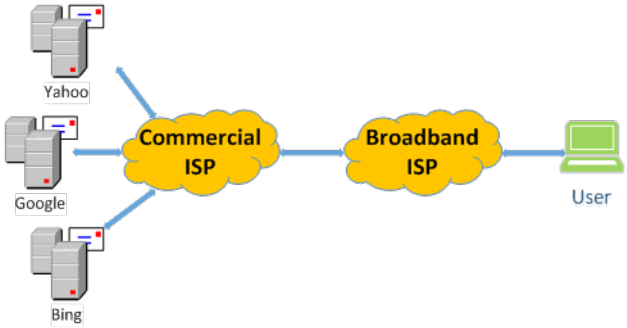
7.1 Two-sided market

Every electronic communications market is in some sense a two-sided market, however, in not every case will a two-sided market analysis provide information that was not available in a conventional analysis. In end-to-end connections, traffic goes through telecommunication operators that provide access to individual end-users (called here broadband ISPs) and commercial ISPs that provide access to the global Internet to telecommunication operators on one side and to content providers (e.g.

Google, Yahoo, Bing, etc.) on the other side. QoS as an end-to-end feature is dependent upon all network players from end-to-end, driven by the market forces on national markets (for broadband ISPs toward end-users) and international markets (for commercial ISPs). Key observations regarding two-sided markets include:

- Promotion of usage is an important societal goal.
- Usage entails two distinct components, characterized by subscription elasticity and usage elasticity.

Figure 7.1: Internet as a two-sided market



Areas where two-sided markets have been considered for electronic communication services include voice call termination payments, network interconnection, as well as arrangements between network operators and content providers, especially in terms of QoS.

The Internet can be thought of as a two-sided market, with the network operators collectively serving as a platform connecting providers of content (e.g. websites) with consumers (Figure 7.1). This interpretation also suggests that quality differentiation is unproblematic. Under this view, some issues are simply about how costs and profits should be divided between the network operators and the two (or more) sides of the market.

When a producer with market power in one market segment attempts to project that market power into upstream or downstream segments that would otherwise be competitive, this constitutes economic foreclosure. Foreclosure should be avoided as it harms consumers, and imposes an overall socio-economic deadweight loss on society. Foreclosure could be a concern in markets where significant market power (SMP) is given free rein.

7.2 Quality of service and pricing

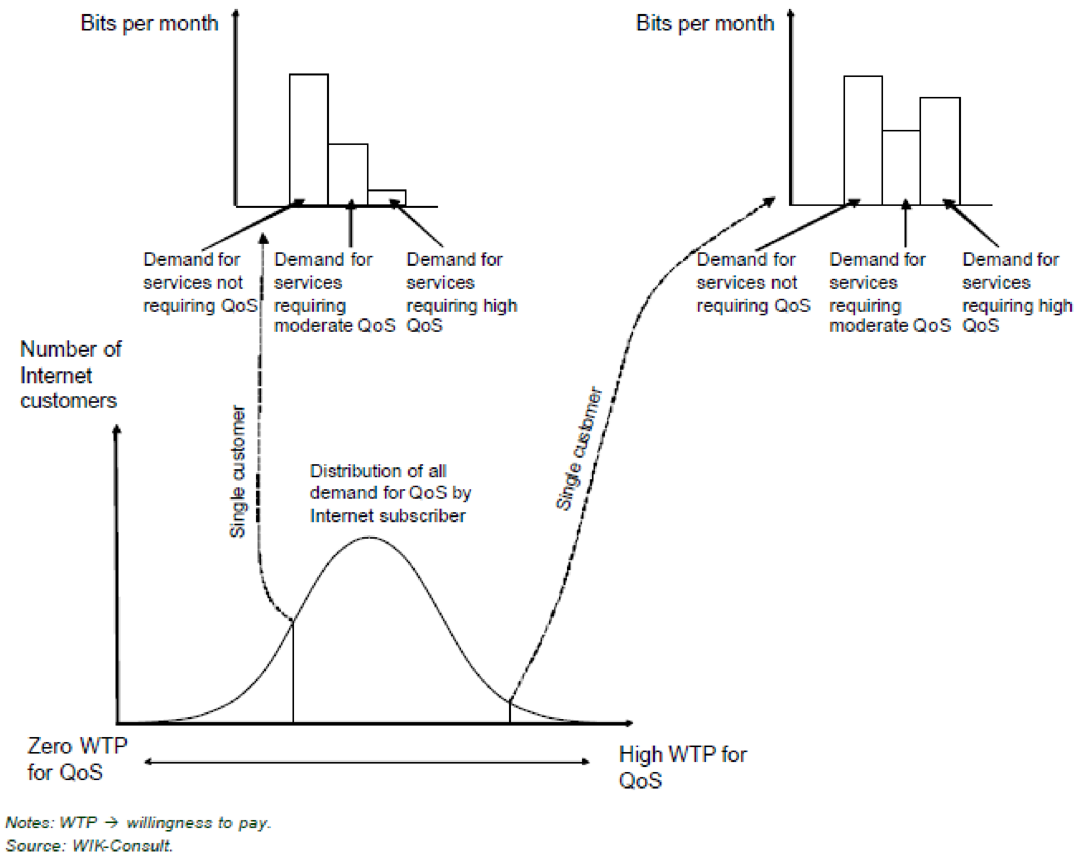
This section is based on ITU report *IP-based networks: Pricing of telecommunication services*. In the past, telephone networks used time-of-day as an element for pricing. Subscription charges are the flat rate charge, with usage being charged on a per-minute (or per-second) basis, and typically varying according to the time of day. The idea with time-of-day pricing is to dissuade callers with low demand from usage during the most congested period, encouraging them to shift their usage to a period when per-minute charges are much lower. This was optimal because the capacity investment costs required to handle the traffic from subscribers with weak demand during peak usage were higher than the present value of their willingness to pay for the capacity needed to satisfy that demand. However, since then, the approaches have changed to mainly flat fee charges regardless of the volume of the voice traffic (on a national basis) since access became broadband (with Mbit/s or tens of Mbit/s per user), and the bandwidth (in bit/s) for voice connections has no changes over time during the connection (i.e. voice requires near constant bit rates in each direction), hence capacity can generally accommodate that. Telephony services with guaranteed QoS provided by fixed and mobile operators have faced competition from OTT voice providers since 2003 (e.g. Skype, Viber, and others). Therefore, charging per minute or per second is being less applied today (e.g. it is primarily applied for roaming calls on mobile networks).

As further detailed in the ITU report on IP-based networks, the pricing of telecommunication services for Internet access service is also related to QoS as pricing has an influence on the demand for a given service and hence has influence on congestion. For example, a lower price for a service increases the consumption of that service, which in turn increases traffic and hence the probability for congestion. Usage-based pricing can be designed to shift some demand from peak to un-peak periods. It can also signal to ISPs when demand is high enough to make it economically worthwhile for them to increase the capacity of their networks. The idea is that customers should rationalize their own usage during periods of congestion according to the relative strengths of each user's demand. For users with very low demand (say, a willingness to pay for service during a congested period of zero, assuming they can use the service during uncongested periods at no marginal cost), there is little benefit gained in terms of QoS by doing so compared to the costs imposed. At times of congestion, however, the cost of sending extra packets would include the additional delay, packet loss and QoS degradation imposed on other users.

When the Internet is uncongested, experience has shown that usage-based pricing is not helpful; it actually has a detrimental effect on economic welfare as explained in the ITU report. At these times, the cost of sending an additional number of packets is virtually zero. We say that the marginal cost of usage is zero, and it is a demonstrable economic axiom that under these circumstances a usage sensitive price is inefficient – it reduces economic welfare – therefore in those circumstances flat-rate pricing is more appropriate.

Another issue identified with time-of-day pricing in an IP environment is that the Internet is made up of many networks, and even in the same time zone, peak usage may well occur at different times in different places. Moreover, an ISP providing transit to several ISPs, some of which have different peak usage times, suggests that different prices would apply at the same time of day to ISPs that are in the same market competing (on the margin) with other ISPs, even if their traffic/time patterns are not the same. This may raise competition neutrality concerns. Therefore, time-of-day pricing is not suited for Internet services.

Figure 7.2: Demand for Internet service deconstructed



Source: WIK-Consult

Finally, the demand for high QoS for services has an influence on customer willingness to pay for higher QoS (Figure 7.2). If the demand for services that require high QoS is very low (compared to demand for services not requiring QoS), then the willingness to pay for high QoS will be also very low. In such a case, telecommunication operators (which are in fact the ISPs nowadays) will have lower interest in QoS. When the demand for services that require high QoS is comparable with demand for services not requiring QoS, then the willingness to pay for QoS is higher. For example, consumers want and are willing to pay for QoS for IPTV (as replacement for traditional TV), VoIP (as replacement for PSTN/ISDN), business services (e.g. virtual private networks – VPNs, as replacement of leased lines), as well as future smart services (e.g. smart cars, smart homes, smart sustainable cities, etc.).

8 Network neutrality and its regulation

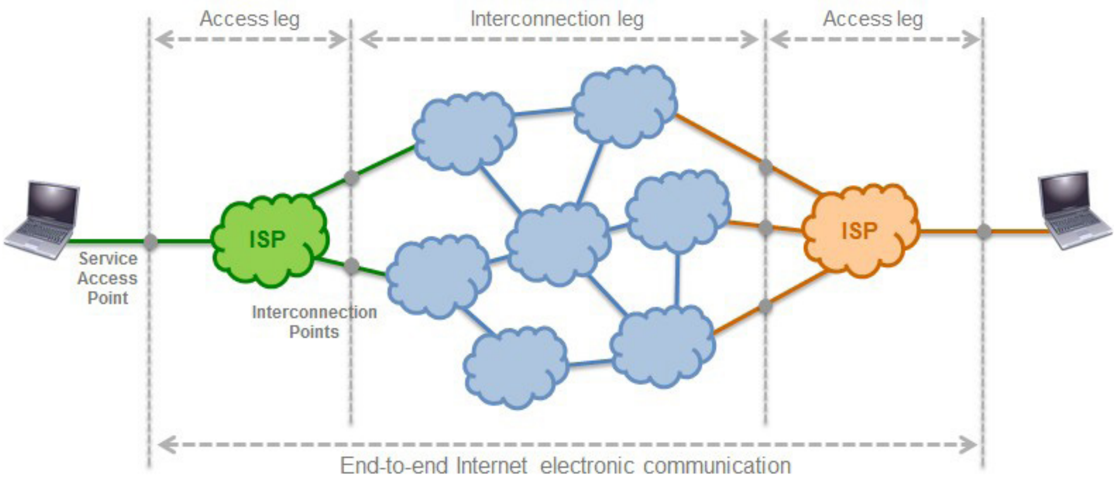
As outlined in ITU Trends in Telecommunication Reform 2013, net neutrality broadly refers to the principle that all Internet traffic should be treated equally. Neutrality proponents claim that telecommunication companies seek to impose a tiered service model in order to control the pipeline and thereby remove competition, create artificial scarcity, and oblige subscribers to buy their otherwise uncompetitive services. Opponents of net neutrality regulation also argue that the best solution to discrimination by broadband providers is to encourage greater competition among such providers, which is currently limited in many areas.

Network neutrality has taken on various meanings, such as in the European Union where it is defined as:

- The ability of all Internet end-users "... *to access and distribute information or run applications and services of their choice*."
- Traffic "... *should be treated equally, without discrimination, restriction or interference, independent of the sender, receiver, type, content, device, service or application*."
- Absence of unreasonable discrimination on the part of network operators in transmitting Internet traffic.

These definitions are not exactly equivalent and do not have the same implications for public policy on the matter. In particular, *all traffic to be treated equally* potentially runs counter (in the more extreme interpretations) to any form of differentiated QoS, while the other definitions do not necessarily prohibit differentiated QoS.

Figure 8.1: Different elements in end-to-end Internet communication



Source: BEREC

Two types of degradation of Internet service(s) were identified by BEREC:

- Degradation of Internet access service (IAS) as a whole: To identify cases of degradation of IAS as a whole, where monitoring the service quality, either proactively or reactively is necessary.
- Degradation of Internet access service with regard to individual applications: In this case individual applications are differentiated in the access part, which may result in congestion and hence require traffic management, and/or network security and integrity protection. In this regard, traffic management mechanisms are used by ISPs to optimize the flow of traffic within their networks. Traffic management can be used to implement both limiting measures (such as blocking and throttling) and enabling measures (such as routing and traffic forwarding). Congestion is the situation met in IP networks when traffic increases to a level at which routers run out of buffer space and are forced to start dropping some IP packets, which typically occurs randomly. Network security and integrity is the protection against externally or internally caused malfunctioning.

To define these cases, BEREC provides the following definitions of the basic concepts:

- Internet: The Internet is the public electronic communications network of networks that use the Internet Protocol for communication with endpoints reachable, directly or through network address translation, via a globally unique Internet address.

- Internet access service: This term refers to a publicly available electronic communications service that provides connectivity to the Internet.
- Specialized services: This term refers to electronic communications services that are provided and operated within closed electronic communications networks using the Internet Protocol. These services rely on strict admission control and extensive use of traffic management in order to ensure adequate service characteristics.
- Internet (electronic) communication: This term is used to refer to the general end-to-end communication provided over the public Internet (Figure 8.1).

When degradation of services by an ISP is noticed, the regulatory authority may intervene and consider imposing minimum QoS requirements. The basic approach to this would be to require the ISP to improve service quality until degradation is eliminated.

8.1 Main regulatory goals of network neutrality by BEREC

Under the framework for quality of service in the scope of net neutrality provided in the BEREC report, and regarding end-user rights, end-users should be able to decide what content they want to send and receive, and which services, applications, hardware and software they want to use for such purposes, without prejudice to the need to preserve the integrity and security of networks and services.

In order to prevent degradation of service and the hindering or slowing down of traffic over networks, countries should ensure that the regulatory authority is able to set minimum QoS requirements on an undertaking or undertakings providing public communications networks. The regulatory authority has the discretion to decide whether to apply any necessary minimum QoS requirements to one, to several, or to all ISPs, and will be able to impose minimum QoS requirements after having identified an instance or a risk of degradation of service, or hindering or slowing down of traffic.

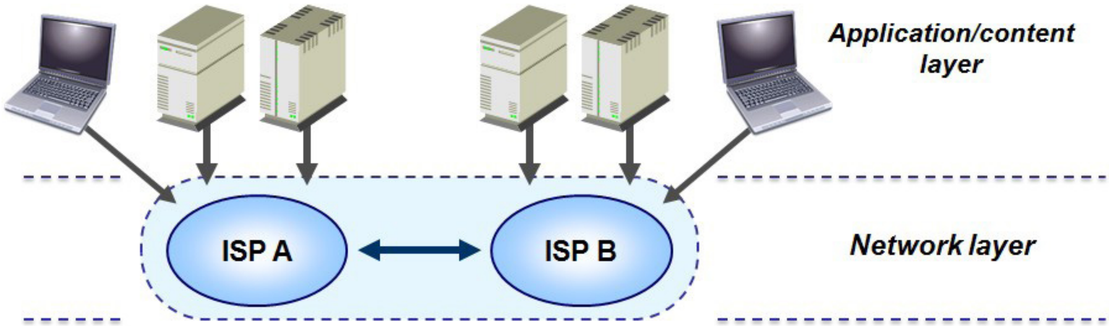
As defined by BEREC, the main regulatory goals of net neutral Internet access services QoS are targeted at:

- achieving the overarching objective of guaranteeing access to content for the interest of citizens;
- ensuring that electronic communications networks run smoothly, in other words to guarantee satisfactory QoS;
- enabling long-term development of the networks and services based on innovation and the development of the most efficient technical and business models; competition plays a fundamental role here, hence the importance of the regulatory authority objective of "*ensuring that there is no distortion or restriction of competition in the electronic communications sector, including the transmission of content*".

The technical aspects to consider in the regulatory processes include the relationship between QoS, QoE and network performance. It is essential to have a clear understanding of the relevant quality concepts and approaches from a technical point of view:

- Network and application layers: the two-layer model (a simplified view of layering model) describes how content and applications relate to the underlying IP network (Figure 8.2).
- Distinguishing between Internet access service and specialized services: specialized services intrinsically offer contractual terms ensuring quality of provision.

Figure 8.2: The two layer model: application/content layer and network layer



Source: BEREC

8.2 Network neutrality business aspects

Regarding relevant market developments, growth in fixed Internet traffic is driven more by the increasing volumes of data being used by each subscriber rather than an increase in the number of subscribers. Whereas growth in mobile data traffic is driven by an increase in the number of subscribers, it is not just the increase in connections which has driven higher traffic. Increased take-up is led by a combination of factors – the availability of powerful mobile devices, fast mobile networks and the ever-growing availability of Internet content and applications (many of which are mobile-specific) – providing the means for consumers to download and upload an increasing quantity of data. However, while overall data traffic is increasing, the growth rate of traffic is declining over time for fixed and mobile networks.

On the business side, the revenues of operators are coming under pressure as a result of a range of market developments. Fixed line voice revenues have long been in decline, mainly from substitution by mobile, but also increasingly from VoIP telephony. In addition, SMS revenues are under threat as, thanks to smartphones and applications such as WhatsApp, consumers can send SMS over IP messages without paying their operator a fee. However, users still have to pay the mobile (or fixed) operator the cost of the Internet access (either flat fee or volume-based fee).

Operators have the option to respond to the rising demand for broadband, traffic growth and the call for infrastructure investment by putting in place traffic management tools to address congestion issues. They can also introduce new business models. As noted by BEREC, ISPs can employ a mix of business models:

- Mobile operators may apply data caps to their tariffs as a way to manage traffic growth.
- They can apply price differentiation based on providing some kind of added value. For example, it can be used for providing faster broadband speeds or *gamer tariffs* that provide the required latency levels to ensure a good gaming experience. Another example is the assured QoS needed for continuous HD streaming.

BEREC further explains that within the context of the IP interconnection market, ISPs that purchase their access from wholesale providers are dependent on the networks of others and may have less control of how traffic is managed and on the QoS delivered to their end-users. Content and application providers may try to prioritize their data delivery.

Differentiation of Internet access service offers is also an important issue. Differentiation of applications regarding traffic management can be done in two main ways:

- <u>Application-agnostic traffic management</u>: treats all applications similarly (e.g. IP packets from all applications put in the same forwarding queue).

- Application-specific traffic management: treats individual applications differently (e.g. VoIP is blocked or P2P is throttled while other applications are not).

8.3 Role of the NRA in the regulation of network neutrality

The need for intervention from the NRA will depend on the quality of the Internet access service and its monitoring and evaluation is necessary to detect degradation. Degradation of the IAS as a whole includes the following possible cases:

- ISPs prioritize specialized services at the expense of the IAS as a whole.
- Internet traffic load grows faster than the increase in available capacity.
- IAS of sufficient quality is accessible to only a limited number of users.

The degradation of the Internet access service as a whole is illustrated in Figure 8.3. In this scenario, the IAS-providing ISPs (ISP1) will not be able to directly control the performance beyond its own interconnections to neighbouring networks (ISP2 and ISP3), but ISPs make interconnection agreements after investigating network performance needs and negotiating with peering and transit partners.

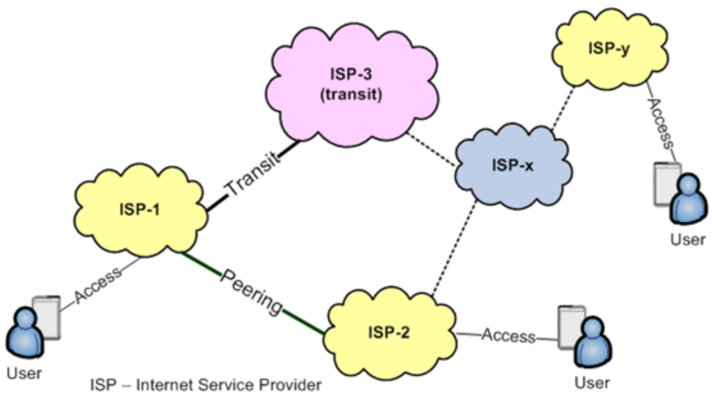
Degradation of IAS with regard to individual applications happens**:**

- VoIP blocking on mobile Internet access services;
- P2P blocking or throttling on mobile or fixed Internet access services;
- differentiation of traffic from content and application providers.

Keeping in mind the possible causes for IAS degradation, the question raised is when is regulatory intervention needed? As noted by BEREC, the market situation should be evaluated to determine whether the problem calls for an intervention taking into consideration:

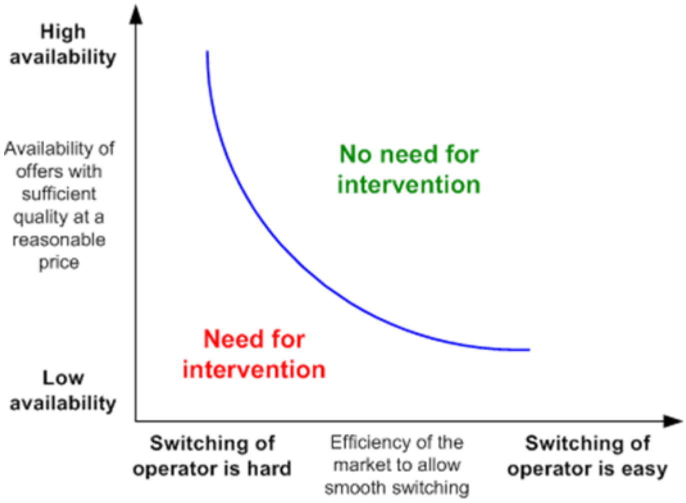
1) the availability of such offers;
2) the ease of switching in a broad sense (switching means the changing of the ISP by the customer), including all burdens faced by customers, such as the price difference between offers.

Figure 8.3: Degradation of the Internet access service as a whole for end-to-end communication between end-users



Source: Based on BEREC guidelines for quality of service in the scope of net neutrality

Figure 8.4: When is regulatory intervention needed?



As stated by BEREC, there is no need for intervention when there is good availability of Internet access service offers with satisfactory quality (i.e. without degradation) at a reasonable price, and the possibility and ease of switching is sufficient.

Regarding the role of the NRA in imposing minimum QoS requirements for IAS, BEREC foresees a regulatory process of up to six steps to determine whether and how to impose minimum QoS requirements:

Step 1: The NRA will typically identify situations that may need further attention.

Step 2: The NRA will perform an evaluation of quality indicators to verify the indications/symptoms and analyse the results in order to determine whether to intervene.

Step 3: If regulatory intervention is needed (based on step 2), the NRA will have to choose which regulatory tool to use.

Step 4: The NRA decides on the type of requirements.

Step 5: he NRA drafts decision and notification.

Step 6: Final decision by the NRA for minimum QoS requirements, and monitoring for compliance.

8.4 Network neutrality regulation case studies

Regulation of network neutrality has been considered within in the context of QoS both in developed and developing countries. This section describes the actual evolution of network neutrality practices, legislation, and regulation in the United States of America and the European Union where the discussion is most advanced.

Countries have taken different approaches to net neutrality regulation[29], including developments in India, where rules against price discrimination were adopted in 2016 (detailed later in this section).

[29] See for example: RATEL (Serbia), *Rulebook on quality parameters for publicly available electronic communication services and monitoring of electronic communication activity*, Official Gazette of RS no. 3/14, 2014, www.ratel.rs/upload/documents/Regulativa/Pravilnici/Telekomunikacije/Rulebook%20on%20quality%20parameters%20for%20publicly%20available%20electronic%20communication%20services.pdf

Another example is Brazil and its Civil Rights Framework for the Internet. Different approaches can include:

- Cautious observation: where countries have currently chosen not to take any specific measures as they may feel no specific action is required; the current regulatory framework may be deemed sufficient;
- Tentative refinement: Where countries have adopted a light-handed approach – e.g. disclosure and transparency, lowering switching barriers, minimum QoS – with some refinements to the existing regulatory regime governing communications services, light-handed net neutrality measures, but not going so far as to prohibit certain behaviours; and
- Active reform: Where countries have taken specific regulatory measures to prohibit specific behaviours by ISPs, often subject to reasonable network management practices.

There is no clear global consensus or one best approach to deal with network neutrality. Several approaches exist, as mentioned above, and the approach taken will depend on each country's respective national circumstances.

8.4.1 Network neutrality regulation in Europe

In the European framework, market power is a key concern. Regulation addresses last mile market power in the fixed network, both for PSTN and for Internet, thus fostering competition. Internet interconnection is generally unregulated to the extent that market power does not seem to be a concern; however, there is no blanket exemption from regulation.

Revisions to the 2003 European regulatory framework were enacted in 2009. The ability of end-users to access content, applications or services of their choice is now an explicit goal of European policy.

Providers of electronic communication services must inform end-users of their practices in regard to traffic management, and provide end-users with the right to change providers without penalty if they are dissatisfied with a change in these practices. The revised framework empowers NRAs to impose, if necessary, minimum QoS obligations on an SMP operator[30]. The approach is based on informed consumer choice rather than explicit prohibitions.

On 11 September 2013, the European Commission proposed a Telecoms Single Market (TSM) Regulation to the European Parliament. Network neutrality was a small but important part of the original legislative proposal; Net neutrality and mobile roaming were the only elements of the TSM proposal that were maintained in the subsequent legislative process.

In November 2015, the European Parliament and the Council enacted Regulation EU 2015/2120, which deals with network neutrality and international mobile roaming. As a regulation, it takes effect in all EU Member States without the need for transposition into national law. Key elements of regulation 2015/2120 include:

- Rights of end-users: "*End users shall have the right to access and distribute information and content, use and provide applications and services, and use terminal equipment of their choice, irrespective of the end user's or provider's location or the location, origin or destination of the information, content, application or service, via their Internet access service*."
- Traffic management**:** Providers of Internet access services *"(are not prevented) from implementing reasonable traffic management measures. In order to be deemed to be reasonable, such measures shall be transparent, non-discriminatory and proportionate, and shall not be based on commercial considerations but on objectively different technical quality of service requirements of specific categories of traffic*."

[30] J. Scott Marcus, *New Network Neutrality Rules in Europe: Comparisons to Those in the U.S.*, May 2016: http://bruegel.org/wp-content/uploads/2016/09/v2.final-Marcus-5.24.16.pdf

- Prohibited practices: Network operators may not "*block, slow down, alter, restrict, interfere with, degrade or discriminate between specific content, applications or services, or specific categories thereof, except as necessary, and only for as long as necessary, …*" in order to comply with legal requirements; preserve the integrity of the network or of end-user equipment; or deal with network congestion "*provided that equivalent categories of traffic are treated equally*".
- Specialized or managed services**:** Network operators, as well as content and application providers, are "*free to offer services other than Internet access services which are optimized for specific content, applications or services, or a combination thereof, where the optimization is necessary in order to meet requirements of the content, applications or services for a specific level of quality*." These services can be offered "*only if the network capacity is sufficient for their provision in addition to any Internet access services provided*."

Regulation EU 2015/2120 goes beyond the changes enacted in 2009, which had ensured that consumers must be informed of network operators' practices, and could switch without penalty if they refused a change. With regard to network neutrality, the regulation further includes the following definitions:

- Overall broadband quality: "*Any significant discrepancy, continuous or regularly recurring, between the actual performance of the Internet access service regarding speed or other quality of service parameters and the performance indicated by the provider of Internet access services … shall, where the relevant facts are established by a monitoring mechanism certified by the national regulatory authority, be deemed to constitute non-conformity of performance for the purposes of triggering the remedies available to the consumer in accordance with national law*."
- Provider of electronic communications to the public**:** Means an "*undertaking providing public communications networks or publicly available electronic communications services*."
- Internet access service: Means "*a publicly available electronic communications service that provides access to the Internet, and thereby connectivity to virtually all end points of the Internet, irrespective of the network technology and terminal equipment used*." This refers to network neutral traffic (not to managed traffic such as QoS-enabled VoIP as PSTN/ISDN replacement or QoS-enabled IPTV).

It further states that "*Providers of Internet access services shall treat all traffic equally, when providing Internet access services, without discrimination, restriction or interference, and irrespective of the sender and receiver, the content accessed or distributed, the applications or services used or provided, or the terminal equipment used*." In that manner, providers of Internet access services shall ensure that any contract which includes Internet access services specifies at least the following:

- "*information on how traffic management measures applied by that provider could impact on the quality of the Internet access services, on the privacy of end users and on the protection of their personal data;*
- *a clear and comprehensible explanation as to how any volume limitation, speed and other quality of service parameters may in practice have an impact on Internet access services, and in particular on the use of content, applications and services;*
- *a clear and comprehensible explanation of the minimum, normally available, maximum and advertised download and upload speed of the Internet access services in the case of fixed networks, or of the estimated maximum and advertised download and upload speed of the internet access services in the case of mobile networks, and how significant deviations from the respective advertised download and upload speeds could impact the exercise of the end-users' rights …*
- *a clear and comprehensible explanation of the remedies available to the consumer in accordance with national law in the event of any continuous or regularly recurring discrepancy between the actual performance of the Internet access service regarding speed or other quality of service parameters…*"

As previously mentioned, QoS is part of consumer protection. Other consumer protection provisions include:

- Supervision and enforcement: "*National regulatory authorities shall closely monitor and ensure compliance with (relevant obligations), and shall promote the continued availability of non-discriminatory Internet access services at levels of quality that reflect advances in technology. For those purposes, national regulatory authorities may impose requirements concerning technical characteristics, minimum quality of service requirements and other appropriate and necessary measures on one or more providers of electronic communications to the public, including providers of Internet access services*."
- Obligations of providers: This includes that they "*shall make available to that NRA (information relevant to the obligations set out in Articles 3 and 4 in particular information concerning the management of their network capacity and traffic, as well as justifications for any traffic management measures applied*."

Regulation 2015/2120 provides the first EU-wide net neutrality rules being applied in all EU Member States since 30 April 2016. The law sets a common standard for net neutrality throughout Europe.

> Internet providers are required to treat all traffic equally, with no blocking or slowing specific content, applications or services from selected senders or to selected receivers.

Based on its mandate, BEREC published on 30 August 2016, *Guidelines to National Regulatory Authorities (NRAs) on the implementation of the new net neutrality*. The guidelines provide detailed recommendations for the consistent application of net neutrality rules by national regulators across Europe. They do not alter the content of the rules in place that guarantee freedom of Internet by protecting the right of every European citizen to access Internet content, applications and services without unjustified interference or discrimination.

The rules and guidelines have been established to avoid fragmentation in the single market, create legal certainty for businesses, and make it easier for them to work across borders. These guidelines also ensure that the Internet remains an engine for innovation, both for advanced technologies being developed today-- Internet of Things, services like connected vehicles, 5G applications-- and those that will be developed in the future. Recommendations are designed to provide guidance on the implementation of the obligations of NRAs. Specifically, this includes the obligations to closely monitor and ensure compliance with the rules to safeguard equal and non-discriminatory treatment of traffic in the provision of IAS and related end-user rights.

Regarding network neutrality in Europe, as presented by BEREC[31], the role of European NRAs includes the following activities:

- Supervision:
  - monitoring contract information, commercial practices, traffic management practices and specialized services;
  - by means of assessment of practices in the market, technical measurements, information-gathering.
- Enforcement**:**

  For example, as well as imposing fines on ISPs**, r**equiring them:

  - to deal with degradation of IAS;

[31] BEREC, *Net Neutrality Guidelines*: https://www.ietf.org/proceedings/96/slides/slides-96-tsvarea-3.pdf

  - to cease or revise problematic traffic-management practices;
  - to cease providing specialized services in absence of sufficient capacity for IAS.
- Reporting**:**
  - NRAs to provide annual reports to BEREC and the European Commission;
  - guidelines set out when to provide reports and what to include in them;
  - BEREC planning to summarise main findings of these annual reports.

To date, network neutrality incidents in Europe have been rare.

In Europe, competition law functions as an ex post complement to *ex ante* telecommunication regulation; however, it is rarely if ever applied to network neutrality challenges. In the United States, by contrast, competition law is largely pre-empted by sector specific telecommunications regulation as a result of a number of court rulings. This is a difference, but perhaps of limited relevance in practice.

8.4.2 Network neutrality regulation in the United States of America

According to regulation in the United States, telecommunication services are subject to numerous regulatory obligations. Information services are subject to fewer explicit obligations as they were felt not to be subject to market power so long as basic services were available on a non-discriminatory basis.

This distinction historically enabled the Federal Communications Commission (FCC) to avoid regulating the Internet core; however, prior to 2002, Internet access was in effect regulated. During the period 2002-2005, the FCC classified broadband access when bundled with Internet service to be an information service (ignoring any last mile market power concerns). This effectively weakened or lifted pro-competitive remedies, thus reversing the growth of retail competition for DSL lines. It also lifted non-discrimination obligations, thus opening the door to possible network neutrality problems.

In 2005, the FCC issued an Internet Policy Statement[32] "*… to ensure that broadband networks are widely deployed, open, affordable, and accessible to all consumers…:*

- *[C]onsumers are entitled to access the lawful Internet content of their choice.*
- *[C]onsumers are entitled to run applications and use services of their choice, subject to the needs of law enforcement.*
- *[C]onsumers are entitled to connect their choice of legal devices that do not harm the network.*
- *[C]onsumers are entitled to competition among network providers, application and service providers, and content providers."*

The Policy Statement reflected the current views of the Commissioners. No specific rules were adopted and no enforcement mechanisms were identified.

The FCC issued an Open Internet ruling in December 2010, which includes the following rules:

"i. ***Transparency***. *Fixed and mobile broadband providers must disclose the network management practices, performance characteristics, and terms and conditions of their broadband services;*

ii. ***No blocking***. *Fixed broadband providers may not block lawful content, applications, services, or non-harmful devices; mobile broadband providers may not block lawful websites, or block applications that compete with their voice or video telephony services; and*

iii. ***No unreasonable discrimination***. *Fixed broadband providers may not unreasonably discriminate in transmitting lawful network traffic."*[33]

[32] FCC: https://apps.fcc.gov/edocs_public/attachmatch/FCC-05-151A1.pdf
[33] FCC: https://apps.fcc.gov/edocs_public/attachmatch/FCC-10-201A1.pdf

The ruling thus imposes fewer burdens on mobile networks. This ruling, too, was aggressively challenged in the courts (Verizon vs. FCC).[34]

In the United States, specialized services are defined by what they are not, namely broadband Internet access services (BIAS). Following the FCC Open Internet Order of 2015[35], BIAS is defined as: "*A mass-market retail service by wire or radio that provides the capability to transmit data to and receive data from all or substantially all Internet endpoints, including any capabilities that are incidental to and enable the operation of the communications service, but excluding dial-up Internet access service. This term also encompasses any service that the Commission finds to be providing a functional equivalent of the service described in the previous sentence, or that is used to evade the protections set forth in this Part.*"

BIAS also "*does not include enterprise services, virtual private network services, hosting, or data storage services.*"

The FCC Report and Order of March 2015[36] goes somewhat further than the 2010 Order.

- No blocking: ISPs *shall not block lawful content, applications, services, or non-harmful devices, subject to reasonable network management*.
- No throttling**:** ISPs *shall not impair or degrade lawful Internet traffic on the basis of Internet content, application, or service, or use of a non-harmful device, subject to reasonable network management.*
- No paid prioritisation**:** ISPs *shall not engage in paid prioritization*.

Paid prioritization refers to the management of a broadband provider network to directly or indirectly favour some traffic over other traffic.

Regarding enforcement, the Order, in Section 5 article 36, states that the FFC may enforce the rules through "*investigation and the processing of complaints (both formal and informal). In addition, the Commission may provide guidance through the use of enforcement advisories and advisory opinions, and it will appoint an ombudsperson. In order to provide the Commission with additional understanding, particularly of technical issues, the Order delegates to the Enforcement Bureau the authority to request a written opinion from an outside technical organization or otherwise to obtain objective advice from industry standard-setting bodies or similar organizations*."

The order does not regulate Internet interconnection, but reserves the right to intervene on a case-by-case basis. The 2015 Order fully includes mobile networks, where the 2010 Order was stricter with fixed networks than with mobile.

The prohibition on paid prioritization was not explicit in the 2010 Order. The Open Internet Order of 2015 faces any number of challenges over the coming years. For example, it is subject to various court challenges. The situation may likely change following the published notice of proposed rule-making by the FCC to return to a light-touch framework for broadband Internet access under Title I of the Communications Act.[37]

8.4.3 Network neutrality regulation in India

As network neutrality and pricing regulation are directly dependent upon QoS, and as differentiated pricing is related to traffic management techniques and may be considered as jeopardizing the network neutrality rules, the India regulator, Telecom Regulatory Authority of India (TRAI), issued a

[34] https://www.cadc.uscourts.gov/internet/opinions.nsf/3AF8B4D938CDEEA685257C6000532062/$file/11-1355-1474943.pdf
[35] FCC: https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-24A1.pdf
[36] https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-24A1.pdf
[37] https://www.fcc.gov/document/restoring-internet-freedom-notice-proposed-rulemaking

comprehensive public consultation on *Regulatory framework for over-the-top (OTT) services* in 2015. The public consultation considered:

- whether OTT service providers should be explicitly licensed as are traditional communication services as communication service providers (CSPs) (as are traditional telecommunication services), as application service providers (ASPs), or should be treated as bulk users of telecommunication services;
- possible enactment of explicit network neutrality rules; and
- what level of payments between content providers and network operators might be appropriate.

TRAI issued a second public consultation on differential pricing for data services in December 2015. Based on the results of the December 2015 public consultation, TRAI issued a prohibition of discriminatory tariffs for data services regulations in February 2016. The new regulation forbids all discriminatory tariffs based on content. Any agreement that has the effect of a discriminatory tariff is forbidden. An exception is made for closed electronic communications networks, unless such tariffs are offered or charged by the service provider for the purpose of evading the prohibition in this regulation. A narrow exception is made for emergency services, or at times of grave public emergency. This effectively prohibits the practice of zero rating (where the traffic volume for some specific content would not count toward a network operator data cap).

8.5 Challenges regarding quality of service and network neutrality

From a regulatory perspective, the management of quality of service poses numerous challenges. Differentiated management of QoS potentially offers benefits not only to network operators, but also to content and application providers, and also to consumers and other end-users. However, OTT service providers are not entitled to QoS provision for their services due to network neutrality rules (where they are applied).

Striking a sensible balance in QoS approaches is not easy. For example, from the business side (e.g. telecommunication operators), the QoS enabled services have expected higher investment and operational costs due to QoS functions in the networks.

Measures/rules regarding network neutrality in Europe (*Telecoms Single Market Regulation*), the United States (The Open Internet Order of 2015), and other countries (e.g. India, etc.) have been recently enacted, but it is too soon to say how effective they will be in practice in the long term because OTT services, which are provided on a network neutrality basis, are global, while network neutrality rules are national, or regional in the case of the European Union.

Network neutrality is often considered as the key driver of innovation in the application and service space. It came about the same time as the Internet, and in the beginning Internet was based on network neutrality and a best effort approach for service provisioning. However, with the convergence of telecommunication networks and services towards Internet-based networks and services, there is a need for end-to-end QoS in the new all-IP environment.

In this environment, all services are (or will be) transferred over IP-based networks, but not all IP networks belong to the open (i.e. public) Internet space. Network neutrality refers only to IAS, i.e. open Internet access, not to every IP-based network and service. For example, telephony provided over all-IP networks by a telecommunication operator, with QoS guarantees, as PSTN/ISDN replacement, is not part of the public Internet, and network neutrality does not refer to it. On the other side, OTT voice services such as Skype, Viber, etc., are provided via the IAS which is based on the principle of network neutrality, and are part of the public Internet. Then, having all telecommunication services in a single market (which is better for the business side) gives network neutral services that are in fact OTT i.e. data services (e.g. WWW, e-mail, Skype, Viber, Facebook, BitTorrent, etc.) to be provided together with QoS-enabled services (also called specialized services). These include VoIP with QoS guarantees (e.g. NGN voice service as PSTN/ISDN replacement), IPTV with QoS guarantees, business services with QoS guarantees (e.g. VPNs), IoT services with QoS guarantees (e.g. smart cities), etc., via the same IP-based fixed or mobile access networks, the same core networks and the same transit networks.

8.6 Network neutrality enforcement

Differentiated QoS can bring significant benefits to consumers, network operators, and content and application providers; however, there is also potential for abuse. Any regulatory approach to network neutrality must therefore take great care in order to strike an appropriate balance, preventing harm without also preventing benefits. With that in mind, we suggest the following checklist on criteria against which to evaluate measures to enforce network neutrality as provided in the European Parliament study on net neutrality[38]:

- Is the legislative or regulatory instrument used sufficiently future proof and technologically neutral?
- Does it appropriately balance costs against benefits in general?
- Does the legislative or regulatory instrument used strike the right balance in preventing harmful divergence, while providing appropriate flexibility?
- Does it strike the right balance in preventing harmful differentiation, while permitting non-harmful differentiation?
- Does it enable prioritization of services that legitimately need it, potentially including real-time voice and videoconferencing over the public Internet, mission critical services (including public protection and disaster relief (PPDR), and transport), and health?
- Does it appropriately balance costs and benefits among the different stakeholders?
- Are all terms defined with adequate clarity?

9 Consumer protection and privacy

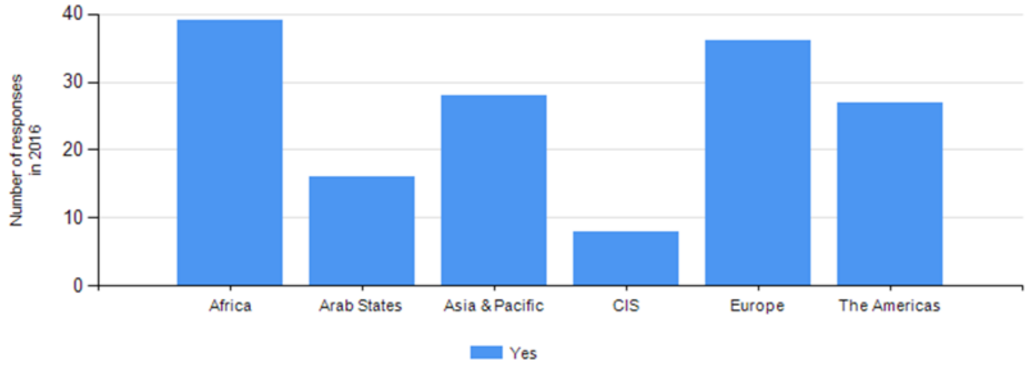
9.1 Consumer protection aspects

Quality of service is important for consumers and is part of consumer protection regulation. The customer/user should have access to QoS information in a clear, transparent, publicly available and appropriate manner. Countries take different approaches to consumer protection with regard to QoS. In 2016, 76 per cent of countries worldwide had a specific telecommunication consumer protection legislation/regulation in place.

A 2013 study by ITU, *Regulation and consumer protection in a converging environment*, found that the most common consumer related provisions addressed by legislation include access to information/transparency, quality of service, equity/right of access to services, protection of personal data, privacy, confidentiality of information, and the right to complain. Less common aspects include a right to end or change a contract, compensation in case of service interruptions, a right to block advertisements, access to emergency numbers, and number portability. Nearly all required network operators to provide consumers with access to pricing/rates information for fixed, mobile, and Internet access and services (for personal computers and smart phones).

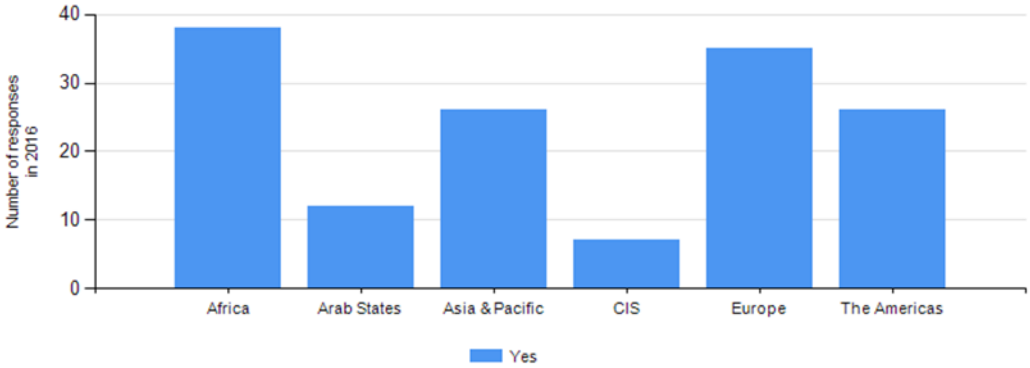
[38] www.europarl.europa.eu/RegData/etudes/STUD/2014/518751/IPOL_STU(2014)518751_EN.pdf

Figure 9.1: Regulator responsible for consumer complaints, 2016



In most countries the national regulatory authority (NRA) is responsible for consumer complaints (Figure 9.1). It is also responsible for consumer education (Figure 9.2). However, regarding the responsibility for tariff information to customers, statistics show that it is mainly the responsibility of regulatory authorities of countries in the Africa region, but in the rest of the world, it can be either the responsibility of the operators or the NRA (Figure 9.3).

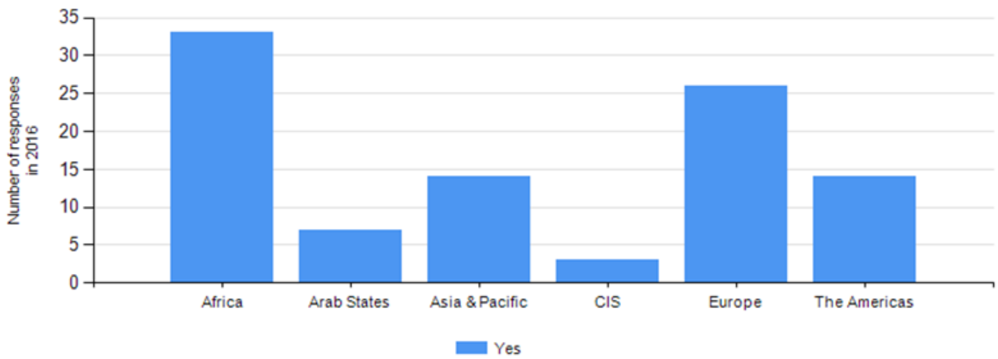
Figure 9.2: Regulator responsibilities for consumer education, 2016



Note: Total country responses: 169 countries.

Source: ITU Telecommunications/ICT Regulatory Database

Figure 9.3: Regulator responsible for tariff information, 2016



Source: ITU Telecommunications/ICT Regulatory Database (Total country responses: 169)

In Serbia for example, according to the rulebook on quality parameters for publicly available electronic communication services and monitoring of electronic communication activity, the operator is required to publish the offer and the quality parameters for the service provided as per the user contract through various means including in all their retailers, on their website or through information channels such as public media, advertising mail, etc., depending on the type of service. The operator is required to indicate in its general conditions the means by which users can obtain information on quality parameters and data on the minimum level of QoS provision. Among the main concerns (regarding consumer protection) expressed by countries include:

- Out of date legal frameworks**:** Many NRAs are experiencing difficulties in relation to enforcement within the converging environment.
- Challenges within the consumer protection agencies**:** Many respondents were experiencing structural problems within the consumer protection agency or agencies, while others expressed concern about a lack of staff expertise or personnel. Separation of the telecoms regulatory authority from that of broadcasting often led to difficulties.
- Challenges on the consumer side: One-quarter of respondents referred to a lack of consumer education and consumer awareness of their rights.

Adopting best practices for consumer protection: Examples of useful principles identified in the 2013 ITU report *Regulation and consumer protection in a converging environment* to consider in implementing consumer protection and QoS in a world of converged services may be summarized as follows:

Update existing legislation/regulations to make them fit for purpose in a converged regulatory framework:

- *Tackle any potential technical/infrastructure barriers that may deter consumers from subscribing to new products and services.*
- *Make full use of relevant complaints statistics when formulating policy.*
- *Review the framework for content regulation.*
- *Use impact assessments to support evidence-based policy-making.*

Consumer education and information:

- *Promote sufficient competition and choice for consumers.*
- *Ensure consumers have access to timely and accurate information, including about speeds and data traffic management.*
- *Ensure that consumers are informed about potential security and privacy challenges they face and the measures available to limit the risks.*

Build consumer trust in converged services:

- *Promote and safeguard e-commerce and mobile commerce by introducing measures to build trust amongst consumers.*
- *Encourage operators to develop security precautions including built-in security features to prevent unauthorized transactions and data breaches.*

Implementation and enforcement:

- *Provide for a strong, well-resourced consumer protection regulatory team or separate agency with communications expertise.*
- *Agree a clear division of responsibilities among the agencies concerned.*
- *Distinguish between implementation failures versus underlying legislation.*

In 2014, the community of NRAs worldwide adopted the GSR14 *Best Practice Guidelines on Consumer Protection in a Digital World*[39] recognizing that measures can be taken to ensure consumers including people with disabilities have easy and reliable access to ICT services as well as web content, such as developing and regularly reviewing minimum quality of service standards and specifications of new technologies and services; monitoring network service providers; regularly assessing telecommunication/ICT services quality and publishing the results. They further stressed that regulators need to ensure that all service providers make available timely and accurate information about their services and products in a clear, transparent and comparable manner that is conducive to rational decision making. In addition, they noted that consumers should "*be able to understand the nature of the services and the quality of service provided, in addition to their own rights and responsibilities. All regulations related to consumers' right to information should be regularly and consistently updated allowing it to be practical and enforceable.*"

[39] www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2014/BestPractices/GSR14_BPG_en.pdf

9.2 Privacy aspects

QoS in IP networks is related to traffic management, where deep packet inspection and other filtering techniques are used by telecommunication operators to see what is carried in IP packets between two and more end-points in the given connection/session (where each IP connection is uniquely identified by the sender and recipient IP addresses, sender and recipient port numbers, and transport protocol such as TCP or UDP). Data used for traffic management (especially data obtained using DPI) may be personally identifiable. This raises privacy issues when regulators specify what can be done for QoS provisioning, for example in terms of traffic management by the operators.

The information that is treated as being personally identifiable can vary from one country to the next. It is not always obvious what data is sensitive; for instance, IP addresses are treated as personally identifiable data in some countries, and they are not, since most of the home networks use private IP addresses which are marked into a single public IP address.

Many countries (e.g. the EU) restrict the uses that can be made of personally identifiable data. Typical restrictions on the use of personally identifiable data may include:

- an obligation to obtain informed consent of the individual;
- a prohibition on uses other than that which the individual specifically approved;
- the duration for which it can be retained.

For example, in the Guidelines on the Implementation by National Regulators of European Net Neutrality Rules[40] issued in August 2016, BEREC explicitly addressed the issue:

"- *In assessing traffic management measures, NRAs should ensure that such measures do not monitor the specific content (i.e. transport layer protocol payload).*
- *Conversely, traffic management measures that monitor aspects other than the specific content, i.e. the generic content, should be deemed to be allowed. Monitoring techniques used by ISPs which rely on the information contained in the IP packet header, and transport layer protocol header (e.g. TCP, UDP) may be deemed generic content, as opposed to the specific content provided by end users themselves (such as text, pictures and video).*"

10 Quality of service enforcement

QoS is becoming more and more important as networks are being used for delivery of multiple heterogeneous services, each with different requirements on QoS (e.g. bit rates, delays, errors, etc.). More people are using telecommunication services and more people have broadband access, either fixed or mobile or both types, and a multitude of things are becoming connected to Internet (e.g. cars, homes, cities, industry, and other vertical sectors), becoming *smart*.

QoS in the telecommunication world is based on standards (e.g. ITU, ETSI, etc.) and licences (e.g. for spectrum for mobile operators). However, QoS will not exist just by having the mandatory standards or licences included, it has to be *maintained*. To do so, we need to define a set of key performance indicators, which are important to the end-users, and for users (as consumers) to be made aware of them; then, we need to perform measurements of such KPIs.

Finally, QoS is related to the cost of networks and services with defined QoS parameters. QoS impacts end-users, network and service providers, and society in general due to penetration of ICTs/

40 http://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/guidelines/6160-berec-guidelines-on-the-implementation-by-national-regulators-of-european-net-neutrality-rules

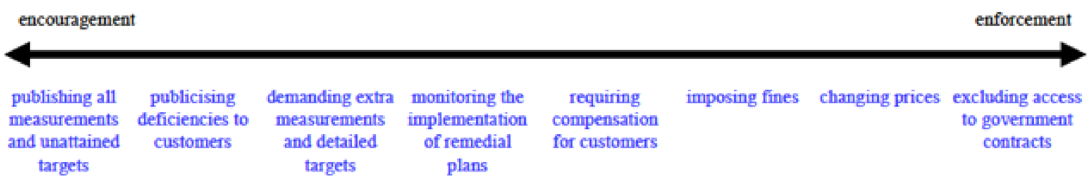
telecommunications into other vertical sectors. Therefore, QoS enforcement is needed (e.g. regulatory notice, publication of KPI measurements, dispute, or penalties).

Enforcement mechanisms of quality of service include the following:

- reports of QoS submitted monthly or quarterly by telecommunication operators to the NRA (may Include technical and non-technical parameters);
- QoS monitoring tools for auditing;
- penalties and disincentives;
- independent customer surveys and their publication.

In general, QoS obligations are only likely to be fulfilled if legitimate concerns are addressed. A requirement for successful QoS monitoring by NRAs, therefore, is to take into account the opinions of operators and consumers fully and openly. This can be achieved through a consultation process, for obligations in licences as well as for obligations in regulations. Typically, at the start and end of a consultation process, the regulator circulates documents that discuss policy options and proposals.

Figure 10.1: Techniques for ensuring compliance



Source: Robert Milne – Antelope Consulting

Figure 10.1 highlights techniques for ensuring that operators fulfil QoS obligations. Serious and persistent failures to fulfil many obligations might be handled by using even more drastic enforcement techniques that are not related directly to QoS, such as withdrawing licences or transferring franchises.

Enforcement techniques are not always practicable – or available under the law in a given country. In particular, one should consider the following aspects regarding QoS enforcement mechanisms:

- Publishing all measurements and unattained targets can be laborious. However, it can help to show that the regulator is fair and open. Publishing at least some measurements is central to helping customers make informed choices: it is often the main technique for encouraging compliance with QoS obligations.
- Publicising deficiencies to customers – by putting remarks in bills, messages or advertisements – needs firm comparisons with other operators or against targets.
- Demanding extra measurements and detailed targets could lead to an emphasis on measurement procedures instead of solutions to problems. Nonetheless, it can be appropriate when the actions needed to improve quality can become effective rapidly.
- Monitoring the implementation of remedial plans may require external agencies skilled in network design and operation to assist regulators. Accompanying this with direct intervention in the activities of the operators could lead to confusion about responsibilities and duties.
- Requiring compensation to customers may not be feasible. It could be useful when customers have better information than regulators about the quality that they receive; can request compensation directly without recourse to regulators or arbitrators; and notice different quality levels very easily (so the compensation can vary with the severity of the deficiency). For example, compensation is more likely to be paid for long fault repair times in fixed wireline networks (or in similar examples) than in other cases of QoS degradation.

- Imposing fines can involve extensive legal processes and may take a long time (as may various other techniques for enforcing compliance with QoS obligations), which is dependent upon the laws in the given country.
- Price changing (by introducing quality factors into price controls, with rewards for good quality as well as penalties for bad quality) needs careful design if it is to act as an incentive to improving quality. The relation between QoS and price controls is not always clear.
- Excluding access to government contracts (e.g. licences) can be difficult to make proportionate to failures by operators, and may not be applicable to several operators at once.

Enforcement mechanisms or techniques require the effort and expertise of various sorts, along with processes that operate efficiently and regularly whenever operators report measurements. In many countries, several techniques are available that provide graduated penalties. Recent examples are presented in the following subsections.

10.1 Quality of service assessment and enforcement: Kenya

In 2011, the QoS report by the Communication Authority (CA) of Kenya found all mobile operators needed to improve QoS, and by 2012, only two operators failed to meet QoS standards. A monitoring report for 2013-2014[41] found all four operators at the time failed to meet service standards as set by the Kenya regulator, leading to fines of KES 500 000.

In 2015, the CA of Kenya introduced a measure that required operators to pay a fine equal to 0.2 per cent of their annual gross revenue if they failed to meet QoS standards. In the 2014/2015 financial year, no mobile operator met QoS standards.

In August 2016, the regulator set rules to improve quality (Figure 10.2). Most of the operators in Kenya indicated they would fall short of scoring 80 per cent on a range of eight indicators, including speech quality, completed calls, call success rate and drop rate. The regulator also called for the public to share their views on the new QoS regulations, which is based on Article 46 of the Constitution of Kenya, which states that consumers have the right to services of reasonable quality. Calls for comments were raised on several issues, including the following:

- Is the range of services under the scope of the proposed QoS assessment framework adequate or inadequate?
- Do you agree with the proposal for the inclusion of the three components namely; Overall Network Performance (NP), End-to-End QoS and Quality of Experience (QoE) in the overall QoS assessment and the ratio of contribution of 20 per cent, 60 per cent, and 20 per cent respectively (see Table 10.1 and Figure 10.2)?
- The given framework did not provide for weighting of samples depending on the area measurements were taken and the authority intends to maintain the status quo. Licensees on the other hand have been advocating for weighting of QoS sampling to reflect larger samples in urban areas and significantly lower weighting of sample volumes measurements taken in rural areas. What should the view on this be?
- Which QoS assessment parameters/KPIs are important?
- Which QoS assessment parameters/KPIs are unimportant and should be excluded in the QoS framework?
- Are the thresholds for parameters (KPIs) well chosen?

These are important questions for any QoS regulation, and particularly enforcement. In fact, establishing the appropriate set of KPIs, their target values, as well as their assessment (by whom, how often,

41 www.ca.go.ke/images/downloads/RESEARCH/Quality%20of%20Service%20Report%202013-2014.pdf

and how in different areas such as urban areas, rural areas, and highways) provide the basis for QoS enforcement later. Therefore all questions listed above should be well justified and clarified (considering all sides, including customers, operators, regulator, and society in general) in each country. The answers to the above questions may differ from one country to another one.

Regarding data sampling, the number of observations (sample size) is stated to have a minimum absolute statistical accuracy of less or equal to 2 per cent with a confidence level of 95 per cent, while coverage assessment statistical accuracy shall be, as a minimum, less or equal to 0.5 per cent. The QoS assessment framework in Kenya currently covers the following services (end-to-end KPIs and their target values are provided in Table 10.2):

- mobile voice;
- SMS and MMS;
- data/Internet.

According to the proposed QoS rules, the CA of Kenya has been using a QoS assessment tool to verify the level of compliance by operators based on the assessment framework. The compliance assessment methodology is guided by set principles and procedures, which include the submission of returns by the operators on the QoS parameters, where the results of each QoS parameter should be the average of all the measurements recorded for all provinces during the entire reporting period of 12 months, commencing from the effective date of notice. The QoS requirement set by the CA of Kenya is to achieve at least 80 per cent of the listed QoS parameters provided for in the licence calculated from operator data and independent QoS measurements.

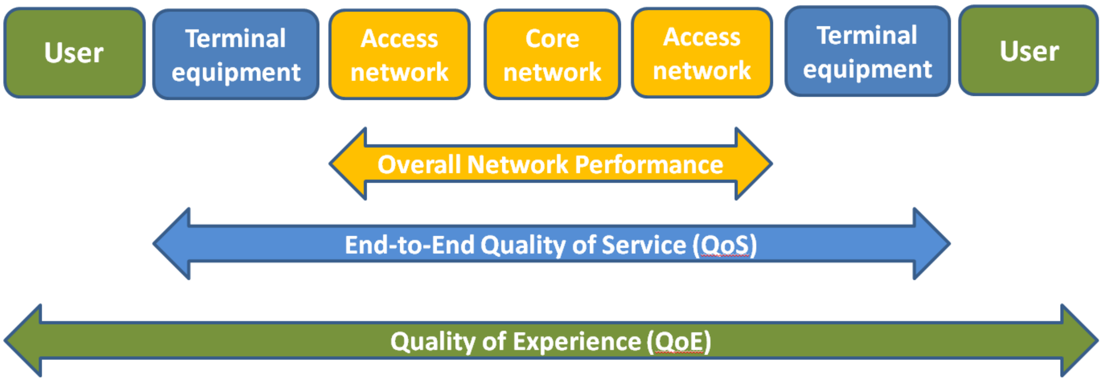
The QoS rules also specify that a failure to achieve at least 80 per cent of the listed QoS parameters upon notification by the authority to the licensee shall be considered as non-compliance with the quality of service condition and may be liable for penalty/sanction as provided in the telecommunication act. In November 2016, the CA fined operators with KES 190 million (USD 18.7 million) for poor quality of service for the 2014/2015 period, which corresponds to 0.1 per cent of their gross annual turnover.

Table 10.1: QoS assessment structure in Kenya

Nature of QoS assessment	Areas of assessment	Source of assessment data	Contribution to the overall assessment
Network performance	The quality of the network infrastructure without terminal devices	Operator network management systems	20%
End-to-end QoS performance	The overall quality of the network including standardized devices	Contracted entities using innovative data capture/analysis	60%
Quality of experience (QoE)	Overall consumer experience	Customer surveys	20%

Source: Communication Authority of Kenya

Figure 10.2: Illustration of QoS functional components (Kenya)



Source: Communication Authority of Kenya

Table 10.2: End-to-end KPIs and target values in Kenya

Service	Key Performance Indicator (KPI)	Target
Voice	Unsuccessful call ratio	< 5%
	Dropped call ratio	< 2%
	Completed call ratio	>= 95%
	Call set up time	Mean value <= 8 s
	Voice quality	>= 3.4 (measured according to ITU-T P.863)
SMS	Successful SMS ratio	>= 95%
	Completion rate for SMS	>= 95%
	End-to-end delivery time for SMS	>= 95% Rate of SMS completed in a delay of less than 30 s. (best practice)
MMS	Successful MMS ratio	>= 95%
	Completion rate for MMS	>= 95%
	End-to-end delivery time for MMS	>= 95% Rate of MMS completed in a delay of less than 180 s. (Best practice)

Service	Key Performance Indicator (KPI)	Target
Data/Internet	Latency	100 ms
	Jitter	50 ms
	Data transfer failure ratio and Throughput of successful data transfer	Data transfer failure ratio (download): =< 10% Data transfer failure ratio (upload): =< 10% (Values proposed for mobile networks) Throughput: highly dependent on access technology Shall be linked to a commercial offer: shall reach 85% of the contractual throughput during the peak period
	Ratio of packet loss	1 / 1,000
	Internet accessibility	>= 98%
	HTTP set-up failure ratio, and HTTP set-up time	HTTP set-up failure ratio: <= 2% HTTP set-up time: 95% within 5 seconds (Values proposed for mobile networks)
	HTTP completion failure ratio, and HTTP completion Time	HTTP Completion failure ratio: <= 90% HTTP Completion Time: 95% within 20 sec. (Values proposed for mobile networks)
	HTTP generic scenario availability	>= 85% (Value proposed for mobile networks)

Source: Communication Authority of Kenya

10.2 Enforcement of quality of service for mobile services: India

In India, the Telecom Regulatory Authority of India (TRAI) formulated standards for mobile Internet under the QoS for Wireless Data Services Regulations 2012, with objectives to:

- understand the current state of QoS for mobile Internet services – policies and practices; and
- provide evidence-based policy recommendations to enhance QoS and promote better enforcement of QoS regulations.

In 2015, TRAI published a consumer handbook on telecommunications providing consumers with a QoS guideline[42]:

The TRAI Act provides that the authority shall lay-down the standards of quality of service to be provided by the service providers and conduct periodical survey of such services so as to protect the interest of the consumers of telecommunication service.

Regarding QoS, the consumer handbook says (Figure 10.3):

TRAI has laid down the Quality of Service standards for various services through QoS regulations issued, from time to time. TRAI has separate QoS regulations governing the standards of quality of service for wireline (Basic), cellular mobile telephone services (2G & 3G), broadband services and recently

[42] www.trai.gov.in/sites/default/files/TRAI-Handbook-2015-ENG-30092015.pdf

for wireline data services. The important parameters on quality of service and the benchmarks for meeting the parameters by the service providers are given at Annex-I and II.

In 2016, a report was published on the QoS of mobile operators in India. Through network measurements, which involved direct evaluation of mobile Internet services at various rural and urban locations, mobile Internet services were evaluated on technical parameters such as throughput, latency, availability, etc. The network measurement study highlighted that the QoS experienced by users differs considerably from the advertised values provided by the various telecommunication providers, and to a certain extent also from the values reported by them to TRAI. It also seemed that in many cases, simply taking better care of the configurations of the cellular networks could lead to better performance.

Figure 10.3: Important QoS parameters, for basic and cellular mobile services

Sl. No.	QoS parameter	Benchmark
1.	Provision of landline telephone after registration of demand	within 7 days (subject to technical feasibility)
2.	Shifting of landline telephone connection	95% of requests to be attended within 3 days
3.	Fault repair in urban areas (landline)	At least 85% by next working day and 100% within 5 days
4.	Fault repair in rural and hilly areas (landline)	At least 75% by next working day and 100% within 7 days
5.	Resolution of billing/charging complaints	At least 98% within 4 weeks and 100% within 6 weeks
6.	Period of applying credit/ waiver/ adjustment to customer's account on resolution of complaints	Within one week of resolution of the complaint
7.	Termination/closure of service	Within 7 days
8.	Refund of security deposit after closure	100% within 60 days

Sl. No.	QoS parameter	Benchmark
1.	Service provisioning/activation time	100% cases in < 15 working days (subject to technical feasibility)
2.	Fault repair/restoration time	99% within 3 days. **Rebate** :Faults pending for > 3 days and < 7 days : rebate equivalent to 7 days of minimum monthly charge or usage allowance. Faults pending for > 7 and <15 days : rebate equivalent to 15 days of minimum monthly charge or usage allowance. Faults pending for > 15: one month rebate equivalent to 1 month of minimum monthly charge or usage allowance.
3.	Resolution of billing complaints	100% within 4 weeks
4.	Refund of deposits after closure	100% within 60 days.
5.	Broadband connection speed (download)	Subscribed broadband connection speed to be met > 80% from ISP Node to user.

Source: TRAI

Figure 10.4: India QoS for mobile services: Consumer satisfaction

Summary of Key Findings			
Parameter	West Bengal	Rajasthan	New Delhi & NCR
Respondents	300	300	130
QoS is the rationale for selecting service provider	42%	52%	64%
Level of Satisfaction with QoS is good	45%	24%	52%
Level of Satisfaction with tariff is good	28%	15%	26%
Awareness levels in respondents is good (regarding data plan)	63%	62%	82%
Service providers should regularly alert customers on data usage	83%	62%	58%
Service providers should mention the exact amount of data that is consumed per month by users	58%	73%	60%
Respondents do not know about bandwidth but want to know the same	92%	56%	92%
Respondents know about TRAI	40%	46%	85%
Respondents do not know about QoS parameters but want to know	65%	93%	81%
Penalties should be put in place for breach of QoS parameters	95%	99%	97%
Service providers should be ranked (quarterly) on the basis of their performance	91%	98%	97%

Source: TRAI

The consumer survey (Figure 10.4) revealed that the respondents across the three states chose their service provider (for mobile Internet) on the basis of QoS but were largely unsatisfied with the service and the high charges. The table provides a snapshot of the data obtained from the respondents. Most consumers (over 95 per cent) requested penalties for breach of the QoS parameters.

The report included recommendations for TRAI to:

- Mandate more rigorous QoS measurement and reporting methodologies by the ISPs, and make the data reflective of actual end-user observed performance. Steps should be taken to make this data available in user-friendly ways to improve consumer awareness. Steps should also be taken to enable auditing of this data by non-state actors.
- Adopt a *nutrition label* for QoS to provide key information such as speed variations, service limits and conditions, pricing and other relevant information to empower consumers with information to compare broadband services in India and make an informed decision.
- Provide complete information to consumers on mobile Internet services, at the time of sales as well as on the service provider websites. Strict rules should be imposed against misleading advertisements by ISPs, and reported performance should be compared with the performance that was originally advertised to understand the differences arising between promised and achieved performance.
- Introduce a system of ranking on QoS performance for mobile Internet service providers to instil competition and enhance QoS efficiency and innovation.
- Set penalties in case of breach of QoS parameter benchmarks by service providers.

The report also called for consumers to be made aware of their entitlements/actual terms of service; and empowered to get necessary information through a speed test, for instance, which would allow them to test their services and compare them with the regulatory benchmarks. In addition to drafting regulations, TRIA was called on to focus on educating consumers of their rights and provisioning of a complete set of information on the product, i.e. mobile Internet.

TRAI was also called on to make its presence felt across India by establishing regional centres and through awareness workshops to inform consumers regarding the relevance of QoS parameters for mobile Internet services.

In 2016, TRAI published a consultation paper on the review of network related quality of service standards for cellular mobile telephone service in India[43]. According to the paper, TRAI monitors network related QoS parameters in a cellular mobile telephone service network, as shown in Table 10.3.

In order to improve the QoS provided by service providers, TRAI has prescribed financial disincentives through *Standards of Quality of Service of Basic Telephone Service (wireline) and Cellular Mobile Telephone Service (Second Amendment) Regulations, 2012 (24 of 2012)*, dated 8 November 2012. Based on this, TRAI has been monitoring compliance to these regulations through monthly/quarterly performance reports submitted by service providers. Wherever non-compliance with the benchmark is observed, the service provider is given an opportunity to explain the matter, and after considering the reply submitted by the service provider, if found unsatisfactory, financial disincentives are imposed on the defaulting service providers. However, TRAI had analysed the compliance reports of cellular mobile telephone service providers for several quarters and concluded that in many cases, the amount of financial disincentives had not been sufficient to provide QoS according to the given benchmarks (i.e. targets for the selected QoS parameters as performance indicators). This situation was considered by TRAI as an indication of the lack of commitment (or initiative) on the part of service providers to improve QoS. Therefore, after undertaking public consultations to review the amount of financial disincentives, TRAI prescribed increasing financial disincentives for consecutive repeat instances of non-compliance with the benchmark through the *Standards of Quality of Service of Basic Telephone Service (wireline) and Cellular Mobile Telephone Service (Fourth Amendment) Regulations, 2015*. The revised amount of financial disincentives are:

- *Not exceeding Rupees one lakh per parameter for first non-compliance with the benchmark in a quarter;*
- *Non-compliance with the benchmark of the same parameter consecutively in two or more subsequent quarters, not exceeding Rupees one and a half lakhs for a second consecutive contravention and not exceeding Rupees two lakhs for each consecutive contravention thereof;*
- *Non-compliance with the benchmark for the same parameter in any subsequent quarter, which is not a consecutive non-compliance, Rupees one lakh per parameter.*

The structure of financial disincentives is based on whether the QoS parameter is met or not, and no consideration is given to the extent of how bad the performance is. The financial disincentive is the same whether the benchmark is not met by 1 per cent or 5 per cent. One option towards streamlining QoS parameters will be to explore the possibility of a scheme of graded financial disincentive so that in the case of very poor performance the financial disincentive could be very stringent. At the same time, there could be reduced financial disincentives in case there is an improvement in performance. TRAI has publicly asked for views on introducing graded financial disincentives based on performance and what the amount/quantum should be for financial disincentives for various parameters. One may note that such an approach could be considered as a good practice for QoS enforcement in a country that is struggling with provision of satisfactory QoS by service providers (telecommunication operators).

43 www.trai.gov.in/consultation-paper-review-network-related-quality-service-standards-cellular-mobile-telephone

Table 10.3: Network service quality parameters 2G and 3G services in India

Name of parameter	Benchmark	Averaged over a period
Network availability		
(a) BTSs accumulated downtime (not available for service) (2G) Node-B accumulated downtime (not available for service) (%age) (3G)	≤ 2%	One Month
(b) Worst affected BTSs due to downtime (2G) Worst affected Node-B due to downtime (%age) (3G)	≤ 2%	One Month
Connection establishment (Accessibility)		
(a) Call set-up success rate (within licensee own network) (2G) (3G)	≥ 95%	One Month
(b) SDCCH/ paging channel congestion (2G) SDCCH/paging channel and RRC congestion (%age) (3G)	≤ 1%	One Month
(c) TCH congestion (2G) TCH and circuit switched RAB congestion (%age) (3G)	≤ 2%	One Month
Connection Maintenance (Retainability)		
(a) Call drop rate (2G) Call drop and circuit switched voice drop rate: (%age) (3G)	≤ 2%	One Month
(b) Worst affected cells having more than 3% TCH	≤ 5% up to	One
drop (call drop) rate (2G)	31.03.2011	Month
Worst affected cells having more than 3% TCH drop	≤ 3% From	
(call drop) and circuit switched voice drop Rate:-	01.04.2011	
CBBH (3G)		
(c) Connections with good voice quality (2G) Connections with good voice quality and circuit switch voice quality (CSV quality) (3G)	≥ 95%	One Month

Source: Telecom Regulatory Authority of India (TRAI), Consultation Paper on Review of network related Quality of Service standards for Cellular Mobile Telephone Service, 2016.

10.2.1 Suggested penalties in India for breach of quality of service

In October 2016, TRAI recommended INR 3 050 crore penalties (approximately USD 45 million) for violating quality of service rules. This amount refers to a combined penalty on Bharti Airtel, Vodafone India, and Idea Cellular, for not giving interconnection to Reliance Jio Infocomm in breach of the licence terms.

TRAI recommended that the Department of Telecommunications (DoT) initiate action against each of the top three carriers in the country, saying that violating licence terms warranted revocation of the licence. Since it would have caused significant inconvenience to consumers, penalties were recommended instead.

10.2.2 Prohibition of discriminatory tariffs for data services

TRAI issued a consultation paper on *Differential Pricing for Data Services* in December 2015, and enacted prohibition of discriminatory tariffs for data services in February 2016. The consultation primarily sought the views of stakeholders on whether the service providers should be allowed to charge differential tariffs based on the websites/applications/platforms being accessed on the Internet.

Based on the responses received and internal deliberations, TRAI has issued regulations aimed at ensuring that consumers get unhindered and non-discriminatory access to Internet. Such regulations intend to make data tariffs for access to the Internet non-discriminatory on the basis of the content.

TRAI has also published the following regulations[44]:

a) No service provider shall offer or charge discriminatory tariffs for data services on the basis of content.

b) No service provider shall enter into any arrangement, agreement or contract, by whatever name called, with any person, natural or legal, that has the effect of discriminatory tariffs for data services being offered or charged by the service provider for the purpose of evading the prohibition in this regulation.

c) Reduced tariff for accessing or providing emergency services at times of public emergency has been permitted.

d) Financial disincentives for contravention of the regulation have also been specified.

TRAI also specified penalties, or consequences for contravention of these regulations on tariffs for data services. If a service provider is in contravention of these regulations, the authority may, without prejudice to the terms and conditions of the licence, or the Act or rules or regulations or orders made, or directions issued, thereunder, direct the service provider to withdraw such tariff(s) and also order such service provider to pay, by way of financial disincentive, approximately USD 730 for each day of contravention, subject to a maximum amount: provided that no order for payment of any amount by way of financial disincentive shall be made by the authority unless the service provider has been given a reasonable opportunity of representing against the contravention of the regulation. The amount payable by way of financial disincentive under these regulations shall be remitted to such head of account as may be specified by the authority.

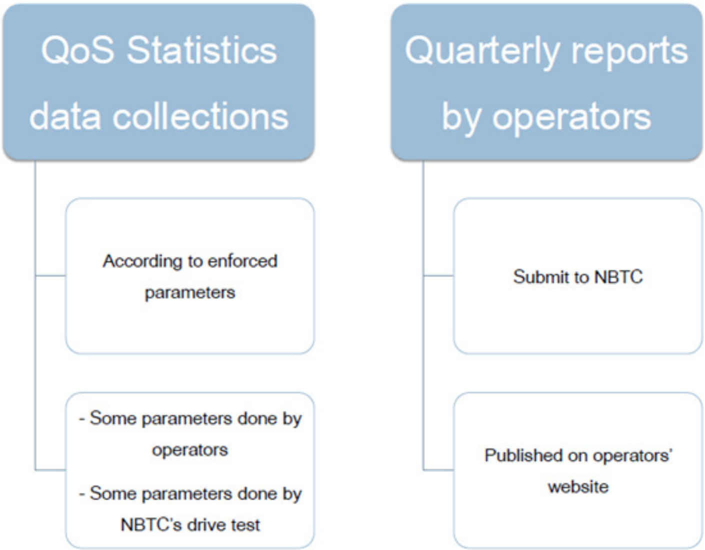
By jeopardizing the network neutrality approach for the Internet access service (e.g. giving toll-free access to a given service, such as Skype, Facebook, Youtube, or any other OTT service), the demand for such services is expected to rise and produce possible additional congestion in some time periods or at some locations (e.g. in a mobile network) that will influence the overall QoS (e.g. available bit rates in a mobile network, which uses shared data channel for all users in a given cell) for Internet access service, i.e. for data services.

10.3 Enforcement of broadband quality of service: Thailand

The approach by the Thailand regulator, the National Broadcasting and Telecommunications Commission (NBTC), to enforce broadband QoS is presented in Figure 10.5. It consists of QoS statistics data collection and quarterly reports by operators.

[44] www.trai.gov.in/sites/default/files/Regulation_Data_Service.pdf

Figure 10.5: Enforcement of broadband QoS



Source: NBTC: Broadband quality of service: Role of the Thai Telecom Regulator, 2015

However, some enforcement concerns have been identified by the NBTC:

- authenticity of the QoS reports, because statistical data is collected by operators, and there are no means to double check authenticity of the data;
- low consumer awareness of the QoS reports;
- QoS reports are not easily accessible on operator websites;
- report publishing is delayed and outdated;
- the penalty procedure and time-frame prescribed by the law is cumbersome.

The policy framework is targeted at introducing modifications to the regulations to address some of these problems/obstacles. Some of the modifications include: QoS reports to be published (linked) from operator homepages with specific banner required by regulator; specifying time limit of the quarterly report submission and website publishing; and conducting parallel QoS testing and measurements by the regulator. The regulator aims to promote consumer awareness and accessibility of QoS data, which could include a QoS survey as well as data from the complaint mitigation centre in order to promote and strengthen healthy competition.

10.4 Internet access service regulation: Europe

In the BEREC guidelines for the Internet access service, NRAs can decide to:

- require an ISP to take measures to eliminate or remove the factor that is causing the degradation;
- set requirements for technical characteristics to address regulation infringements, for example, to mandate the removal or revision of certain traffic management practices;
- impose minimum QoS requirements;
- impose other appropriate and necessary measures, for example, regarding the ISP obligation to ensure sufficient network capacity for the provision of high quality non-discriminatory Internet access service (IAS);
- issue cease and desist orders in case of infringements, possibly combined with periodical (daily/weekly) penalties, in accordance with national law;

- impose cease orders for specific specialized services unless sufficient capacity is made available for IAS within a reasonable and effective time-frame set by the NRA, possibly combined with periodical (daily/weekly) penalties, in accordance with national law;
- impose fines for infringements, in accordance with national law;
- prohibit the blocking and/or throttling of specific applications;
- prohibit congestion management practice that is specific to individual applications;
- require access performance, such as minimum or normally available speeds, to be comparable to advertised/maximum speeds;
- place qualitative requirements on the performance of application-specific traffic;
- requirements and measures could be imposed on one or more ISPs, and it may also, in exceptional cases, be reasonable to impose such requirements in general to all ISPs in the market; and
- the imposition of any of these requirements and measures should be assessed based on their effectiveness, necessity and proportionality.

Penalties are not included in the BEREC guidelines as these will depend on the national legislation of the European countries. However, Article 6 of the guidelines published in September 2016 states: *Member States shall lay down the rules on penalties applicable to infringements of Articles 3, 4 and 5 and shall take all measures necessary to ensure that they are implemented. The penalties provided for must be effective, proportionate and dissuasive.*

The practice so far shows that imposing penalties is not the first enforcement measure taken in European countries. The market is competitive and QoS enforcement in Europe is currently based on a soft touch approach, which is targeted mainly to audit measurements on QoS and their publication for consumers to make informed decisions on services, less on applying penalties.

10.5 Quality of service regulation and sanctions: Ghana

In pursuance of the mandate of the National Communications Authority (NCA) of Ghana to ensure fair competition and protect consumers in Ghana, QoS obligations have been outlined in Annex D1 and D2 of the cellular mobile licence[45]. These obligations are monitored and enforced through consumer oriented methodologies:

- Monthly operator reports: Daily busy hour conditions for the radio network and each interconnect route among all operators are reported through a common template with definitions for each parameter. This enables the authority to assess the network level performance of each operator. This is useful for trend analysis and guides directives on remedies for congestion and network instability.
- Billing verification: The tariffs of each operator to all national and selected popular international destinations are verified quarterly or when new tariffs are implemented by any operator. This is to ensure billing accuracy.
- Consumer satisfaction survey: A total of 5 000 mobile users are sampled in the 168 districts to achieve the 95 per cent confidence level at an error margin of + 1.39 per cent. The stratified sample allocation to each of the five operators is per respective market share and network availability in the districts of Ghana. These capture the consumer ratings of service attributes and expectations. This has been useful in focusing on consumer concerns and the formulation of regulatory policies.

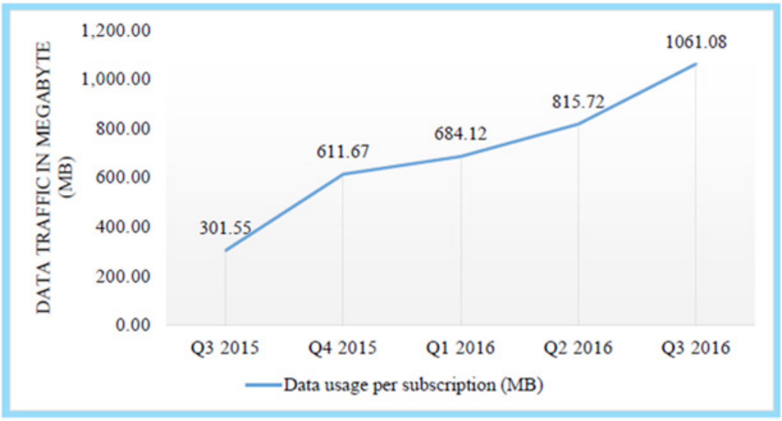
[45] https://nca.org.gh/industry-data-2/reports-2/monitoring-reports-2/?url=/industry-data-2/reports-2/monitoring-reports-2/

- <u>Assessment of radio network parameters</u>: Automated drive testing of all operators is done simultaneously in localities during busy hours to ascertain the quality of experience to mobile phone users. These measure and analyse parameters such as: coverage strength, call set-up time, call set-up failure rate, call congestion rate, call drop rate, call completion rate and call audio quality.

Ghana has high mobile cellular penetration (129.7 subscriptions per 100 inhabitants) and high mobile broadband penetration (66.8 subscriptions per 100 inhabitants) among the membership of the West Africa Telecommunication Regulators Assembly (WATRA), according to ITU ICT-Eye data from 2015. The penetration of fixed telephony (one subscription per 100 inhabitants) and fixed broadband (0.3 subscriptions per 100 inhabitants) in 2015 was negligible compared to the number of mobile subscribers. Hence, similar to other countries in West Africa, QoS regulation is mainly targeted at the mobile sector.

Tables 10.4 to 10.10 show the QoS parameters (KPIs) for different services and target values, set by NCA and include: interconnection, cellular mobile service, basic telephone service, Internet service, and broadband wireless access. Statistical bulletins are published every quarter, and according to 2016 third-quarter data, there is constant growth in mobile telephony minutes, number of SMS, and mobile Internet traffic (in gigabytes). This shows a high penetration of mobile customers, including traditional mobile telephony and SMSs, and mobile broadband. Figure 10.6 illustrates the almost exponential increase of mobile data usage per subscription.

Figure 10.6: Mobile data usage per subscription in Ghana



Source: National Communications Authority of Ghana; Mobile Network Operators, 2016.

Figure 10.6 shows that Internet traffic per mobile user has tripled in a period of one year, from 2015 Q3 to 2016 Q3; this is remarkable considering that mobile broadband subscriptions had reached 69.2 per cent of the population by 2016 Q3. However, Ghana has also faced QoS problems in the mobile networks. NCA started to work with mobile operators on improving QoS around 2010. To boost QoS in the country, NCA also applied QoS enforcement measures with penalties in the period 2011-2015, as outlined in the boxes with news articles from that period. QoS enforcements in the given examples refer to mobile voice services, for unavailability of the services, or high call blocking and/or call dropping probabilities for voice services as KPIs for voice were not met. Since mobile voice in the given period was circuit switched, blocking appears to be due to the unavailability of a free voice channel because of congestion, while dropping probability happened due to unavailable free channels for handover of an established voice connection from one cell (old cell) to another cell (new cell) due to congestion in the new cell or cells (meaning the call cannot be handed over and is dropped). This is mainly due to network planning and optimization. Capacity is not enough in these cases for the served number of customers in the peak time/busy hour of the day (peak time/busy hour is the hour in a given day on average that has higher traffic volume for a given service, such as voice in this analysis).

Overall, this example highlights that enforcement led to improvements in 2016 and the sanctions on default of QoS compliance remained in the latest version of QoS regulations in Ghana as provided in Table 10.11. The sanctions NCA can apply as per 2016 QoS regulation include a directive to expand capacity, financial compensation, and fines depending on the parameters. These are listed in Table 10.4.

Table 10.4: QoS parameters for interconnection in Ghana

No	Parameter Name	Target	Measurement Formula
1	Interconnection route utilization	Not more than 70% of capacity	Amount of carried traffic to another network x100 Total capacity of route to another network
2	Time to repair (TTR) interconnection route	Not more than One Hour	Time of total service restoration-Time of notification of fault

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.5: QoS parameters for cellular mobile service in Ghana

No	Parameter Name	Target	Measurement Formula
1	Service coverage	>-75dBm (for indoors) >-85dBm (for in-vehicles) >-95dBm (for outdoors in city)	Field strength measurements
2	Call connection success rate	> 99%	Number of successfully connected call attempts x100 Total number of attempts
3	Call drop rate	< 2%	Number of calls dropped x100 Total number of attempts
4	Voice service access delay	< 10 seconds	Maximum time taken for voice service connection in all cases
5	Voice quality (Mean Opinion Score {MOS})	> 3.5	ITU Recommendation on Voice Quality Testing
6	Downtime for cell (site)	< 4 hours	Time restored- Time of fault
7	Downtime for interconnect route	< 1 hour	Time restored- Time of fault
8	Minimum data speed rate	> 2 Mbit/s	Throughput
9	Data service availability	≥ 99.9%	As measured in data networks
10	Data service utilization	≤ 80%	As measured in data networks
11	Data service access time	< 5 seconds	Maximum time taken for data service connection in all cases
12	Data access success rate	≥ 99%	Number of service connections made x100 Total number of connections requested

No	Parameter Name	Target	Measurement Formula
13	Data service drop rate	≤ 1%	Number of service connections lost x100
			Total number of service connections made
14	SMS/MMS delivery success	> 99%	Number of SMS/MMS to recipients delivered x 100
			Total No. of SMS/MMS received at service centre
15	SMS/MMS delivery time	< 5 seconds	Time of service delivered to destination number – Time of service sent from originating number
Billing, customer service & satisfaction measures			
16	Voice calls	Accurate charging	Per second charging
17	Messaging	Accurate charging	Message length of 160 characters
18	Internet services	Accurate charging	QoS charging; volume charging; time charging
19	Interactive voice response (IVR)	< 15 seconds	Duration of announcement of the entire IVR options before a customer can make a choice
20	Call centre operator response	< 30 seconds	Duration of waiting after the option to a customer care assistant has been chosen by the customer
21	Customer satisfaction on overall quality of service	> 95%	Number of answers as good quality Number of customers interviewed

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.6: QoS parameters for basic telephony service in Ghana

No	Parameter Name	Target	Measurement Formula
1	Time to repair (TTR)	≤ 8 hours	Sum of duration of each repair time in hours for all the fault incidences in a day
2	Call connection success rate	> 99%	Number of successfully connected call attempts x100 total number of attempts
3	Call drop rate	< 2%	Number of calls dropped x100 total number of attempts
4	Voice service access delay	<10 seconds	Maximum time taken for voice service connection in all cases
5	Voice quality MOS	> 3.5	ITU Recommendation on Voice Quality Testing
Billing, customer service and satisfaction measures			
6	Voice calls	Accurate charging	Per second charging
7	Provision and installation of telephone on premise after payment	≤ 5 days	Number of days from service request to service operations

No	Parameter Name	Target	Measurement Formula
8	Interactive voice response(IVR)	< 15 seconds	Duration of announcement of the entire IVR options before a customer can make a choice
9	Call centre operator response	< 30 seconds	Duration of waiting after the option to a customer care assistant has been chosen by the Customer
10	Customer satisfaction on overall quality of service	> 95%	Number of answers as good quality Number of customers interviewed

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.7: QoS parameters for Internet service in Ghana

No	Parameter Name	Target	Measurement Formula
1	Call connection success rate	< 99%	Number of successfully connected calls x100 total number of attempts
2	Call drop rate	< 2%	Number of calls dropped x100 total number of connected calls
3	Voice service access delay	< 10 seconds	Maximum time taken for voice service connection
4	Voice quality MOS	> 3.5	ITU Recommendation on Voice Quality Testing
5	Downtime for cell (site)	< 4 hours	Time restored- time of fault
6	Downtime for interconnect route	< 1 hour	Time restored- time of fault
7	Minimum data speed	≥ 2Mb/s	Throughput
8	Data service availability	≥ 99.9%	As measured in data networks
9	Data service utilization	≤ 80%	As measured in data networks
10	Date service access time	< 5 seconds	In all cases
11	Data access success rate	≥ 99%	Number of successful connections made x100 Total number of connections requested
12	Data service drop rate	≤ 1%	Number of connections lost x100 Total number of connections made

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.8: Billing, customer service and satisfaction measures for Internet service in Ghana

No	Parameter Name	Target	Measurement Formula
13	Provision and installation of Internet equipment (modem and related accessories) on premise after payment	≤ 5 days	Number of days from service request to service operations

No	Parameter Name	Target	Measurement Formula
14	Interactive voice response (IVR)	< 15 seconds	Duration of announcement of the entire IVR options before a customer can make a choice.
15	Call centre operator response	< 30 seconds	Duration of waiting after the option to a customer care assistant has been chosen by the customer.
16	Customer satisfaction on overall quality of service	> 95%	Number of answers as good quality Number of customers interviewed

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.9: QoS parameters for broadband wireless access in Ghana

No	Parameter	Target	Remarks
1	Service delivery Waiting time for service activation	< 2 days	This depends on availability of service coverage within the customer's area of interest.
2	Service coverage	>-75dBm (for Indoors) >-85dBm (for In-vehicles) >-95dBm (for outdoor in city)	Field strength measurements
3	Point of interconnection utilisation	≤ 70%	
4	Peak hour traffic utilization	≤ 80%	Ratio of utilized capacity in resource bocks (RBs) to configured RBs on the radio interface
5	Latency	≤80 milliseconds	
6	Data service availability	≥ 96%	
7	Data service access time	< 5 seconds	In 100% of cases
8	Data service access failure rate	≤ 1%	
9	Data service drop rate	≤ 1%	
10	Minimum download data speed minimum upload data speed	≥ 10 Mbit/s ≥ 2.5 Mbit/s	Upload – download ratio 1:4 for each subscriber at all times
11	Downtime for interconnect route	< 1 hour	Within 24 hours
12	Downtime for radio access/ mean time to repair (MTTR)	< 1 hour	Within 24 hours
13	Voice call set-up time	< 10 seconds	In 100% of cases
14	Call connect failure rate	≤ 1%	

No	Parameter	Target	Remarks
15	Voice and /or video MOS	> 3.5	International Telecommunications Union (ITU- T Recommendation POLQA Rating 1 to 5)
16	SMS / MMS delivery success	> 99%	Number of SMS/MMS to recipients delivered x 100
			Total number of SMS/MMS received at service centre
17	SMS/MMS delivery time	<5 seconds	Time of service delivered to destination number- time of service sent from originating number
18	Voice calls	Accurate charging	Per-second charging
19	Messaging	Accurate charging	Message length of 160 characters
20	Internet services	Accurate charging	QoS charging; volume charging; time charging
21	Interactive voice response (IVR)	< 15 seconds	Duration of announcement of the entire IVR options before a customer can make a choice
22	Call centre operator response	< 30 seconds	Duration of waiting after the option to a customer care assistant has been chosen by the customer
23	Calls to customer service call centre	> 95% of the calls should be successful.	

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.10: Customer satisfaction attributes for all service types in Ghana

Functional Attribute	Benchmark
Customer satisfaction on overall quality of service	> 90%
Percentage of customers satisfied with the provision of service	> 90%
Percentage of customers satisfied with the network availability	> 90%
Percentage of customers satisfied with reliability	> 90%
Percentage of customers satisfied with billing performance	> 90%
Percentage of customers satisfied with help/enquiry services	> 90%

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

Table 10.11: Sanctions on default on QoS compliance in Ghana

No	Parameter Name	Sanction	Amount (Ghana Cedis)
1	Interconnection route utilization	Directive to expand capacity within 3 months	GHS 50 000 per day after 3 months on default of operator(s) responsible for delay
2	Time to repair (TTR) intercon-nection route	Compensation	GHS 50 000 per hour to be paid by defaulting operator to the other intercon-nect party
3	SDCCH Congestion	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
4	Call connection success rate	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
5	Call drop rate	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
6	Voice service access delay	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
7	Downtime for cell (site)	Announcements to affected locality after first hour	GHS 50 000 per hour after 4 hours to be paid
8	Data service availability	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
9	Data service utilization	Directive to expand capacity within 3 months	GHS 50 000 per day after 3 months on default of operator(s) responsible for delay
10	Data service access time	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
11	Data access success rate	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
12	Data service drop rate	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
13	% of SMS / MMS delivery success	Fine	GHS 50 000 per hour per locality to be paid by defaulting operator to authority
14	Time to repair (TTR) a fixed telephone service	Compensation	GHS 500 per hour after 8 hours per customer
15	Provision and installation of telephone on premise after payment	Compensation	GHS 3 000 per day after 5 days per customer
16	Provision and installation of Internet equipment (modem and related accessories) on premise after payment	Compensation	GHS 3 000 per day after 5 days per customer

No	Parameter Name	Sanction	Amount (Ghana Cedis)
17	Accurate charging of services	Fine after notification by authority to correct in four (4) hours	GHS 50 000 per hour per locality to be paid by defaulting operator to authority

Source: NCA, *The National Communications (Quality of Service) Regulations 2016*

10.6 Quality of service regulation: Bangladesh

In Bangladesh, organizational responsibility for enforcement of licensing conditions, and monitoring and enforcement of QoS lies with the NRA, the Bangladesh Telecommunication Regulatory Commission (BTRC), endowed under the Telecom Act. The Telecom Policy and the Telecom Act of Bangladesh emphasize the quality of service to be rendered by the licensees, and the licences issued by the Commission, and specify the QoS parameters, standards and the benchmarks that must be complied with. The provisions made therein:

- to direct operators to submit reports along with necessary information on any of their activities (Art.31 (i));
- to ensure auditing of operators' procedure and systems in order to measure compliance with the directions issued by the Commission, to examine the propriety of the reporting system of the operators, and to give directions on these matters (Art.31 (j));
- to provide necessary directions to operators to ensure that the Commission has sufficient opportunity to inspect the books and records of the operators and to monitor their activities (Art. 31 (k));

Duties and functions with regard to QoS, standards, monitoring and enforcement also empower BTRC to issue enforcement orders to ensure compliance with the provisions of the Act and, in appropriate cases, to impose and realize administrative fines (Art. 31 (n)).

10.7 Southern African Development Community countries: Quality of service regulation and enforcement

This section highlights the experience of selected countries from the Southern African Development Community (SADC) on QoS regulation and enforcement, targeted mostly at mobile services, as contained in the workshop report from the 2017 ITU and SADC training on quality of service, and quality of experience for SADC.

10.7.1 Botswana

The mandate of the Botswana Communications Regulatory Authority (BOCRA) covers QoS regulation and enforcement as specified in the national Communications Act. BOCRA has published QoS guidelines that cover mobile voice, fixed voice, SMS, fixed and mobile Internet parameters, which include targets, measurements methods, reporting formats and periods, as well as management parameters, such as service down times and call centre response times. There are also many published guidelines such as procedures for reporting infringement, enforcement, revocation and cancellation, however, there are no provisions for compensation to be paid to consumers. The development of these guidelines was guided by ITU standards, extensive industry consultation, country benchmarking, and country experience.

The measurement methods in the guidelines include operator submissions on mobile voice and fixed Internet parameters, independent monitoring tools using site test probes, consumer feedback campaigns, scheduled operator meetings, site visits geared towards corroborating information received from operators, as well as ad-hoc investigations where licensees were visited without notice.

Fixed and mobile voice, SMS, and Internet services are monitored independently with probes located at strategic areas and with scheduled calls to each other. BOCRA used two mobile probes for drive tests carried out on identified problem areas. The results were compared with submissions from operators for verification.

BOCRA has recently launched a customer feedback campaign, in both paper and online formats (*My Network, My Quality),* to identify problem areas being faced by customers, investigating three main QoS parameters, call set up success, call drop rate, and call quality. In addition, BOCRA holds biannual customer satisfaction surveys and provides a consumer on-line complaints procedure.

10.7.2 Malawi

The Malawi Communications Regulatory Authority (MACRA) has the mandate to protect the interests of consumers, purchasers and other users of communication services in respect of prices, quality of the services provided and terminal equipment supplied, and has the responsibility of monitoring the activities of licensees to ensure compliance with the terms and conditions of their licence and applicable regulations. Currently, QoS parameters and targets are specified in operator licences and include provisioning, customer care, network infrastructure, short messaging (SMS), billing, mobile and fixed voice/data services. The parameters and targets were arrived at through benchmarking exercises with other regulators; international best practices; consultation with operators and other stakeholders; and country experience.

Currently, the measurement of the parameters is done through customer surveys, drive tests, quarterly reports from operators and technical audits. The Consolidated ICT Regulatory Management System (CIRMS) is being implemented to allow MACRA to obtain measurements in real-time. The results would be published in the public media. The objectives of the measurements include to assist customers to make informed choices, to independently verify compliance to terms and conditions of licensees, as well as to help operators maintain and improve QoS delivery. The failure by an operator to meet a QoS target amounts to a breach of licence. The sanctions for breach of licence are as follows:

- Issue a warning.
- Issue a compliance order directing licence to take appropriate remedial steps.
- Impose a penalty – maximum penalty is USD 40 000; minimum penalty USD 2 500.
- Revocation of licence for substantial breaches, if a QoS target is missed for the first time, a first warning is issued. If it is missed for a second time, a second warning is issued. The third time sees the revocation of the licence.
- The licence may not be renewed for failure to adhere to licence terms and conditions, including QoS targets.

Generally, licensees can defend themselves before any regulatory sanction is taken against them. There are no provisions for compensation to the user.

10.7.3 Mauritius

The Information and Communication Technologies Authority (ICTA) of Mauritius is responsible for QoS regulation and deals with monitoring and enforcement as provided under the ICT Act 2001 as amended (https://www.icta.mu/acts.html) below:

"The ICTA under section 18(1) (b) of the ICT Act 2001 is to provide economic and technical monitoring of the information and communication industry in accordance with recognized international standard practices, protocols and having regard to the convergence of technology. Also, under section 18(1) (f) of the ICT Act 2001 ICTA is to establish, for public operators, performance standards and linkage standards in relation to the provision of international and local telephone services, and monitor compliance with both of those standards" and

"to report, in such manner as may be required, to the Minister or to any other person on any matter that lies within its purview, such as the performance of public operators, the quality of consumer service and consumer satisfaction, measured against the best available international standards of practice. In furtherance to section 18(1) (n) of the ICT Act 2001, ICTA is to ensure the safety and quality of every information and communication services including telecommunication services, and for that purpose, determine technical standards for telecommunication network, the connection of customer equipment to telecommunication networks."

QoS regulation was released in April 2014 empowering ICTA to enforce QoS measures (https://www.icta.mu/docs/laws/qos.pdf). The next step is to update the QoS monitoring and enforcement framework in order to deploy the appropriate mechanisms to monitor QoS.

10.7.4 Mozambique

The *Instituto Nacional das Comunicações de Moçambique* (INCM) has the mandate to define the parameters, indicators, and methodology for measuring QoS. The QoS indicators are defined in Annex I in the QoS Regulation approved by Decree No. 6/ of May 2011. In 2015, Annex I was revised to amend the parameters, indicators and targets, and introduced Annex II which defines the methodology, including network performance monitoring and drive testing.

In 2015, INCM engaged consultants to conduct a pilot drive testing in the Maputo region to assess the new indicators and targets. INCM was responsible for measuring network related indicators in the revised Annex I, while operators were responsible for measuring non-network related parameters. In 2017, a contractual process to acquire a network performance monitoring system based on the raw data from operators was started.

10.7.5 Namibia

The objectives of the Communication Act of 2009 include promotion of the availability of high quality, reliable and efficient telecommunication services to all users in Namibia, and ensures consumer protection. Section 129 empowers the Communications Regulatory Authority of Namibia (CRAN) to make regulations prescribing QoS.

Regulations on licence conditions for telecommunication service licensees (2012) stated that telecommunication licensees shall comply with QoS standards as prescribed by the authority in terms of the regulations regarding network quality, infrastructure, billing, and service quality.

Following regulations that set out licence conditions for spectrum use licences (2013), licensees are obliged to provide information to enable the authority to monitor and enforce consumer protection and quality of service. Regulations prescribing QoS standards applicable to service licensees (2015) specify QoS parameters and targets, as well as enforcement measures and process. The services covered by the regulations include fixed telephony, network coverage, cellular mobile telephony, cellular mobile data services, SMS, customer care services, call centre services, interconnection and network infrastructure.

The parameters and targets specified in the regulations are guided by ITU Recommendations, ETSI documents, industry consultation, as well as benchmarking with other countries. The measurement of parameters is currently carried out through operator documents and reports. In 2016, independent field tests were outsourced to assess applicable QoS parameters and targets.

On enforcement, any licensee who fails to maintain the minimum QoS standards or fails to submit the required reports is guilty of contravening the regulations. In these cases, the authority can issue a warning and final date for submission, require the licensee to implement a remedial plan, or order the licensee to compensate subscribers or consumers for poor quality of service. The associated penalties are:

1. NAD 500 000 (approximately USD 37 000: For failure to perform measurements for reporting, submitting false or misleading information and contravening quality of service standard set out in Section 2 of Annexure A (billing and customer service);
2. NAD 1 000 000 (approximately USD 74 000): For contravening quality of service standard as set out in Sections 1 and 3 of Annexure A (service quality and network quality) and for repeat offenders; and
3. NAD 5 000 000 (approximately USD 368 000): For failure to implement a remedial plan agreed with the authority.

Before imposing the fine, the authority gives the licensee the opportunity to be heard before the authority decides whether to impose a penalty.

10.7.6 South Africa

The Electronic Communications Act No. 36 of 2005 mandates the Independent Communications Authority of South Africa (ICASA), established by ICASA Act No. 13 of 2000, to set out the minimum standards for the end-user and subscriber Service Charter. The provisions on QoS and its enforcement are contained in the end-user and subscriber Service Charter 2016. SANS (South African National Standards) 1725 defines the QoS parameters and measurement methods. The license terms and conditions commits to the Service Charter and SANS 1725.

The services covered by SANS 1725 include fixed telephony, network coverage, cellular mobile telephony, and SMS. The measurement of cellular mobile voice and data parameters are currently monitored by quarterly drive tests conducted in all provinces. Enforcement of the Service Charter is carried out through mediation and rebate as per Regulations 13 of the end-user and subscriber Service Charter. Sanctions include monetary fines of up to five million Rand, or non-monetary fines, such as publishing the breach in national media channels.

10.7.7 Swaziland

The Swaziland Communications Commission (SCCOM) QoS regulations, enacted in 2016, have yet to be implemented and will include activities such as monitoring and enforcement. The QoS regulations include both penalties and compensation to the user as part of the sanctions.

10.7.8 Zimbabwe

The 2001 Postal and Telecommunication Act (Chapter 12:05) gave the Postal and Telecommunications Regulatory Authority of Zimbabwe (POTRAZ) the mandate to monitor QoS in Zimbabwe. The Postal and Telecommunications (Quality of Service) Regulations Statutory Instrument 42 of 2016 (SI 2016-042) is the legal instrument that specifies QoS standards and enforcement measures. Regarding ICTs, the Statutory Instrument covers cellular telecommunication services, public fixed voice telephony services, data and Internet services, interconnection services, and customer care parameters.

The main objectives of QoS regulations include:

a. Promoting the interests of the consumer by setting minimum QoS standards.
b. Enabling the authority to monitor operators and enforce minimum QoS standards.
c. Promoting effective competition in the sector.
d. Improving performance of public operators.

The obligations of the licensee in terms of QoS regulations should be:

a. Meet or exceed the minimum QoS standards as set by the authority.

b. Provide consumers with enough information to enable them to make informed decisions.

c. Submit network performance data as required by the authority.

d. Retain QoS raw data for the minimum of time specified by the authority.

POTRAZ currently operates two different but complementary approaches to QoS monitoring based on:

- network element counters, whereby QoS audit reports are generated by processing and analysing probe measurement files; and
- active testing (stationary/walk/drive testing) whereby QoS audit reports are generated by processing and analysing log files from active tests.

Zimbabwe experienced a significant drop in penalty calls, going from 1 104 penalty cells in August 2016, to 295 in March 2017. Currently, the penalty schedule is being reviewed to bring it into line with the QoS regulations published in 2016.

10.7.9 Southern African Development Community countries recommendations on quality of service regulation

Overall, the Communications Regulators' Association of Southern Africa (CRASA) focuses on harmonization of the ICT regulatory environment in the SADC region. Considering the current state of QoS regulation and enforcement in the SADC countries, the following recommendations to CRASA can be considered as some of the most recent:

- CRASA should come together and move towards a common position on net neutrality as a regional group that consequently determines QoS policies and regulations on Internet services.
- CRASA may consider adopting the EU programme on mapping broadband in southern Africa with the main target of support planning of broadband investments, as well as reduction of investment costs.
- CRASA may consider developing a common broadband measurement platform[46], similar to the one being developed in the EU[47]
- Strengthened participation of CRASA members is recommended in ITU activities on QoS regulation, as well as capacity building via the ITU QoS Training Programme (QoSTP).

10.8 Short guidelines on quality of service enforcement

As a guideline on QoS enforcement, the regulatory authority may start with recommendations and move towards obligations in cases where the recommendations are important and practical, and the operator is not willing to comply. As already stated in Chapter 3 on QoS regulatory frameworks, the regulator can start by *naming and shaming* strategies to tighter regulation, before using financial penalties and finally moving to more drastic legal enforcement. Encouragement and enforcement should be graduated and proportional for the benefit of end-users. However, there is currently a noticeable difference in QoS enforcement between countries with developed (i.e. mature) telecommunication markets and countries with developing (i.e. less mature) markets. In mature (or competitive) telecommunication markets, QoS enforcement should be targeted to regulatory notice and publication of QoS measurements (on different KPIs for different services) on a website or in an official gazette,

[46] https://ec.europa.eu/digital-single-market/en/news/mapping-broadband-services-towards-integrated-platform-european-level

[47] https://ec.europa.eu/digital-single-market/en/news/mapping-broadband-services-towards-integrated-platform-european-level

with the aim of informing consumers. In less mature markets, regulatory authorities should consider applying financial penalties as a tool for QoS enforcement (for example in Kenya and India) after having given prior notice to telecommunication operators to improve QoS in a given time period (e.g. several months).

Furthermore, in less mature telecommunication markets and as part of QoS enforcement, the following measures may be considered as good practice:

- Requirement for operators to submit and/or publish additional information about the quality of the relevant services, including but not limited to its implementation of a remedial plan within a time-frame determined by the authority.
- Implementation of cost effective measurement systems that could independently assess the quality of service delivered by operators and perceived by consumers.
- Constructive dialogue on findings and possible remedies.
- Directives including but not limited to directing operators to compensate subscribers/consumers for poor QoS.
- Directive to meet KPI target values within a given realistic time period (e.g. three months) and impose fines after the given period if the directive is not fulfilled.
- Fines/penalties for poor QoS on selected technical KPIs for voice, SMS/MMS, and Internet/data services, which are of importance (e.g. voice call success rate, voice call drop rate, data service availability, data access success rate, data traffic congestion, guaranteed minimum bit rates in downlink and uplink, etc.).
- Fines/penalties for poor performance on the non-technical KPIs (e.g. accurate charging/billing of services, etc.).
- Compensation to customers (e.g. for longer time periods to repair a non-working service, provision and installation of Internet equipment such as modem, etc.).
- Fines/penalties for failures by an operator to perform measurement, reporting and record keeping as set out in national QoS regulations.
- Fines/penalties for submission or publication of false or misleading information about the QoS.
- Fines/penalties for obstructing or preventing an investigation by the regulator in respect of the QoS measurement, reporting, data collection and record-keeping procedures.
- Stating specific QoS conditions (KPIs, target values, and enforcement measures for cases of non-compliance) in the spectrum licences of mobile operators (because they are the dominant way to access telecommunication services in less mature telecommunication markets).

Overall, there is no global rule on applying penalties for QoS enforcement, therefore it should be done on a per country basis, by considering all relevant factors that could influence QoS degradation, and considering the benefits for end-users and society in general, as well as the telecommunication market and business aspects.

QoS must be encouraged and can be enforced.

11 Summary and concluding remarks

Regulation and management of QoS and QoE today are becoming increasingly important and complex with a profusion of ever evolving technologies, networks and services with different QoS capabilities in a highly competitive, challenging and globalized digital environment.

ITU-T Regulation Guidelines (published as Supplement 9 to E.800-series) provide the fundamentals of quality of service regulation, including QoS parameters and activities, recommended approaches, including information gathering, penalties and dialogue, specifying parameters, levels and measurement methods. This manual extends ITU-T Supplement 9 to ITU-T E.800 series Recommendations, *Guidelines on regulatory aspects of QoS* by introducing more hands-on information about QoS and QoE, as well as practical approaches in QoS regulation for telecommunication/ICT services.

Overall, the aim of QoS regulation remains to ensure fairness and high quality user experience. Nowadays, QoS regulation can be targeted to two types of services:

1. Individual services, session or connection, with QoS guarantees, such as QoS-enabled VoIP, QoS-enabled IPTV, or mission-critical services (specialized services over IP networks) are provided with QoS guarantees by the operator (e.g. IoT, machine-to-machine (M2M) services), etc.

   Individual services have different sets of KPIs (per service). When these services are provided over IP-based networks, which is a typical scenario today, then the common KPIs for IP-based services can also be applied to these individual services. The QoS of TV and IPTV services are rarely regulated (of course, this statement is valid if one does not include here the spectrum management for terrestrial TV broadcast systems).

2. Internet access service, by enforcing KPIs for Internet access services (e.g. bit rates in uplink and downlink, delay, jitter, loss ratio), the regulatory authority may ensure that end-users will have satisfactory quality when using OTT services (e.g. web services, e-mail, Skype, Viber, Youtube, Google, Google docs, Facebook, Twitter, BitTorrent, etc.), provided in a best effort manner based on principles of network neutrality. However, consumer education is also an important part of QoS regulation as home network (e.g. WiFi) or user equipment (e.g. low end CPU and memory) can result in lower QoE, and vice versa.

QoS regulation is directly related to QoS monitoring. Different regulatory approaches can be used to implement a quality monitoring system, including:

- Traditional regulation: The quality monitoring system may be implemented and run by the regulatory authority, either by the authority itself or by using an independent measurement provider. With a sufficient legal basis, the regulatory authority may also impose the establishment of a quality monitoring system on the operators. This option allows full control over the methodology for implementation, as well as the generated measurement data.
- Co-regulation: The regulatory authority in some cases may find it appropriate to establish joint regulator-stakeholder systems, rather than imposing implementation merely on the operator. Under such a scheme, cooperation with stakeholders may be useful to meet specific needs and/or regulatory objectives, such as:
  - system development by independent research institutions;
  - performing measurement campaigns with the help of consumer organizations;
  - publishing results on third party comparison websites.

  In this case, the regulatory authority can choose to involve different stakeholder categories and set up a cooperative monitoring system to share responsibilities and costs with independent research organizations and other third parties. Such cooperative systems using different governance solutions are already in place in some national markets. These may include public-private partnerships based on inter-institutional agreements; advisory bodies such as steering committees and technical round tables; and international cooperative forums. Co-regulation should be guided by the same principles as formal regulation, i.e. it should be objective, justified, proportional, non-discriminatory, and transparent.

- Self-regulation: The regulatory authority may decide to leave measurement systems to be deployed by the market, and to promote self-regulatory initiatives, as well as publishing monitoring results[48]. For example, NRAs may launch education and information campaigns to increase consumer awareness of the availability and use of measurement tools, while inviting operators to make available user friendly tools to their customers. With this method, the regulatory authority may have some influence, but does not control the methodology of the QoS monitoring system, its implementation or generated data from measurements.

To enable consumers to test their broadband connection and monitor the broadband quality, regulatory authorities are increasingly providing broadband speed test tools free to all via their websites.

Defining appropriate and transparent QoS requirements can assist operators to provide quality services at affordable costs to consumers and regulatory authorities have a key role to play. Consultation and collaboration between regulatory authorities and regional and international organizations, including ITU, is very important in developing QoS regulation, and in particular monitoring and measurement tools.

With the publication of QoS commitments, and hence enforcement via "truth in advertising", the division of responsibilities between all parties could vary (e.g. the regulator, the operators, third-party service providers, vendors of monitoring tools and equipment, experts engaged in the process of QoS monitoring that will result in QoS enforcement, law and policy-makers, government, etc.), but primary responsibility is a matter of consumer protection. However, when the QoS monitoring indicates QoS levels significantly below advertised values (e.g. below 80 per cent of advertised values, as an example), then the regulatory authority should consider applying financial penalties to *quality* non-conformant operators. Such penalties should be gradual and proportional, trying to achieve a balance between having high quality telecommunication/ICT services on one side, while maintaining/ensuring sustainability of telecommunication operators and service providers in a single competitive market on the other.

Based on country experiences and good practices identified in previous ITU Trends in Telecommunication Reform reports (2003-2016), the following recommendations for QoS regulation can be made:

- The human capacities and technical resources of the telecommunication operators and customer opinions through widespread consultations, working groups, and open meetings helps to make monitoring effective.
- The performed measurements should be important for customers, practical for operators and comparable between operators. They should concentrate on only a few aspects of QoS.
- The measurements published should be accessible and helpful to customers, and fair to operators. They should be made available in ways appropriate to the intended users.
- Any targets set should be useful for customers and realistic for operators.
- Monitoring tasks should be regularly updated regarding measurement tools and applied tests (for example, to test higher bit rates, larger files are needed for upload and download).
- Defining appropriate and transparent QoS requirements can assist operators in developing countries to provide quality services at affordable costs.
- The NRA needs to define appropriate parameters, KPIs, and methodologies for QoS measurements, which are applicable to networks run by telecommunication operators, supporting both IPv4 and IPv6.

[48] BEREC, *Monitoring quality of Internet access services in the context of net neutrality*

- When defining appropriate quality of service standards, it is also important to maintain an environment where consumers have the ability to choose services according to their needs.

NRAs should have the appropriate skill set to carry out QoS regulation; therefore continuous capacity building is key to adapting to market and regulatory changes. NRAs can benefit greatly by learning from each other. The arguments for cooperation between regulators are very strong and can bring substantive benefits through the sharing of good practices and mutual learning.

Annex 1: Quality measurement tools

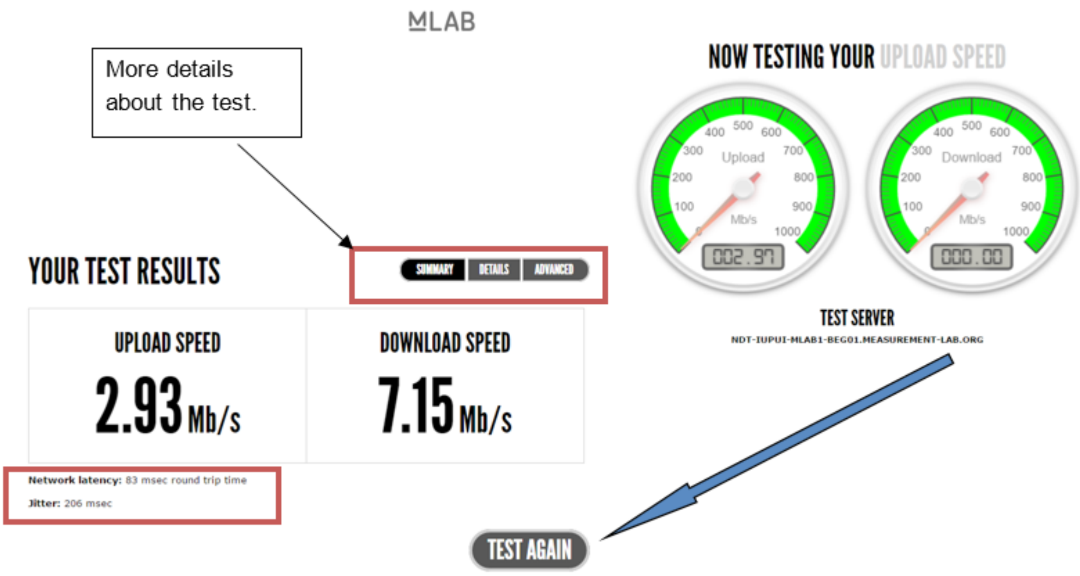
There are many tools available to perform broadband QoS measurements, some of them are available for free, and some of them are commercially offered to ISPs. This section describes several quality measurement tools. It is not intended as an exhaustive list of tools available, but rather to serve as a starting point.

A.1.1 Network diagnostic tool

A network diagnostic tool (NDT) is a client/server program that provides network configuration and performance testing for a user desktop or laptop computer. The system is composed of a client program (command line or java applet) and a pair of server programs (a web server and a testing/analysis engine). Both command line and web-based clients communicate with a Web100-enhanced server to perform diagnostic functions. Multi-level results allow novice and expert users to view and understand the test results.

Both client and server processes are used to perform a specific set of tests. The server processes include a basic web browser to handle incoming web-based client requests. The server also runs a second process that performs the specific tests needed to determine what problems, if any, exist. That process then analyses the test results and returns these results to the client. NDT tests can be run via a web page (Figure A.1.1) or via a Unix command line tool.

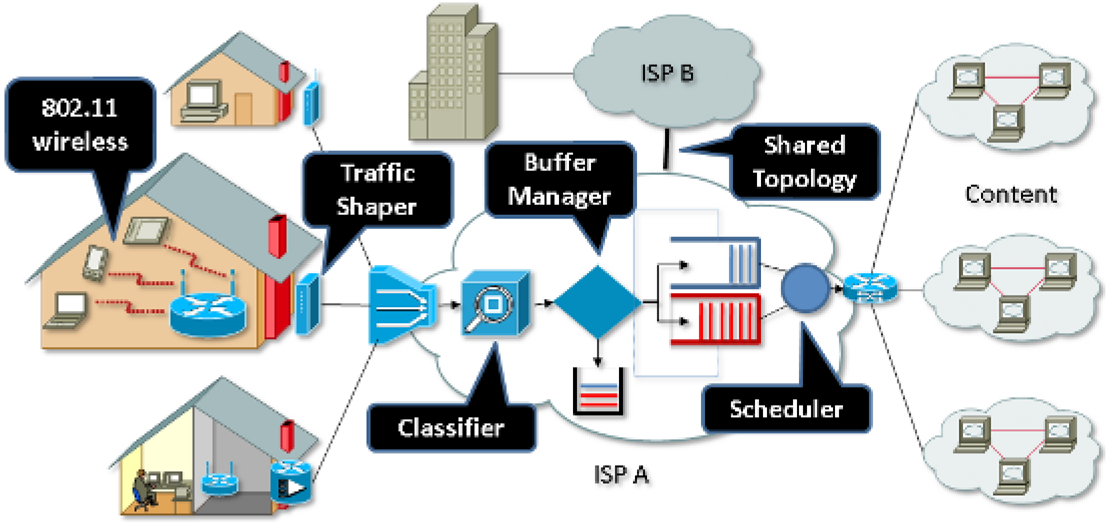
Figure A.1.1: Example measurements with the NDT tool



Source: M-Lab[49]

[49] Network diagnostic testing by M-Lab is available via: https://www.measurementlab.net/tests/ndt/

Figure A.1.2: NetInfer tool illustration of end-to-end Internet path



Source: NetInfer

Figure A.1.2: NetInfer tool illustration of end-to-end Internet path

A.1.2 NetInfer: End-to-end inference of Internet performance problems

NetInfer (http://netinfer.net/) provides a suite of tools for inference and diagnosis of Internet performance problems. NetInfer offers:

- **DiffProbe, Detecting ISP Traffic Discrimination.** The goal of DiffProbe is to detect if an ISP is classifying certain kinds of traffic as low priority, providing different levels of service for them. DiffProbe actively (and non-intrusively) probes the network path and tries to diagnose the nature and extent of traffic discrimination.
- **ShaperProbe Detecting ISP Traffic Shaping**. The DiffProbe ShaperProbe makes use of the Measurement Lab (M-Lab) research platform. (http://netinfer.net/diffprobe/shaperprobe.html)
- Illustration of the implementation of NetInfer is provided in Figure A.1.2.

A.1.3 Measurement tool for investigating network neutrality: Neubot

Neubot (network neutrality bot: www.neubot.org/**)** is a free software Internet bot, developed and maintained by the Nexa Center for Internet and Society at Politecnico di Torino, Italy, that gathers network performance data useful to investigate network neutrality. Once installed, it runs in the background and periodically performs active transmission tests with M-Lab servers (https://www.measurementlab.net/tools/neubot/). Three tests are currently implemented: a speed test that emulates HTTP; bit-torrent, which emulates Bit-Torrent; and raw, which performs a raw TCP test. All tests measure the application-level throughput and round-trip time, both in upload, and download directions.

A.1.4 Measurement tool SpeedTest by OOKLA

The SpeedTest by OOKLA is available at www.speedtest.net/ (Figure A.1.3). It measures ping round-trip time, upload and download speed. OOKLA claims that this is used by 80 per cent of ISPs globally. The OOKLA website also claims that approximately 10 billion speed tests have been carried out as of January 2017.

Figure A.1.3: SpeedTest by OOKLA

Source: OOKLA

OOKLA (https://www.ookla.com/) also offers commercial solutions called NetGauge to ISPs (based on SpeedTest technology) through a claimed set of customizable broadband performance testing and monitoring tools.

Annex 2: Quality measurement platforms

The basic idea of a controlled measurement platform is to provide infrastructure and architecture that allow for active measurements (client/server architecture). Such platforms may provide a pre-defined set of measurement tools or even offer an open infrastructure where any measurement tool may be implemented. The tools used can be either hardware or software based. Hardware-based probes are used as these measurement platforms are designed to allow for precise measurements under controlled conditions, following detailed measurement scenarios.

A.2.1 Measurement Lab (M-Lab)

Measurement Lab (M-Lab https://www.measurementlab.net/**)** is an open, distributed server platform provided to researchers to deploy Internet measurement tools developed by different parties. M-Lab is not a complete measurement platform by itself; it does however provide the infrastructure to set-up a measurement platform by deploying respective measurement tools on top of it. Data collected by those tools is released into the public domain (open data principle).

An important aspect of M-Lab software is that it is licensed as open-source. Users and organizations have the possibility to verify the security of the platform from their perspective, can modify the existing software for their special needs, and can develop new software with the option of it becoming an M-Lab tool.

Another important point is that all the collected and stored measurement results in M-Lab servers are publicly available to the community (open data principle). The advantage of this solution is that everyone can use the data; in addition, historical data can be easily collected and processed. It is then up to the NRA or third parties to process and present the data in a coordinated way.

At present some NRAs in Europe are cooperating on the basis of a Memorandum of Understanding with M-Lab. The Hellenic Telecommunications & Post Commission (EETT) in Greece uses the NDT and Glasnost tools for its HYPERION tool. The Office of the Commissioner of Electronic Communications and Postal Regulation (OCECPR) in Cyprus has also adopted M-Lab tools, using the same interface as EETT. In Austria, the Regulatory Authority for Broadcasting and Telecommunications (RTR) has integrated the NDT into its RTR-NetTest.

A.2.2 RIPE Atlas

RIPE Atlas (https://atlas.ripe.net/) is the main RIPE Network Coordination Centre (NNC) Internet data collection system. It is a global network of hardware devices – called probes and anchors – that actively measures Internet connectivity (Figure A.2.1). Anyone can access this data via Internet traffic maps, streaming data visualisations, and an API (application programming interface). RIPE Atlas users can also perform customized measurements to gain valuable data about their own networks.

Figure A.2.1: All RIPE Atlas probes are shown on a map on the website

Source: RIPE

RIPE Atlas probes and anchors conduct built-in measurements including ping, traceroute, DNS, SSL/TLS (Secure Sockets Layer/Transport Layer Security) and HTTP. User-defined measurements can also be defined. RIPE Atlas Probes are small, USB-powered hardware devices that hosts connect to an Ethernet port on their router. RIPE Atlas Anchors (Figure A.2.2) are both enhanced RIPE Atlas probes with more measurement capacity, as well as regional measurement targets within the greater RIPE Atlas network. As such, RIPE Atlas anchors provide valuable information about local and regional connectivity and reachability of the Internet. There are currently over 9 000 active probes in the RIPE Atlas network, spread across all regions in the world. The network is constantly growing.

Figure A.2.2: All RIPE anchors locations

Source: RIPE

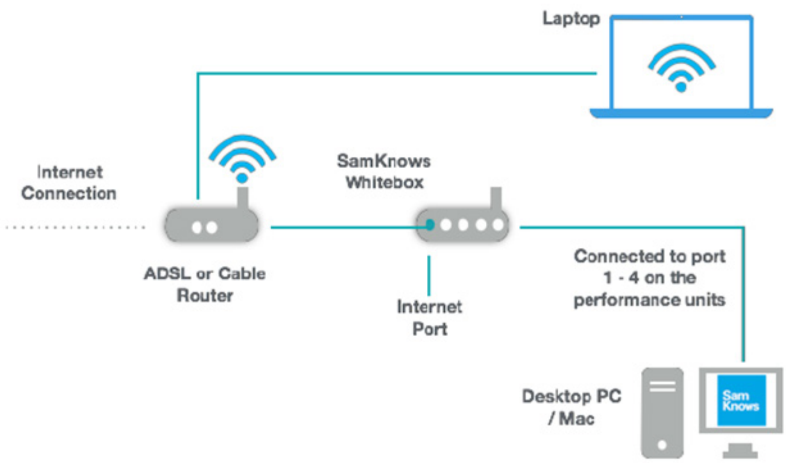
A.2.3 The global platform for Internet measurement: SamKnows

The SamKnows performance monitoring framework (https://www.samknows.com/) is a distributed network of Whiteboxes in actual consumer homes used to accurately measure the performance of fixed line broadband connections based on real-world usage. These are controlled by a cluster of servers, which host the test scheduler and the reporting database. The data is collated on the reporting platform and accessed via a reporting interface and secure FTP. The framework also includes a series of speed-test servers, which the nodes call upon according to the test schedule.

SamKnows uses hardware probes (Whiteboxes) for the purpose of accurately measuring end-user broadband performance (Figure A.2.3). The Whiteboxes execute a series of software tests over the broadband connection they are connected to. The results of these tests are reported securely on to hosted backend infrastructure.

The majority of tests run against a network of test nodes. These are dedicated servers either "on-net" (on the local ISP's network) or off-net (on the public Internet). Some tests will execute against real applications hosted on the Internet, mimicking their behaviour and measuring key performance variables. When a testing cycle has been completed, the results are encrypted and transmitted over SSL to the hosted backend infrastructure for processing and presentation through a web interface to each panellist and other interested parties. Panellists are, as part of the terms of service, required to leave their Whitebox and other networking equipment permanently powered on and connected to ensure consistent testing.

Figure A.2.3: SamKnows probe location



All SamKnows Whiteboxes run a custom distribution of Linux, derived from OpenWrt. Many standard OpenWrt features have been removed to save space on the device, and some additional features have been added to support the measurements. The custom firmware is flashed at the factory and is not directly upgradeable by the user hosting the Whitebox. The firmware is remotely upgradeable by SamKnows. This cut-down operating system provides network connectivity and the measurement applications alone – there is no web interface and the Whitebox provides no routing functionality. Panellists have no ability to disable, reconfigure or influence the SamKnows software in any way through normal usage.

SamKnows firmware makes use of General Public License (GPL) v2.0 licensed code. The source code for SamKnows' firmware build is available at: https://files.samknows.com/~gpl.

All communications between the Whitebox and the Data Collection Service on the backend hosted infrastructure are initiated by the Whitebox, encrypted over SSL and subject to authentication. The Whitebox communicates with the target test nodes over a variety of TCP and UDP ports. The Whitebox will also communicate with some unmanaged services over both TCP and UDP. The SamKnows software suite has the ability to auto-update itself, download updated binaries and testing schedules from the Data Collection Service, and store locally in RAM or flash

Determining the best measurement server

Upon start up, the application runs a brief latency measurement to all measurement servers hosted by SamKnows. This process determines the nearest measurement server (in terms of latency). The measurement server with the lowest round-trip latency is selected as the target for all subsequent measurements (throughput, latency and packet loss). Additionally, if the ISP has installed 'on-net' measurement servers within their network, then the application will also select the nearest one of these servers. Measurements are run against both the on-net and off-net servers.

Cross-traffic, in-home network issues and configuration differences

One of the key advantages of the hardware-based Whitebox is its ability to detect cross-traffic and defer tests. Furthermore, its position within the home network (connected directly to the modem or gateway) means that it is unaffected by in-home network issues (such as those caused by wireless networks).

A purely software-based approach is not able to account for such issues. However, a number of mechanisms can be applied in an attempt to reduce or detect their impact. Cross-traffic within the local client (e.g. PC) is measured and tests will not be executed if the client is transferring more than 64 kbit/s.

Additionally, the web-based test will poll the user's gateway via UPnP (Universal Plug and Play) for traffic counters. This allows for cross-traffic within the home to be fully accounted for, and measurements will not be executed if the gateway is transferring more than 64 kbit/s. However, this UPnP-based approach is far from universally supported. A study from February 2012 showed that approximately 22 per cent of gateways in Europe supported traffic counter reporting by UPnP, but this figure is expected to rise[50].

In-home network issues (such as poor wireless) cannot be excluded by the web-based test. However, we can attempt to identify them. In particular, the web- based test records the connection media used by the client and its connected speed (e.g. Ethernet at 100 Mbit/s, or wireless at 54 Mbit/s). Additionally, the web-based test will also run a brief ICMP (Internet Control Message Protocol) latency and packet loss measurement to the user's gateway. If this reports more than 2 ms latency and 0% packet loss, then the measurements are aborted with a message stating that the user's in-home network appears to be operating poorly.

Client configuration issues (such as insufficient TCP settings, firewall products, RAM or CPU) are checked for before measurements begin. If these fall outside of accepted bounds, then the tests are aborted and the user is informed. In all of the error conditions above, the user will be informed of the reason why the measurements were not executed. The user may override the failure and run the measurements anyway, but the results will be recorded on the server side with a *tainted* flag, indicating that they were not run under optimal conditions.

The SamKnows methodology and platform have been designed to be flexible enough to allow for whatever future modifications or enhancements are required, but at the same time the out-of-the-box solution provides a fully inclusive package of every available performance measurement test. Table A.1 shows details about possible measurements.

50 https://ec.europa.eu/digital-single-market/en/news/quality-broadband-services-eu-march-2012

Table A.1: Primary measures with SamKnows

Metric	Primary measure(s)
Web browsing	The total time taken to retrieve a page and all of its resources from a popular website
Voice over IP	Upstream packet loss, downstream packet loss, upstream jitter, down-stream jitter, round-trip latency
Download speed	Throughput in Mbit/s utilising three concurrent TCP connections
Upload speed	Throughput in Mbit/s utilising three concurrent TCP connections
UDP (User Datagram Protocol) latency	Average RTT of a series of randomly transmitted UDP packets
UDP packet loss	Percentage of UDP packets lost from latency test
DNS resolution	The time taken for the ISP recursive DNS resolvers to return an A record for a popular website domain name

Source: SamKnows (https://www.samknows.com/)

Table A.2: Example test schedule with SamKnows (Europe)

Test Name	Test Target(s)	Test Frequency	Test Duration	Est. Daily Volume
Web browsing	3 popular websites	Hourly, 24x7	Est. 3 seconds	8.4MB
Voice over IP	1 off-net test node	Every other hour, 24x7	Fixed 10 seconds at 64 k	1.92MB
Download speed	1 off-net test node	Once 12am-6am Once 6am-12pm Once 12pm-6pm Every hour 6pm-12am	<30M bit/s = 6MB 30-50 Mbit/s = 12MB file size >50 Mbit/s = 10 seconds duration	54MB 108MB >~540MB
Upload speed	1 off-net test node	Once 12am-6pm Once 6am-12pm Once 12pm-6pm Once 6pm-12pm	<10 Mbit/s = 3MB fixed size 10-20 Mbit/s = 6MB >20 Mbit/s = 10 seconds duration	18MB 36MB >~216MB
UDP latency	1 off-net test node	Hourly, 24x7	Permanent	1MB
UDP packet loss	1 off-net test node	Hourly, 24x7	Permanent	N/A (uses above)
DNS resolution	3 popular websites	Hourly, 24x7	Est. 1 second	0.1MB

Source: SamKnows

A sample test schedule of the SamKnows platform is shown in Table A.2. The SamKnows Internet measurement platform actively performs testing in more than 40 countries on behalf of telecoms regulators and ISPs (https://samknows.com/global-platform) including CRTC in Canada, the Federal Communications Commission (FCC) in the United States, the Office of Communications (Ofcom) in the

United Kingdom, the InfoComm Media Development Authority (IMDA) in Singapore, OFCA in Hong Kong, China, Anatel in Brazil, ACCC (Australian Competition and Consumer Commission) in Australia, the European Commission, and others.

Acronyms

ACCC	Australian Competition and Consumer Commission
ADSL	Asymmetric digital subscriber line
AGCOM	Autorità per le Garanzie nelle Comunicazioni
AMR	Adaptive multi-rate
API	Application programming interface
ARCEP	Autorité de Régulation des Communications électroniques et des Postes
AS	Autonomous system
ASP	Application and service provider
ATM	Asynchronous transfer mode
BEREC	Body of European Regulators for Electronic Communications
BI	Business interface
BIAS	Broadband Internet access service
BOCRA	Botswana Communications Regulatory Authority
BTRC	Bangladesh Telecommunication Regulatory Commission
BTS	Base transceiver downtime
BUTS	Bulk users of telecommunication services
CA	Communication Authority (Kenya)
CAP	Content and application provider
CBBH	Cell bouncing busy hour
CCI	Call clarity index
CDNs	Content delivery networks
CDR	Call data record
CE	customer edge
CIRMS	Consolidated ICT Regulatory Management System
CIS	Commonwealth of Independent States
CM	complaint management
CPI	Comparable performance indicators
CPU	Central processing unit
CRAN	Communications Regulatory Authority of Namibia
CRASA	Communications Regulators' Association of Southern Africa
CRTC	Canadian Radio-television and Telecommunications Commission
CSCF	Call session control function
CSP	Communication service provider
CSV	Circuit switch voice

dBm	Decibel-milliwatts
DHCP	Dynamic Host Configuration Protocol
DL	Download
DNS	Domain name system
DoT	Department of Telecom
DPI	Deep packet inspection
DSCP	Differentiated Services Code Point
DSL	Digital subscriber line
DSLAM	Digital subscriber line access multiplexer
DTMF	Dual tone multi frequency
EAM	End-user application measurement
EDM	End-user device measurement
EDGE	Enhanced Data rates for Global Evolution
EETT	Hellenic Telecommunications & Post Commission
EPS	Evolved packet system
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission (US)
FRT	Fault repair time
FTP	File transfer protocol
FTTH	Fibre-to-the-home
FTTN	Fibre-to-the-node
FTTP	Fibre-to-the-premises
FTTX	Fibre-to-the-x
GPL	General Public License
GPON	Gigabit-capable passive optical networks
GPRS	General Packet Radio Service
GSM	Global system for mobile communications
HD	High-definition
HFC	Hybrid fibre-coaxial
HSPA	High speed packet access
HTML	HyperText Markup Language
HTTP	Hypertext transfer protocol
IANA	Internet Assigned Numbers Authority
IAS	Internet access service
ICANN	Internet Corporation for Assigned Names and Numbers

ICASA	Independent Communications Authority of South Africa
ICMP	Internet Control Message Protocol
ICT	Information and communication technology
ICTA	Information and Communication Technologies Authority (Mauritius)
IETF	Internet Engineering Task Force
IMDA	InfoComm Media Development Authority (Singapore)
IMS	IP multimedia subsystem
IoT	Internet of Things
INCM	Instituto Nacional das Comunicações de Moçambique
INMD	In-service non-intrusive measurement device
IP	Internet Protocol
IPDV	IP packet delay variation
IPER	IP packet error ratio
IPLR	IP packet loss ratio
IPRR	IP packet reordering ratio
IPTV	Internet Protocol Television
IPTD	IP packet transfer delay
IPXs	IP eXchanges
IVR	Interactive voice response
IXP	Internet eXchange Points
IRA	ineffective registration attempt
ISDN	Integrated services digital network
ISP	Internet service provider
ITU	International Telecommunication Union
IVR	Interactive voice response
KPI	Key performance indicators
LTE	Long-Term Evolution
M2M	Machine-to-machine
MACRA	Malawi Communications Regulation Authority
MDT	Mean down time
MMS	Multimedia Messaging Service
MOS	Mean opinion score
Ms	Millisecond
MTBF	Mean time between failures
MTTF	Mean time to failure

MTTR	Mean time to repair
NAP	Network access point
NB	Narrowband
NBTC	National Broadcasting and Telecommunications Commission (Thailand)
NCA	National Communications Authority (Ghana)
NDT	Network diagnostic tool
NER	Network error rate
NGN	Next generation network
NNC	Network Coordination Centre
NP	Network performance
NRA	National Regulatory Agency
NS	Network section
OCECPR	Office of the Commissioner of Electronic Communications and Postal Regulations (Cyprus)
OECD	Organisation for Economic Co-operation and Development
OFCA	Office of the Communications Authority (Hong Kong)
Ofcom	Office of Communications (UK)
OLT	Optical line terminal
ONT	Optical network terminal
OS	Operating system
OSI	Open Systems Interconnection
OSP	Online service provider
OTT	Over-the-top
P2P	Peer-to-peer
PC	Personal computer
P-CSCF	Proxy call session control function
PoC	Push-to-talk over cellular
PDP	Packet data protocol
PPDR	Public protection and disaster relief
PE	Provider edge
PESQ	Perceptual evaluation of speech quality
PLMN	Public land mobile network
POI	Point of interconnection
POLQA	Perceptual objective listening quality assessment
POTRAZ	Postal and Telecommunications Regulatory Authority of Zimbabwe
POTS	Plain old telephone service

PS	Packet switched
PSM	Project self-management
PSTN	Public switched telephone network
QCI	Quality classification identification
QoE	Quality of Experience
QoS	Quality of Service
QoSD	QoS delivered by service provider
QoSE	QoS experienced/perceived by customer/user
QoSO	QoS offer/planned be service provider
QoSR	QoS requirements of user/customer
QoSTP	Quality of Service Training Programme
QSDG	Quality of Service Development Group
RAB	Radio access bearer
RAM	Random-access memory
RB	Resource blocks
RIO	Reference Interconnect Offer
RRC	Radio resource control
RTCP	Real-time transport control protocol
RTP	Real-time transport protocol
RTR	Austrian Regulatory Authority for Broadcasting and Telecommunications
RTT	Round-trip time
SA	Service availability
SADC	Southern African Development Community
SCCOM	Swaziland Communications Commission
SCR	Session completion ratio
SDCCH	Stand-alone Dedicated Control Channel
SDH	Synchronous digital hierarchy
SDO	Standards Developing Organization
SDS	Short Data Service
SEER	Session establishment effectiveness ratio
SG12	Study Group 12
SG12RG-AFR	Regional Group on QoS for the Africa Region
SIP	Session initiation protocol
SLA	Service Level Agreement
SMP	Significant market power

SMS	Short Message Service
SON	Self-organizing networks
SP	Service provider
SQA	Service quality agreement
SQEG	Speech Quality Experts Group
SRD	Session request delay
SRVCC	Single radio voice call continuity
SSL	Secure Sockets Layer
SWB	Super-wideband
TCH	Traffic channel
TCP	Transmission control protocol
TDM	Time division multiplexing
TE	Terminal equipment
TI	Technical interface
TLS	Transport Layer Security
TRAI	Telecom Regulatory Authority of India
TSM	Telecoms Single Market
TTR	Time to repair
UDP	User datagram protocol
UL	Upload
UMTS	Universal Mobile Telecommunications System
UNI	user-network interface
UPnP	Universal Plug and Play
USB	Universal Serial Bus
VDSL	Very high bit rate digital subscriber line
VoIP	Voice-over-IP
VoLTE	Voice over LTE
VPN	Virtual private network
VQEG	Voice Quality Experts Group
WAP	Wireless application protocol
WATRA	West Africa Telecommunication Regulators Assembly
WB	Wideband
WCIT	World Conference on International Telecommunications
WLAN	Wireless local area network
WPs	Working Parties

WTP	Willingness to pay
WTSA	World Telecommunication Standardization Assembly

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