International Telecommunication Union

ITU-T

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

E.802

Amendment 2

(06/2018)

SERIES E: OVERALL NETWORK OPERATION, TELEPHONE SERVICE, SERVICE OPERATION AND HUMAN FACTORS

Quality of telecommunication services: concepts, models, objectives and dependability planning – Terms and definitions related to the quality of telecommunication services

Framework and methodologies for the determination and application of QoS parameters

Amendment 2

Recommendation ITU-T E.802 (2007) – Amendment 2

ITU-T

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Recommendation ITU-T E.802

Framework and methodologies for the determination and application of QoS parameters

Amendment 2

Summary

Recommendation ITU-T E.802 provides a framework and methodologies for the identification of QoS criteria relevant to users and guidelines for conversion of these criteria into QoS parameters that can be used to evaluate the QoS of telecommunication services.

Guidelines are also given to obtain user's QoS requirements and to prioritize the criteria or parameters. All these may be applied to services supported by the terrestrial and wireless legacy networks as well as services supported by the emerging IP network.

Amendment 1 incorporates Annex A, which provides guidance on the selection of representative samples in the measurement of QoS parameters. At the time of publication Recommendation ITU-T E.802 had opted not to give this guidance because "the selection of representative samples is a process that is heavily influenced by specific technical and operational conditions of the measurement task." (see *clause 8.5).* Annex A therefore provides guidance that takes into account these technical (statistical) and operational (practical QoS data collection) conditions by proposing a simple random sampling methodology.

Amendment 1 also adds Appendices IV and V with additional information on the implementation of the sampling algorithm included in Annex A, and on the use of sample-based QoS parameters.

Amendment 2 adds analysis and information on the degree of variability function defined in Annex A.

The electronic attachment that was introduced by Amendment 1, and which contains sample calculator files, is not included with this issue of Amendment 2, but remains available bundled with Amendment 1.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T E.802	2007-02-08	2	11.1002/1000/8848
1.1	ITU-T E.802 (2007) Amd. 1	2017-03-01	12	11.1002/1000/13167
1.2	ITU-T E.802 (2007) Amd. 2	2018-06-13	12	11.1002/1000/13620

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T E.802 (2007) plus its Amd. 1 (2017).

1 Scope

This Recommendation[1] provides a framework and methodologies for the identification of QoS criteria relevant to users and guidelines for conversion of these criteria into QoS parameters that can be used to evaluate the QoS of telecommunication services.

Guidelines are also given to obtain user's QoS requirements and to prioritize the criteria or parameters. All these may be applied to services supported by the terrestrial and wireless legacy networks as well as services supported by the emerging IP network.

These QoS criteria are primarily of interest to users and service providers. Those criteria which are of primary concern to the service/network providers (e.g., network performance parameters that contribute to QoS and other performance criteria) to ensure the delivery of the required level of QoS to the user are not covered in this Recommendation.

NOTE – For information on performance measures from the service/network provider's perspective, refer to [ITU-T E.419] on key performance indicators (KPI).

The QoS criteria are based on the 'QoS Requirements of the User', one of the four viewpoints mentioned in Figure 1 of [ITU-T G.1000]. These criteria, with slight modifications, may be used for expressing the offered QoS, the delivered QoS and the perceived QoS as described in [ITU-T G.1000]. The particular use/application of each of these four QoS viewpoints is given in clause 6.1.1.

This Recommendation introduces three models for the identification of QoS criteria of any telecommunication service. All models or a combination of these models may be used for a particular service to enable most, if not all, QoS criteria to be identified. For a particular purpose, a selection of QoS criteria may be chosen from the list of criteria identified. Guidelines are given on how to convert the identified criteria into measurable QoS parameters and on the adoption and measurement of the parameters.

The QoS parameters may be used for various purposes including:

- Specifying the level of quality of service in customer telecommunication service contracts or in the description of terms and conditions of the service.
- Comparing the level of quality and quality commitments of services of different service providers.

[1] Amendment 1 to this Recommendation included an electronic attachment with the files needed for the implementation of a sample calculator that demonstrates the sampling methodology given in clause A.2. These files are not distributed with Amendment 2.

- Preparing long-term studies on the level of quality attributes of a specific service.
- Preparing statistics, reports and publications of the quality of a service.
- Regulatory purposes including specification of the minimum level of quality (e.g., for universal service, interconnection regulations) and monitoring of services by, for example, reports on a regular basis and statistics for specific situations.

Appendix I provides references for the development of QoS metrics and examples of QoS parameters.

Appendix II gives quality objectives that are currently available in standardization.

Appendix III gives examples for the use of the three models for the identification of QoS criteria.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T E.419] ITU-T Recommendation E.419 (2006), *Business oriented key performance indicators for management of networks and services*.

[ITU-T E.470] ITU-T Recommendation E.470 (2005), *Operational considerations for QoS of voice over IP-based networks with PSTN-IP-PSTN architecture*.

[ITU-T E.800] ITU-T Recommendation E.800 (1994), *Terms and definitions related to quality of service and network performance including dependability*.

[ITU-T G.1000] ITU-T Recommendation G.1000 (2001), *Communications quality of service: A framework and definitions*.

[ITU-T G.1010] ITU-T Recommendation G.1010 (2001), *End-user multimedia QoS categories*.

[ITU-T G.1020] ITU-T Recommendation G.1020 (2006), *Performance parameter definitions for quality of speech and other voiceband applications utilizing IP networks*.

[ITU-T G.1030] ITU-T Recommendation G.1030 (2005), *Estimating end-to-end performance in IP networks for data applications*.

[ITU-T G.1040] ITU-T Recommendation G.1040 (2006), *Network contribution to transaction time*.

[ITU-T G.1050] ITU-T Recommendation G.1050 (2005), *Network model for evaluating multimedia transmission performance over Internet Protocol*.

[ITU-T I.350] ITU-T Recommendation I.350 (1993), *General aspects of quality of service and network performance in digital networks, including ISDNs*.

[ITU-T O.211] ITU-T Recommendation O.211 (2006), *Test and measurement equipment to perform tests at the IP layer*.

[ITU-T Y.1540] ITU-T Recommendation Y.1540 (2002), *Internet protocol data communication service – IP packet transfer and availability performance parameters*.

[ITU-T Y.1541] ITU-T Recommendation Y.1541 (2006), *Network performance objectives for IP-based services*.

[ITU-T Hdbk QoS] ITU-T Handbook (2004), *Quality of Service and Network Performance*.

[ISO 9000] ISO 9000:2005, *Quality management systems – Fundamentals and vocabulary*.

[ISO/IEC Guide 62] ISO/IEC Guide 62:1996, *General requirements for bodies operating assessment and certification/registration of quality systems*.

[ISO/IEC Guide 65] ISO/IEC Guide 65:1996, *General requirements for bodies operating product certification systems*.

[ETSI ETR 003] ETSI ETR 003 ed.2 (1994), *Network Aspects (NA); General aspects of Quality of Service (QoS) and Network Performance (NP)*.

[ETSI EG 202 057-1] ETSI EG 202 057-1 V1.2.1 (2005), *Speech Processing, Transmission and Quality Aspects (STQ); User-related QoS parameter definitions and measurements; Part 1: General*.

[ETSI EG 202 057-2] ETSI EG 202 057-2 V1.2.1 (2005), *Speech Processing, Transmission and Quality Aspects (STQ); User-related QoS parameter definitions and measurements; Part 2: Voice telephony, Group 3 fax, modem data services and SMS*.

[ETSI EG 202 057-3] ETSI EG 202 057-3 V1.1.1 (2005), *Speech Processing, Transmission and Quality Aspects (STQ); User-related QoS parameter definitions and measurements; Part 3: QoS parameters specific to Public Land Mobile Networks (PLMN)*.

[ETSI EG 202 057-4] ETSI EG 202 057-4 V1.1.1 (2005), *Speech Processing, Transmission and Quality Aspects (STQ); User-related QoS parameter definitions and measurements; Part 4: Internet access*.

3 Definitions

This Recommendation defines the following terms:

NOTE – Several terms and definitions used in this Recommendation are defined in [ITU-T E.800] and [ITU-T G.1000].

3.1 accuracy: A performance criterion that describes the degree of correctness with which a function is performed. (The function may or may not be performed with the desired speed.)

3.2 availability: Availability of an item to be in a state to perform a required function at a given instant of time or at any instant of time within a given time interval, assuming that the external resources, if required, are provided.

3.3 confidence level: This is a level at which precision levels are constructed and it is selected by the user. A 95% confidence level, for example, means that when real traffic is repeatedly sampled, the average value of the QoS parameter being measured (e.g., dropped call ratio) will converge to the true value of the QoS parameter 95% of the time (i.e., 95 out 100 samples will have the true population value within the specified level of precision).

3.4 criterion: A single characteristic of a product or a service that is observable and/or measurable.

3.5 customer: The party that uses a telecommunication service(s) under a contractual agreement.

3.6 flexibility: The degree of variations in the function within the boundaries of technical and operational characteristics of the service.

3.7 frequency distribution: This is a table that shows a summarised grouping of data, divided into distinct categories which give the frequency/count of occurrence within each category. For example, the frequency distribution of call traffic within every hour of the day displays the count of calls made in every hour.

3.8 **level of precision** (also known as **margin of error/sampling error**): This is the range (plus/minus) in which the true value of the QoS parameter (that is, the value calculated from real traffic instead of sampled traffic) is estimated to be. For example, a level of precision of ±5% in the calculation of a sample size from which a calculated QoS parameter, say dropped call ratio is 9%, means the true value of dropped call ratio lies between 4% (9-5) and 14% (9+5).

3.9 **measure**: A unit by which a parameter may be expressed.

3.10 **network operator**: An organization that provides and operates a telecommunication network for the purpose of transporting bearers of telecommunication services.

NOTE – If the same organization also offers services, it also becomes a service provider.

3.11 **quality**: The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs, where the characteristics should be observable or measurable. When the characteristics are defined, they become parameters and parameters are expressed by measures.

3.12 **quality of service**:

1) Totality of characteristics of a telecommunication service that bear on its ability to satisfy stated and implied needs of the user of the service.
2) The collective effect of service performances, which determine the degree of satisfaction of a user of the service.

NOTE – These definitions may be seen to be considered complementary, and either or both definitions may be used.

3.13 **four viewpoints of QoS**: Concept for clarifying the management of QoS by sub-classifying QoS into four viewpoints:

3.13.1 **QoS requirements of user/customer**: A statement of the level of quality required by the applications of customers/users of a service, which may or may not be expressed non-technically.

3.13.2 **QoS offered by the service provider**: A statement of the level of quality expected to be offered to the customer by the service provider.

3.13.3 **QoS delivered/achieved by the service provider**: A statement of the level of the actual quality achieved and delivered to the customer.

3.13.4 **QoS perceived by user/customer**: A statement expressing the level of quality that customers believe they have experienced.

3.14 **QoS parameter**: A definition of the scope of a QoS criterion with clear boundaries and explicit measurement method to enable a quantifiable or qualifiable value to be assigned.

3.14.1 **objective (quantitative) parameters**: Parameters that may be measured with instruments and the performance value assigned may be classified as objective parameters.

3.14.2 **subjective (qualitative) parameters**: Parameters that can be expressed using human judgement and understanding may be classified as subjective or qualitative parameters. Qualitative parameters are expressed by opinion ratings.

3.15 **reliability**:

1) Probability that a product or system will perform as required for a specified period of time.
2) The ability of an item to perform a required function under given conditions for a given time period.

NOTE 1 – It is generally assumed that the item is in a state to perform this required function at the beginning of the time interval.

NOTE 2 – The term reliability is used as a measure of reliability performance.

3.16 security:

1) 'Security' is the protection of information availability, integrity and confidentiality.

2) The term 'security' is used in the sense of minimizing the vulnerabilities of assets and resources. An asset is anything of value. A vulnerability is any weakness that could be exploited to violate a system or the information it contains. A threat is a potential violation of security.

3) The ability to prevent fraud as well as the protection of information availability, integrity and confidentiality.

3.17 service provider: An organization that offers a telecommunication service to the customer and/or users.

3.18 simplicity: Ease and lack of complexity in the benefit to the user of a function of the service.

3.19 speed: A performance criterion that describes the time interval required to perform a function or the rate at which the function is performed. (The function may or may not be performed with the desired accuracy.)

3.20 telecommunications: The technical process of sending, transmitting and receiving any kind of message in the form of signs, voice, images or sounds by means of telecommunications systems.

3.21 telecommunication service: The provision of telecommunications and the provision of other additional services that are closely related to the provision of telecommunications, e.g., billing, directory services.

3.22 telecommunications systems: The technical equipment or systems capable of sending, transmitting, switching, receiving, steering or controlling as messages identifiable electromagnetic signals.

3.23 user: An individual or organization using or requesting publicly available telecommunications services.

3.24 verification campaign: A campaign carried out by measuring QoS parameters and checking whether the associated quality objectives for the telecommunications services are met. (See clause 8.5).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CDR	Call Detail Record
INMD	In-service Non-intrusive Measurement Device
IP	Internet Protocol
KPI	Key Performance Indicator
KQI	Key Quality Indicator
NI	Network Interface
NP	Network Performance
POTS	Plain Old Telephone Service
QoS	Quality of Service
SLA	Service Level Agreement

5 Conventions

None.

6 Methodology for identification of QoS criteria and parameters

6.1 General considerations

6.1.1 Viewpoints of QoS criteria

Management of QoS may be clarified by sub-classifying this into four viewpoints. These viewpoints cover all aspects of QoS, both from the service provider's and user's (and customer's) viewpoints.

NOTE – The concept of the four viewpoints of QoS is copied from and explained in detail in [ITU-T G.1000]. An overview on this concept is given here for convenience.

These four viewpoints are:

- customer's QoS requirements;
- service provider's offerings of QoS (or planned/targeted QoS);
- QoS achieved or delivered;
- customer perception (survey ratings of QoS).

The four viewpoints are to be applied as follows:

Customer's QoS requirements	This is an expression of the level of QoS required by the customer. The criteria and parameters identified to express these reflect the requirements.
Service provider's offerings of QoS	The QoS criteria or parameters offered by the service provider are formal terms specified unambiguously and may be used for the following: • As the basis for SLA between the service provider and clients on a bilateral basis of agreement. • Public declaration by the service provider about the level of quality that can be expected by the users at large. • As the basis for planning and maintaining the service at the level of performance being offered. • As the basis for users to choose a level of quality to meet their particular requirements among the service provider's offerings.
QoS achieved or delivered	The QoS delivered is the actual level of quality achieved or delivered by the service provider and may be used for the following: • As the basis to compare the delivered with the offerings by the users, regulators and as a check in the SLAs. • As the basis for any corrective action by the service providers.
Customer/User perception	The QoS perceived by the user may be expressed by ratings based on customer surveys and is an indicator of what the user thinks the level of quality received or experienced. This data may be used for: • Comparison with delivered quality and identifying causes of any ambiguities. • Planning any corrective actions.

When identifying the quality criteria of a telecommunication service, these different viewpoints need to be taken into account. The pertinent QoS criteria or parameters should be used for a given application or context. This consideration is necessary for sharply focused interpretation of the meaning of the values represented by the QoS criterion or parameter. Based on this approach, the QoS parameters that are relevant to the users can be defined and measurement methods as well as quality assessment methodologies can be elaborated.

6.1.2 General aspects of quality of service criteria and parameters

The following basic aspects of QoS criteria and parameters have to be considered when identifying the criteria and determining the scope and measurement methods of parameters:

NOTE – Detailed information on these aspects is given in the following clauses.

- QoS criteria and parameters are to be considered on a service-by-service basis.
- QoS criteria are to be specified on an end-to-end basis, the end-to-end being the points at which the user's terminals are connected.
- QoS criteria and parameters are to be specified in terms understandable to the customers. In addition, where necessary, these criteria and parameters may also be specified in more technical terms for use within the industry. (Both customer terms and industry terms may use ITU-T recommended definitions to eliminate ambiguity and to provide the most efficacious understanding.)
- Different segments of the customer population may require different orders of priorities for the various performance parameters.
- The preferred levels of performance for diverse segments of the population may be different for various user population segments.
- The QoS profile of a customer segment may vary with time and it is essential for the service provider to ascertain the customer's changing requirements. The profile consists of order of priority of QoS parameters as well as the preferred levels of performance for each parameter.

6.1.3 Choice of QoS parameters

Sets of QoS parameters are designed to be understood by the users of various telecommunications services. However, subsets of these parameters can be selected for use in different circumstances. For example, a specific parameter might be relevant for many users in some countries or markets but the same parameter might not be of relevance in others, e.g., call set-up time could be pertinent in an all-analogue network but not on an all-digital network.

Therefore, users, customers, regulators, service providers, network operators and other parties interested in the use of QoS parameters may decide which parameters should be used in their particular situation with the cooperation of the relevant parties.

This decision should take account of:

- The precise purpose for which the parameters will be used.
- The quality and performance as expected by the users of state-of-the-art technology.
- The usefulness and relevance of the parameters from the users' perspective.
- The degree to which the parameters will provide a reliable comparison of performance.
- The cost and resources needed in order to measure and report each parameter.

All these aspects will influence the decision on the kind of parameters (quality criteria to be examined) and the number of parameters (granularity of quality analysis) to be chosen for a specific purpose.

However, even though parties may design their own set of QoS parameters according to their needs, the usage and application of internationally agreed upon parameters should be aimed at. For the determination of additional parameters, it should be considered to use already existing standards as a basis for further work.

6.1.4 Application of QoS parameters

A common application of QoS parameters will be the monitoring of telecommunication services and cross-checking whether quality objectives/goals have been met. In order to set up useful and meaningful quality objectives, it is especially important to take into account on the one hand, the areas of application and the technical potentials of the parameters and, on the other hand, the resources and costs for measuring the parameters.

QoS parameters can also be used by service providers to manage and improve how they offer their services, as well as by the customers to ensure that they are getting the level of quality according to their contractual agreements. They may also be used in call-minute trading, where price is determined by volume and quality grade. Another application of QoS parameters is that they can be used by regulatory authorities for defining quality levels for regulatory purposes of interconnection and interoperability aspects of networks and services.

QoS parameters are used to assess the quality of certain aspects of a service. Depending on the objective of the quality assessment, appropriate parameters with the desired granularity of quality evaluation may be determined. Quality of service parameters may also be selected to measure the overall quality of a service as perceived by the user. Thus, the range of usage of QoS parameters may range from an in-depth quality assessment to a simple assessment of the general perception of a service.

6.2 Identification of user's QoS criteria

Before defining QoS parameters, the relevant QoS criteria relevant to the users must first be identified. For this purpose, three models (Tables 1, 2 and Figure 1) are presented in this clause.

The basic approach of the models is to provide a matrix or table; by filling in each field of the matrix or table, quality criteria can be identified and allocated to functional elements of the service. The intention is to establish a list with all (relevant) aspects that might have an influence on the quality of service. The models are applied by various means like expert consultations, questionnaires, face-to-face and telephone interviews, analysis of complaints or case studies.

The first model (universal model) illustrates the generic categories under which all QoS criteria may be grouped. Thus, most, if not all, QoS criteria may be grouped under performance criteria, aesthetic criteria, presentational aspects and ethical aspects. The QoS criteria for any telecommunication service may be determined by an iterative process of evaluating the issues for each of the cells formed by these four categories against the functional elements of a service. The functional element of a service is a uniquely identifiable segment of a service, which collectively comprises all features of a service.

The second model (performance model) is predominantly suitable for services based on the legacy network, both terrestrial and wireless.

The third model (four-market model) is more suited for multimedia services offered on IP-based network.

Appendix III gives examples of QoS criteria to illustrate the use of these models.

Depending on the granularity of the QoS criteria to be identified, the number of criteria for a given service may be specified. For example, for basic POTS as many as 43 QoS criteria have been identified using the model in Figure 1. However, in practice as few as 10-13 criteria are adequate for management of the service for most of the population.

All models or a combination of these models may be used for a particular service to enable most, if not all, QoS criteria to be identified. For a particular purpose, a selection of QoS criteria may be chosen from the list identified.

6.2.1 Universal model

This model (shown in Table 1) is generic as well as conceptual. In this model all QoS criteria may be grouped under four categories, performance, aesthetic, presentational and ethical. With breaking down a service into uniquely identifiable functional elements, it is shown that QoS criteria may be reached at for each of the cells arising out of the resulting matrix. The objective is to provide a structured approach and the template in the model should facilitate this activity.

Each functional element of the service is cross-checked against the four predefined quality components and criteria. There is no fixed list of functional elements on the y-axis because the nature and number of elements depend on the service under investigation and could change with the service chosen. An example of applying this model is shown in Appendix III.

Functional elements comprise all the uniquely identifiable components of the service that, put together, cover all the functional aspects of the service. These elements essentially cover the product life cycle from the provision of the service to the end of its life.

By going through each cell of the matrix, the quality criteria of a service may be determined. It may be necessary to indulge in an iterative process and to check relevance before determining one or more set of quality criteria.

One functional element may need to be considered in more than one column. All cells may not be populated for every element. In the end, the model produces a list of functional elements of the telecommunication service with associated quality criteria. These may then be specified as parameters with suitable measures, where necessary, to represent indicative values.

The models in Table 2 and Figure 1 are an expansion of the portion of the model comprising performance criteria and functional components. The model in Table 2 is a direct expansion of this portion. The model in Figure 1 uses a different concept. However, the results obtained fulfil the determination of QoS criteria of a service. These models are explained in more detail in clauses 6.2.2 and 6.2.3.

The QoS criteria obtained from application of this model for a particular service may be defined as parameters as explained in clause 6.3.

The elaboration of adequate definitions and measurement methods for the quality parameters to measure the quality criteria is not part of the model. This has to be done in a subsequent separate step. This may be done by taking existing parameters in standardization as they are already defined or one can take them as a basis and use modifications. It may also be necessary to define new parameters. Further details can be found in clause 6.3.

Table 1 – Universal model

	Quality components and criteria			
	Performance criteria	**Aesthetic criteria**	**Presentational aspects**	**Ethical aspects**
Functional elements				
1. ... 2. ... 3. ... ... n. ...				

Performance criteria: Criteria covering technical and operational elements inherent to a telecommunication service. The criteria are used to assess the characteristics of these elements, the way how they perform and meet the expected results and modes of operation. Performance criteria may be quantitative or qualitative or a combination of both. (The performance component of the above model is further elaborated in Table 2 and Figure 1.)

Aesthetic considerations: Criteria and considerations related to the ease of interaction between the user and the telecommunication service/product and the sensual perception of the service/product by the user. Examples of aesthetic criteria are ergonomic considerations, simplicity, functionality and clarity of design, optimum use of resources, style, etc. The aesthetic quality criteria are less quantifiable than the performance criteria; however, these play an important part in how an entity is held in esteem or otherwise.

Presentational aspects: Criteria determining the quality aspects of the manner in which a service is marketed or supplied to the customer. Examples of presentational aspects are: service surround; packaging of entity to the user; customization of bills; tariff packages/options, etc.

Ethical aspects: Criteria associated with how a service or product is offered to the user. These aspects may be classified as quality components, such as acceptable use of labour (evidence of lack of exploitation of labour) and 'green' issues. Examples of ethical aspects are conditions for cutting off services, subsidies for the poor and the disabled, services for the disabled, etc.

6.2.2 Performance model

This model is more suited for determining the performance criteria of a telecommunication service. The objective is to provide a structured approach to analyse the performance aspects in detail. The benefit of this model is that the quality criteria identified can be easily transferred into QoS parameters since it is very detailed and close to the understanding of network performance parameters and management functions. Thus the definitions and measurement methods of the QoS parameters can be expressed on commonly used and well-understood technical terms.

Table 2 – Performance model

		Service quality criteria						
		Speed 1	**Accuracy 2**	**Availability 3**	**Reliability 4**	**Security 5**	**Simplicity 6**	**Flexibility 7**
Service function								
Service manage-ment	Sales & pre-contract activities 1							
	Provision 2							
	Alteration 3							
	Service support 4							
	Repair 5							
	Cessation 6							
Connection quality	Connection establishment 7							
	Information transfer 8							
	Connection release 9							
Billing 10								
Network/service management by customer 11								

The model is basically a matrix with a list of service functions on the y-axis and quality criteria on the x-axis. The service functions are uniquely identifiable performance elements of a service, which when put together, cover most, if not all, aspects of a telecommunication service. For each service function, it can be determined what kind of quality criterion is applicable to it by going through the 77 cells of the matrix. This is illustrated in Table 2.

Each cell of the matrix is investigated in an iterative process. All cells may not be populated for every service function. The number of cells to be populated depends upon the kind of service under investigation or upon the desired granularity of the quality criteria. It would be rare for all cells to be populated for any one function.

After determining the quality criteria, quality and performance parameters can be defined as described in clause 6.3.

6.2.3 Four-market model

This model (in Figure 1) is especially suited for multimedia services since the separation between the transport and service layer is taken into account. There is a complex chain of actions for multimedia services, from content creation, service management, delivery network and customer equipment.

Different parties may be in charge of transport, provision and content and the supply of terminal equipment. Thus the overall quality of a service (as perceived by the user) is a combination of different elements that are working independently of each other. Therefore a model is needed that allows for a separate investigation of these different elements and identification of respective quality criteria. This is achieved by the four-market model that consists of four components that are used to describe the different elements of the services that contribute to the QoS. The model enables to identify and categorize more easily the QoS criteria that are pertinent to this type of services.

For a given telecommunication service, the model can be used to focus on each of the four components separately and to identify quality criteria. It is not necessary to analyse all components. Depending on the aspects of a service under consideration, it may be sufficient to only identify quality criteria of one or more components.

After determining the quality criteria, quality parameters may be defined as described in clause 6.3.

An overview of the model and explanation of the four components is given in Figure 1.

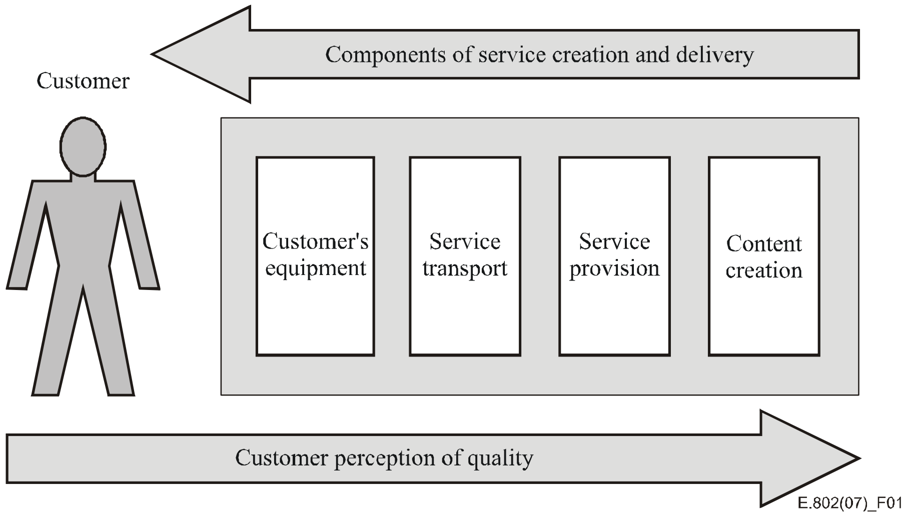


Figure 1 – Four-market model

Customer's equipment: All kinds of equipment that is needed by the user to gain access to the network and thus the service. This equipment consists of personal computers, television sets, set-top boxes, video recorders, modems, multimedia kiosks, etc. Not only the hardware but also the software needed for correct operation of the equipment has to be taken into account.

Service transport: All kinds of telecommunication networks that are used for the distribution of telecommunication services like terrestrial (fixed and wireless) and satellite broadcast networks.

Service provision: All activities and functions related to the packaging, presentation and management of telecommunication services.

Content creation: All activities related to the generation, distribution and packaging of content that is offered via a telecommunication service.

Appendix III lists the QoS criteria for a multimedia service obtained using this model.

6.3 Conversion of QoS criteria to QoS parameters

Quality criteria identified from one or more of the above models have to be converted into quality parameters before they can be used to express quantitatively or qualitatively the QoS of telecommunication services. This is done in order to exactly specify the scope of the quality to be determined and to allow for reproducible measurements and comparable quality figures. The aim is to arrive at a harmonized set of quality parameters that can be used for evaluating the quality of a telecommunication service and to allow for the comparison of different service offers in a specified population.

A quality criterion, which is usually descriptive, needs to be tightly defined both in its scope and boundary to enable an unambiguous understanding of its functionality. This is necessary for use by all parties associated with the use of this performance criterion. When specified as such, the criterion becomes a parameter.

It is essential that QoS parameters are defined so that there are no ambiguous interpretations and any service provider may be able to carry out the measurements. Where parameters are defined quantitatively, explicit calculating rules have to be recommended. When they are defined qualitatively, e.g., helpfulness of operator services, a suitable definition based on opinion rating has to be recommended.

When converting a quality criterion into a parameter, there are usually different possibilities for the specification of the definition and measurement method. For example, a user may state the number of outages she/he may put up with over a period of one year. This may be specified as a parameter as:

a) number of outages over a cumulative period of one year = n;

b) a period in which the user cannot use the service for more than = 'b' units of time;

c) maximum duration of any one outage = not more than 'p' seconds;

d) minimum duration between outages = 'q' hours.

A single, all or a combination of the specifications may be chosen; the decision depends on the intended use and purpose of the parameter.

Therefore, the following main applications for QoS parameters should be considered when specifying the parameters:

- They characterize the quality level of a service being offered, and ultimately the user satisfaction. QoS parameters represent subjective and user-perceived quality expressed in numeric ratings.
- They may be used as the basis for SLAs as well as in a public manner for promotion purposes.
- Service providers and network operators may use these parameters as the basis for planning purposes. It may be necessary to decompose the end-to-end performance parameters into network element performance parameters for planning purposes. NP parameters derived from the end-to-end QoS requirements or planning targets may not be of interest to the users.
- QoS parameters may be used to specify the delivered quality (the third element in the four viewpoints of QoS).

6.3.1 QoS parameter definition and measurement method

The definition of a parameter determines the range of application and thus the intended use of the parameter. Therefore, the scope of the parameter needs to be precise and well-defined. There is also a close dependency between the scope of a parameter and the possible and most suitable measurement methods.

Thus, the definition of parameters and the recommended measurement method have to be seen as a package. Even if the scope of two parameters is the same, a difference in measurement methods may lead to a situation where different aspects of the QoS criteria are measured. In this case, the information provided by the parameters would not be the same.

Therefore, in order to ensure repeatable and comparable performance values, an aligned definition/scope and a recommended method of measurement need to be specified for QoS parameters. A universally agreed measure enables comparisons to be made between various organizations within a country as well as internationally.

6.3.2 Prioritization of QoS parameters and establishing preferred values

Besides identifying quality criteria, a prioritized list of parameters and the preferred performance values are required to complete the user's QoS requirements.

NOTE – The elaboration of comprehensive guidance on the prioritization of parameters is still under study. The following text provides a list with basic aspects that should be considered.

Different segments of the population could have differing priorities for the QoS parameters or there may be different quality expectations for different pricing levels. Moreover, each segment may require a preferred value of performance for each parameter. Profiling the segments of the user population requiring their own order of priorities and preferred performance values would complete the mapping of user requirements of QoS.

To identify these groupings, if not already known, a start may be made by finding out the QoS requirements of the user groupings of the Standard Industrial Classification (SIC). The service provider may identify further uniquely identifiable groupings.

Besides a segmentation based on different user groups and applications, it may be necessary to take geographical aspects into consideration, for example, if QoS parameters are intended to be used for monitoring trends in different developed areas of a country.

An issue to be considered is a reasonable number of criteria/parameters in order to achieve the right compromise between the number of parameters and a meaningful QoS evaluation. Too many parameters will bring unnecessary high costs while too few will result in overlooking some key aspects.

When QoS parameters are defined or measured, it has to be done according to the target study area. Therefore, it is very important that the identification of the quality criteria is done carefully in accordance with the aim of the study and usage of the service and the results weighted according to the type of user.

6.4 Publication of QoS parameters

Parties who publish QoS statistics in accordance with this Recommendation should provide explanatory text in order to facilitate the understanding of the statistics. If the statistics is based on parameters that require knowledge of basic technical and operational background of the provision and function of telecommunication services, this information should also be provided. It may be assumed that a reader who is interested in comparable QoS statistics and parameters is willing to become acquainted with technical and operational aspects.

It is important to choose the scope of parameters so as to minimize the risk that measurement results could be misinterpreted. It is recommended that reference be made to the document which describes the measurement method, so that the background of the definitions and measurement methods are readily available. A fair and justified comparison of the published data of the different services offered, i.e., quality aspects of different telecommunication services, is only possible if the data is strictly used according to the scope of the defined QoS parameters.

Parameters should not need to be measured with high precision and published in ways which suggest that measured differences are perceptible to users when they are not.

The auditing of the processes, in accordance with international standards, the determination of raw data and the presentation of results for publication are recommended for establishing the credibility of the published QoS data. The [ISO/IEC Guide 62] and [ISO/IEC Guide 65] may be considered for this purpose.

The frequency of publication may be left to the individual nations and/or the service providers. The publication media may also be left to the individual organizations. However, for international comparisons, it is suggested that a 6-month or yearly interval should be considered for the publication of the delivered quality for each of the main services.

6.5 Practical issues when using QoS parameters

QoS parameters of a telecommunication service are normally specified in a way that they can be applied to numerous service offers of different providers in order to allow for comparison. So the definitions and measurement methods need to cover different technologies, technical implementations and business models, and therefore they are written in a more generalized manner. This should be kept in mind when determining and using sets of QoS parameters to produce quality statistics over a number of networks/services (e.g., for national comparisons).

For the preparation of comparison and benchmarking of different networks/services, it is important to be aware of the impact that the individual ways of implementation/application of technology and equipment of the network operator and service providers will have on the significance of the QoS parameters. This may have an influence on the measured data and may lead to an adoption of the measurement concept, post-processing of the data and presentation of the statistics of the quality campaign. Therefore the following aspects should be considered:

- Depending on the exact purpose and field of application of QoS parameters, different concepts may be followed: A parameter may be designed in order to explicitly measure the quality of a service aspect with high accuracy and thus it will provide precise results. Or a parameter is suitable for comparison of a wide range of service offers with less significant results.
- Measurement methods are triggered by certain technical processes and service events (physical parameters, protocol information, operational processes). These trigger points may vary or have tolerances. This can lead to the situation in which, with different implementations or use of different technologies, the results are not directly comparable even if the same quality criteria are measured (or intended to be measured).
- QoS parameters only provide a statistical representation of the service quality that a certain population of users is likely to perceive; they are not intended to provide quality statements for individual users (e.g., as used in SLAs).
- It is important to understand the context the parameters are used within, to be aware of the design concept of the parameters that has been followed and to know the underlying measurement and publication policy for producing final QoS statistics.

7 Measurement of QoS parameters

QoS parameters are measured either objectively by technical means (by measuring physical attributes of circuits, networks, network elements and signals) or subjectively (perceived QoS) via surveys and subjective tests amongst users.

Subjective measurements are performed in order to measure the QoS as perceived by the user. This of course is a time-consuming and expensive procedure. The results of subjective measurements often provide highly variable results that need to be carefully analysed. Therefore, objective measurements are often used where specific network-related technical parameters (network performance parameters) are measured, when those parameters can be correlated to the user's perception of QoS (either directly or by the use of models).

QoS parameters are user-oriented and end-to-end (i.e., service), while network performance parameters may or may not be end-to-end. While QoS and network performance parameters are different in nature and serve different purposes, it is clear that there exist intrinsic relationships between QoS and NP parameters, one having a direct or indirect, and sometimes even inverse, influence on the other.

Since the term QoS is a measure for "the degree of satisfaction of a user of a service", one would assume that ideally subjective measurement methods should be used to measure the quality of a service. However, subjective measurements bear the risk that individual opinions are overestimated and that human judgements and misunderstandings falsify the results. Therefore subjective measurements are complex and time consuming. So, wherever possible, objective measurements are preferred since they often provide a good correlation to the results of subjective measurements. Objective measurements of network performance parameters can be used to identify and examine specific network-related problems with QoS.

A QoS measurement policy has to take into account parameters influencing the resulting quality of a service including both ends of the communication and telecommunication network architecture aspects. Therefore, both objective and subjective measurement methods have to be considered to get the whole QoS picture.

Objective measurements are carried out in the case of network performance parameters and other QoS parameters where these can be quantified. Subjective measurements are carried out in the case of subjective aspects and also for quantifiable parameters to determine how the customers perceive the quality they think they receive.

NOTE – For a more detailed overview on measurements and further information, see also [ITU-T Hdbk QoS].

7.1 Objective measurements

Criteria like call set-up time, call failures and interruptions can quite easily be measured with appropriate probes in appropriate locations. Measurements can be made either on real traffic or on artificially generated traffic on public traffic or private networks.

Since QoS may be different with respect to location, the geography of the network should be taken into account for the measurements, particularly if the choice is not to monitor all parts of the network.

A compromise should be reached between the choice of sampling rates to reflect an adequate confidence in the measurements and the costs of taking these measurements. Optimization of the measurements may also need to focus on some key points of the network or to perform the measurements at the busiest hours of the day or week.

7.1.1 Intrusive measurements

This type of measurements is performed on artificially generated traffic and can provide more information since the traffic can be tailored to check almost everything. The drawback of intrusive measurements is to add traffic to the actual one and therefore to lead to additional costs and some possible disturbance.

7.1.2 Non-intrusive measurements

This type of measurements is performed on real traffic conditions and therefore is expected to give a more realistic vision of the QoS but its drawback is that some deficiencies might be missed since not all the possibilities are checked.

7.1.3 Use of models

Models attempt to map objective measures of network performance to subjective opinions. The objective measurements needed as input values for the mapping function are normally taken from INMD measurements. The customer opinion model for INMDs should be able to relate the network performance (as represented by the objective measurements such as speech level, echo loss, etc.) to customer perceived performance (represented by an opinion score).

7.1.4 Monitoring and analysis of signalling information

Objective measurements may also be based on the monitoring and analysis of signalling information. These measurements are performed on real customer live traffic. They are often based on counters or CDRs from network elements. But more and more, with the increase in complexity of networks and services, especially in mobile networks, the use of network-independent monitoring, based on non-intrusive Signalling System No. 7 (SS7) and IP probes, and exploiting the richness of signalling data, allows to provide more real-time and more service-related xDRs, KPIs/KQIs and alarms related to QoS.

The advantage of internal monitoring is that a large volume of records can be collected which allows day-to-day evaluation of network performance. The disadvantage is that this method does not have the capability of detecting tones or speech and therefore cannot present a complete representation of all call dispositions.

7.2 Subjective measurements

Subjective measurements are the only means to assess the user perception aspects of the QoS, e.g., those aspects that cannot be measured easily by technical means or that may be missed due to a reduced number of measurement points. This is the case for instance for billing accuracy, quality of customer care or relevance of the answer of the help desk.

Subjective measurements when compared to objective measurements could indicate whether improvements in the network or customer education are needed. However, due to the characteristics and individual variations of human judgement, subjective measurements should be carefully designed and it should be kept in mind that they may not always measure the projected quality aspects or produce reliable results.

7.3 Who should perform the measurements

If the QoS parameters are used by a service provider for its own purposes, e.g., SLAs, promotion purposes and service monitoring, the measurements will be performed by the provider itself or contract the measurements to another party. The service provider may wish to improve the confidence in the quality of the statistics, by having the measurements audited by an authorized body in accordance with international standards.

QoS measurements are also carried out in order to compare the quality provided by different service providers, to comply with quality requirements and to produce regular QoS reports. In most cases, this will be done for regulatory purposes but also independent organizations may be interested in quality statistics.

If a third party is involved, that is a party other than the affected service providers, there are in principle two ways to perform the measurements; direct and indirect measurements:

- Direct measurement – The third party, e.g., a regulatory authority, itself performs the measurements. That means that it is responsible to take all the necessary steps to conduct the measurements and to analyse the data in order to calculate the quality ratings of the parameters.
- Indirect measurement – The third party authorizes other parties to perform the measurement. This may be the service providers themselves or any other independent party, e.g., independent audit companies, organizations of certification.

When using indirect measurements, the quality information is obtained by the third party without intervening directly in the process. Thus it has to be considered whether the measurements should be certified. The certification of the QoS measurements have to be done by qualified independent organizations.

The advantages and disadvantages of the direct and indirect measurements can be seen in the table below:

Measurement		Advantages	Disadvantages
direct		High confidence in the information provided Immediate proactive action by the third party is possible (e.g., adoption of measurement methodology, additional parameters if needed)	High costs mainly if measurements have to be performed on a number of providers and services
indirect	certified	Confidence in the information provided	Another party is involved that has to be managed. (e.g., independent certification offices)
	uncertified	Low cost	Low confidence in the QoS statistics provided

One good commitment between cost and confidence of the information is to use indirect measurements (with certification) and to perform additionally direct measurements randomly.

8 Guidelines for defining quality objectives

8.1 General considerations

Quality objectives are used to determine minimum and maximum performance limits and the desired (optimum) performance level of QoS parameters. For each parameter, a reference value can be specified. However, for interoperability issues, mandatory parameters or international comparisons, it should be considered to use generally accepted reference values for the main services.

Depending on the QoS parameter under consideration, the reference value can consist of a threshold value (e.g., the performance should be better than a minimum threshold) or of an acceptable performance range. The final determination of a specific reference value depends on the kind of parameter (e.g., whether it is based on network performance parameters or subjective aspects), the technology involved and the kind of verification methodology used.

The intended purpose of the reference value should also be taken into consideration. Quality objectives can be used in order to report on the present quality of a telecommunication service, cross-checking whether quality obligations have been fulfilled or for setting targets in order to improve the quality of general available services within a certain time-frame.

Since the QoS parameters are focused on the user requirements with regard to quality, it should be kept in mind that the user must be able to understand the meaning of the reference value and be capable of comparing the (subjectively) perceived quality with the reference value. Thus, the end user's perspective should be considered before deciding for which QoS parameters quality objectives should be set and how they should be specified.

8.2 Defining initial quality objectives

If there is no quality reference – either in standardization or by experience – for a specific service available, one has to determine quality objectives from scratch. This process involves the following steps:

- The service under consideration must be analysed and the quality criteria and the resulting QoS parameters must be identified. Depending on the intended purpose, a set of QoS parameters that are thought of being of utmost importance must be determined. For these QoS parameters, quality objectives can be specified.

- In order to acquire information on the present performance of a service, a time period for measurements is set to collect data. Based on this data, a first impression on reasonable limits for the quality objectives can be obtained. The methodology used to collect data has to be clearly defined in order to eliminate whatever kind of doubt in the validity of the data obtained. This is especially important in a multi-operator environment.
- The user's perspective needs to be considered. Therefore surveys among users have to be conducted in order to assess the users' perception and demand of the service quality.
- In a conciliation process, the quality references obtained from the collected data (the service providers perspective) and the surveys (the user's perspective) need to be combined into final quality objectives.

8.3 Defining target values

Target values are determined in order to improve the quality of a service within a specified period of time. Depending on the service aspect that is subject for improvement, target values are fixed for specific QoS parameters.

When establishing targets, the following points should be considered:

- The target values should be realistic, i.e., the service provider should be capable of achieving the quality level within the fixed time period. Any improvement of quality is associated with investments and binding of resources. The efforts needed and the degree of improvement to be achieved should be well-balanced.
- The target values should be beneficial to the users, i.e., the QoS parameter targets should be set so as to be meaningful to the users and aim at quality aspects that are relevant to the users. They should be able to perceive easily an increase or decrease in quality. In this way, the accomplishment of the target can be verified by surveys, and problems can be identified in an early stage through user complaints.
- The target values should be based on well measurable QoS parameters allowing for a straightforward verification procedure. There should be clear objectives directly linked to network performance objectives or service operational aspects so that the accomplishment of the targets can be easily verified and failures can be dedicated to specific service/network elements.
- The establishment of target values should consider diversities of services. One target value that is appropriate for a specific situation may not be good for another. If target values are determined for services available in huge areas and/or many customers, the intrinsic diversity of the service shall be analysed. Diversities may be presented, for example, in terms of geography, user expectation, social aspects, applications.
- The implementation stage of the service should be considered. Services that are in a transitory stage have to be treated in a different way than those whose operation is already in a stable phase. This may occur if new technology is introduced or technology is changed (e.g., GSM to WCDMA) or if a substantial rate of growing of the service in terms of users or infrastructure takes place.

8.4 Tuning quality objectives

In order to adopt the quality objectives to changes in technical development and user perception, and to verify their fitness for purpose, the values should be audited on a regular basis.

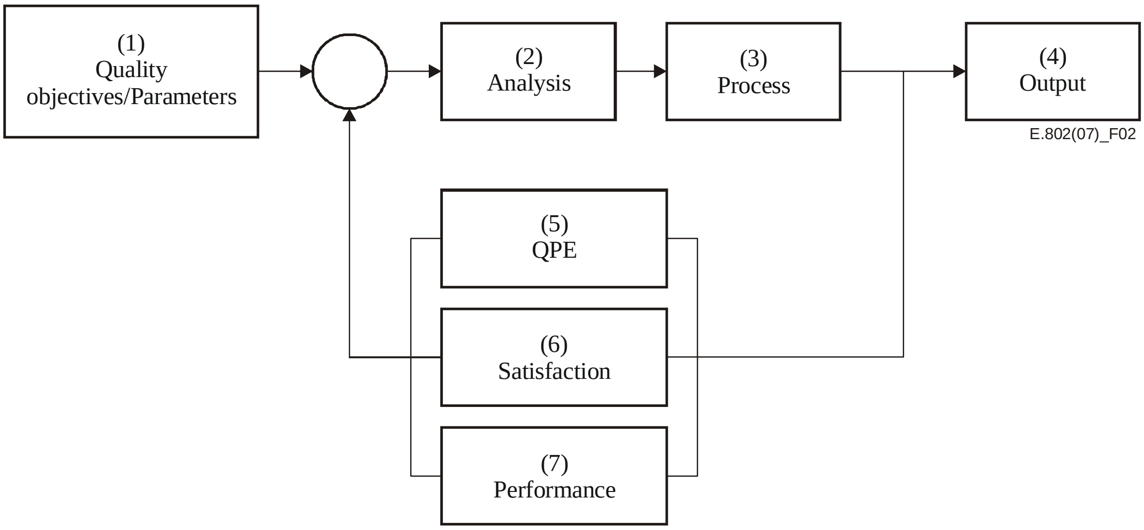
It should be cross-checked whether:

- the quality objectives reflect the user perception and expectation of quality;
- the originally determined initial quality objectives are still valid;
- the quality objectives need to be adjusted to reflect improvements in technology;

- additional quality objectives are needed to cover additional services or service elements;
- there are mismatches between the underlying QoS parameters and the intention associated with the quality objectives;
- the targets are still up to date, i.e., the target values should be reviewed constantly;
- the determined target values correspond to internationally agreed performance levels;
- the frequency of evaluation of parameters or target value is still appropriate concerning the type of service and the geographical area (region) under consideration.

The adjustment of quality objectives is in general terms a process of management of quality policy and, due to this, it involves a process of information feedback. Within this process, the particularities of each service, the effectiveness of the parameters or quality objectives in order to ensure a level of quality, the perception of customers and the information provided by service providers have to be taken under consideration.

Figure 2 illustrates the process of managing a quality policy:



1) Quality objectives: The service provider (or a regulatory body) first defines the target values to be applied to the telecommunication service. The respective parameters have already been created and the quality objectives were established within a close observation of the customer's requirements, historical evolution, benchmarking, etc.
2) Analysis: Initially, the action represented by this block is not applied. This block represents the action where studies, reflections, weights and comparisons are done taking into consideration the quality objectives established and the information provided by the feedback channels.
3) Process: This block represents the process developed by the service provider in order to deliver a service with a level of quality as specified by the quality objectives.
4) Output: It is the quality effectively delivered to the customer by the service provider as the result of the quality process.
5) QPE (Quality Perception): This feedback channel provides information on the perception of quality delivered by the service provider to the customers.
6) Satisfaction: This feedback channel provides information on the customer's level of satisfaction with the provided service.
7) Performance: This feedback channel provides information on the quality parameters as a result of the process of each service provider (the values reached, evolution in the period observed, difficulty to measure, etc.).

Figure 2 – Process of managing quality policy

8.5 Verification of QoS objectives

Quality objectives for telecommunication services are set by determining quality objectives for deliberately chosen QoS parameters. It has to be verified on a regular basis whether the objectives are met, i.e., a service is working within its stated quality limits. To achieve this, a verification campaign that specifies the required procedures and operations needs to be elaborated. The accomplished campaign will result in a report that allows for a decision in terms of conformity or non-conformity.

The verification campaign is performed by measuring QoS parameters and checking whether the associated quality objectives are met. The QoS parameters and quality objectives are well known and have been predetermined according to the guidelines in this Recommendation. Thus there are clearly defined measurement methodologies available. Based on this information, measurement samples may be taken. The remaining task is to specify a sampling methodology that ensures that the results adequately reflect the QoS as it is perceived by the user.

There are two basic methods of sampling:

- Simple sampling/random sampling – It consists of the selection of a random sampling of a universe, where the probability is equal for everyone.
- Cluster sampling – The service/network under consideration is divided into clusters and a few of these (often randomly selected) clusters are sampled.

Since performance and quality may be different with respect to location, the geography of the network carrying the service should be taken into account for the measurements, particularly if the choice is made not to monitor all parts of the network. In addition, the number and temporal distribution of the measurement samples taken need to be considered.

The selection of representative samples is a process that is heavily influenced by specific technical and operational conditions of the measurement task. Therefore a detailed guidance cannot be given.

The following aspects should be considered when setting up a verification campaign:

The verification campaign should be dedicated to the specific services/parameters that are to be measured, i.e., the particularities need to be considered.

In cases where the measurements are performed by parties other than the network provider (third parties), it must be ensured that all relevant information that may influence the results is at hand. Normally only the network operator is aware of the specific technical characteristics of the network access, software implementations, routing, etc. Depending on the parameters measured, often additional information is needed in order to obtain comparable results. This is especially valid for measurements of connections over more than one network.

Samples should ensure that traffic variations during the measurement period are taken adequately into account.

Depending on the kind of network(s) under study, i.e., fixed, mobile or a combination of both, network specific characteristics and user behaviour need to be taken into account.

Network performance measurements are often based on the analysis of signalling information or on tones. When using such information, the measuring party must know in detail what type of signalling system and/or tones are used in the network(s) under consideration. Especially any deviations to existing standards must be known.

Measurements of parameters such as call set-up time should take account of whether the calls are terminated on a user terminal or a function such as a mail box within the network. Such parameters will also be affected by some supplementary services (e.g., call forwarding). Moreover, the performance for different number ranges may be different, e.g., number translation services such as free phone and shared cost services may have increased call set-up times.

Optimization of the measurements may need to focus on some key points of the network or to perform the measurements at the busiest hours of the day or week.

In most cases, objective measurement methods are used as they can quite easily be measured via adequate probes in appropriate locations. Measurements can be made either on real traffic or on artificially generated traffic.

Both intrusive and non-intrusive methods are useful and can be combined. Besides active and passive measurement methods, performance and quality evaluations can also be based on the analysis of automatically stored signalling and protocol data.

It is obvious that there is a high correlation between the kind of QoS parameters, i.e., measurement method, and the sampling methodology finally chosen. Therefore, when specifying the verification campaign, it may likely be that different QoS parameters or even quality objectives are found to be more suitable than those previously chosen. The most satisfying solution may be found by an iterative process of defining parameters, setting quality objectives and specifying the verification campaign. However, for interoperability issues, mandatory parameters or international comparisons, the verification campaign should correspond to the generally accepted and agreed upon standards.

Annex A

Guidelines on selection of representative samples

(This annex forms an integral part of this Recommendation.)

Introduction

In some cases, especially in Africa 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. 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.

In these cases, the specification of QoS parameters and the desired targets are therefore also tied to penalties, where a service provider may be sanctioned accordingly for failure to comply with such specifications. Applying these sanctions can be experienced by regulatory authorities as difficult (see [b-ITU-T ESupp.9]), as service providers may argue the measured QoS results are not representative of their performance. There is then a need to carry out these measurements in such a way that they can be proven to reflect a service provider's "true" performance. The regulator's resources may not always allow for QoS measurement for the whole population of the service provider and consequently, only a subset (samples) of the service provider's activity will have to be used for this purpose. "Sample surveys are used to obtain information about a large population by examining only a small fraction of that population." [b-Rice]. When samples, instead of the whole population, are used to arrive at QoS measurements, selecting a statistically significant sample can ensure that the resulting QoS measurements reflect the service provider's true performance with a certain degree of confidence that will allow for such measurement to be admissible under the law of evidence.

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. This annex 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%.

A.1 Scope

This annex specifies a simple random sample as the sampling design (see clause A.2). Appendices IV and V contain additional information on the implementation of the sampling algorithm and on the use of sample-based QoS parameters.

A.2 Methodology for selection of representative samples

A.2.1 Sample size calculation

For populations that are large, Cochran [b-Cochran] developed the following equation, which yields a representative sample:

$$\boldsymbol{n_0 = \frac{Z^2 pq}{e^2}} \quad (1)$$

Where

n_0 is the sample size

Z ~~Z^2~~ represents the quantile of normal distribution, found in statistical tables, for a desired level of confidence (for 95% level of confidence Z = 1.96).~~represents the desired confidence level and the value of Z is found in statistical tables~~

e is the desired level of precision

p is the estimated proportion of the attribute that is present in the population

q is $1 - p$

Note that pq = degree of variability

Note that best international practice is to use the 95% level of a confidence with accuracy not exceeding 10%.

A.2.1.1 Study of the variation of the function of degree of variability (S^2)

$$S^2 = p \times (1 - p)$$

Whereith p: is the estimated proportion of the attribute that is present in the population

And then $p \in [0,1]$,

Knowing this, the function S^2 has a "flat optimum" for $p = 0.5$, which is $S^2_{max} = 0.25$ (Figure A.1) Then $S^2 \in [0,0.25]$ [b-Ardilly].

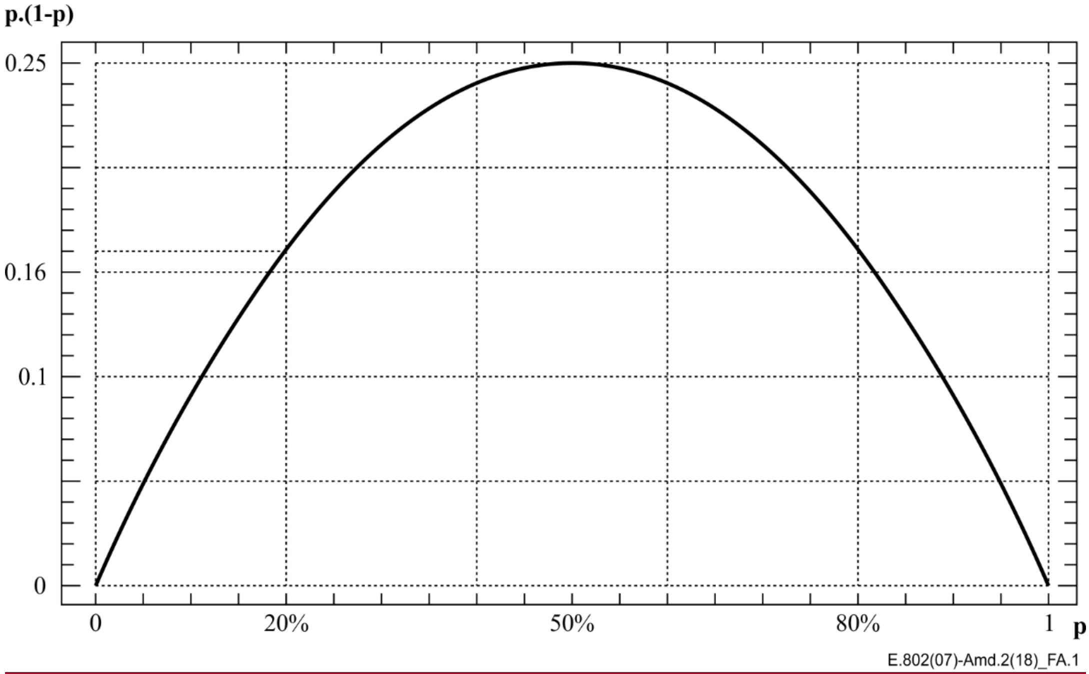


Figure A.1 – S^2 function curve

A.2.1.2 Value range of degree of variability:

In the case where proportion S^2 can be estimated according to proportion p, and if there is no idea about p, the pessimistic case is assumed where $S^2 = S^2_{max} = 0.25$. Then the sample sizes for 95% confidence level are as shown in Table A.1.

Table A.1 Sample size for S^2_{max}

Sample size (n) for precision (e) of:									
Confidence level	95%								
Degree of variability	0.25								
Precision level	±2%	±3%	±4%	±5%	±6%	±7%	±8%	±9%	±10%
Sample size	2401	1067	600	384	267	196	150	119	96

However, in the case of QoS/QoE campaign, *p* represents the proportion of failed/successful attempts, with an idea of the order of magnitude of the proportion according to previous QoS campaign or according to systems KPIs communicated by operators. Therefore, this case can be less pessimistic, and *p* is chosen as the highest/lowest value of proportion of failed/successful attempts.

In practice, the highest value of proportion of failed attempts varies between 10% and 20%, then $S^2 \in [0.09,0.16]$ which represent a low amplitude interval for S^2. Tables A.2 and A.3 show that the sample size decreased 36% in the case of $S^2 = 0.16$ (Table A.2) and 64% in the case of $S^2 = 0.09$ (Table A.3), for the same precision level in comparison to the case of S^2_{max}:

Table A.2 Sample size for $S^2 = 0.16$

Sample size (n) for precision (e) of:									
Confidence level	95%								
Degree of variability	0.16								
Precision level	±2%	±3%	±4%	±5%	±6%	±7%	±8%	±9%	±10%
Sample size	1537	683	384	246	171	125	96	76	61

Table A.3 Sample size for $S^2 = 0.09$

Sample size (n) for precision (e) of:									
Confidence level	95%								
Degree of variability	0.09								
Precision level	±2%	±3%	±4%	±5%	±6%	±7%	±8%	±9%	±10%
Sample size	864	384	216	138	96	71	54	43	35

~~Using the above equation, different sample sizes for different levels of precision at the greatest level of variability (50%) and 95% confidence level have been calculated for a certain service provider A. The **degree of variability** in the attributes being measured refers to the distribution of attributes in the population. The more heterogeneous a population, the larger the sample size required to obtain a given level of precision and the less variable a population, the smaller the sample size. A proportion of 50% indicates a greatest level of variability.~~

~~The results are presented in Table A.1. According to clause 7.1, "A compromise should be reached between the choice of sample size that will reflect an adequate confidence in the measurements and the costs of taking these measurements". Thus, depending on the resources of the party performing measurements, Table A.1 gives different sample sizes that can be used if a 95% confidence level is desired in the results, with different levels of precision and assuming the highest degree of variability.~~

~~International best practice is to use the 95% confidence level with a maximum precision level of ±10; ETSI also recommends that "measurements must provide a relative accuracy of greater than 10% with a level of reliability of 95%". For example, if 96 sample measurements are carried out, you will be 95% confident that the true value of the QoS parameter lies within a range of ±10.~~

~~Table A.1 – Sample sizes~~

	~~Sample size (n) for precision (e) of:~~
~~Confidence level~~	~~95%~~

Degree of variability	0.5			
Precision level	±3%	±5%	±7%	±10%
Sample size	**1067**	**384**	**196**	**96**

A.2.2 Traffic variations of the service provider

As stated in clause 8.5, "samples should ensure that traffic variations during the measurement period are taken adequately into account." This is the distribution of the sample measurements during the verification campaign. To determine this distribution, it is recommended that a 12-month traffic, for example, total number of calls made on a network over a period of 12 months, be studied. The 12-month period has proven to be robust enough to account for volatile changes in the traffic. Figure A.2 depicts a 12-month distribution of traffic of a network distributed hourly.

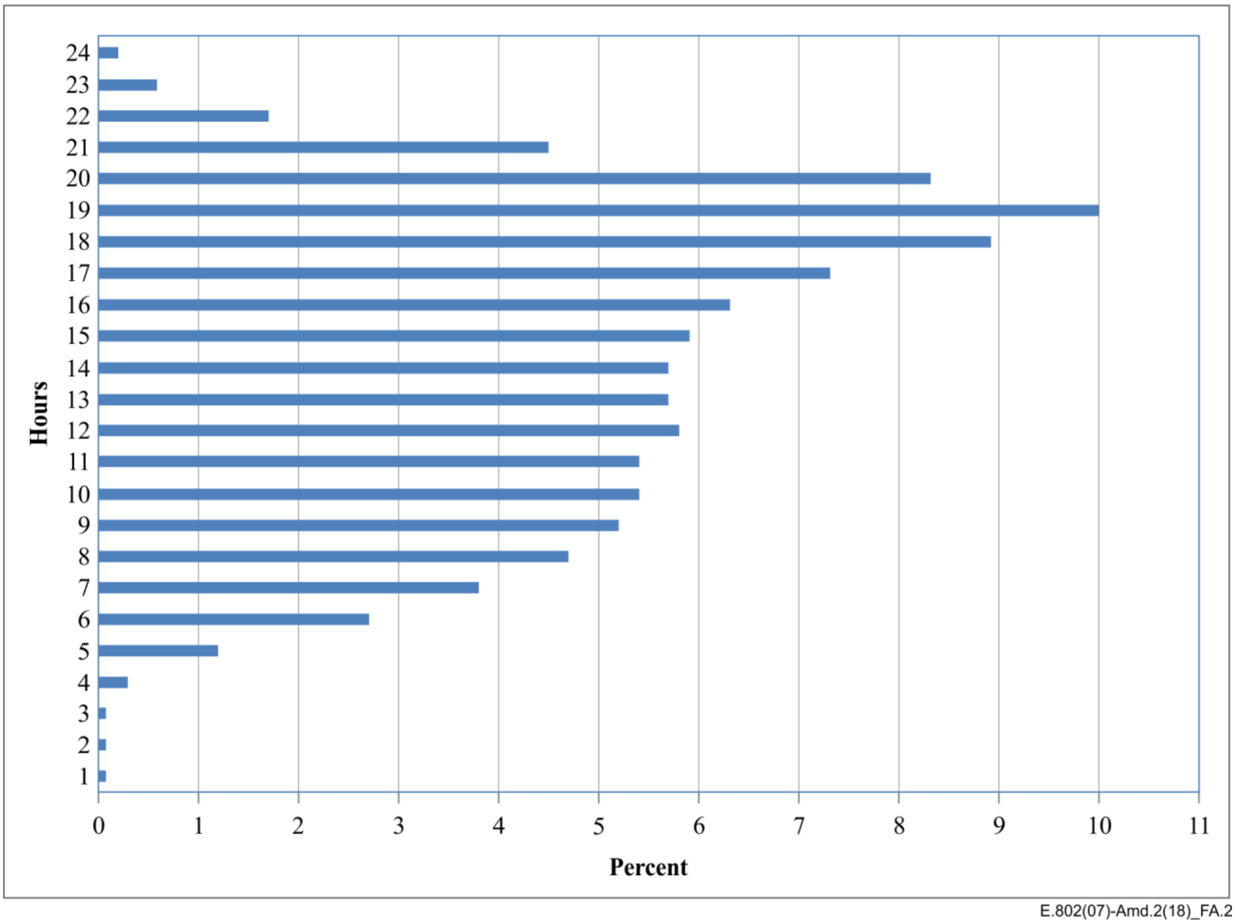


Figure A.2 – 12-month hourly traffic (call) pattern

A.2.3 Distribution of sample measurements matching traffic variations

Once the traffic pattern on a network is known, it becomes easy to determine how the sample measurements will be distributed in such a way that the different peak and off-peak periods in the traffic of a network whose QoS is to be verified are accurately reflected.

If a precision level, i.e., margin of error/sampling error, of 10% and a confidence level of 95% is sought, then using Equation (1), the calculated sample size will be 96 (Table A.1). To distribute the 96 sample measurements, the entire range of the call traffic was divided into non-overlapping groups using the binning algorithm (SPSS version 21) with a defined cut-off point at the mean and ±2 standard deviations. The analyses created four distinct groups within which sample measurements can be carried out/distributed. (Table A.4 shows the distribution of the 96 sample measurements, rounded up to 100 for practical purposes, and Figure A.3 shows a graphic depiction of the distinct groups).

Table A.4 – Distribution of sample measurements

Group	Range of hours	No. of hours	No. of measurements
1	11:01 pm – 5 am	6	2
2	5:01 am – 8 am & 10:01 pm – 11 pm	4	9
3	8:01 am – 5 pm & 9:01 pm – 10 pm	10	55
4	5:01 pm – 9 pm	4	34
Total sample measurements		**24**	**n=100**

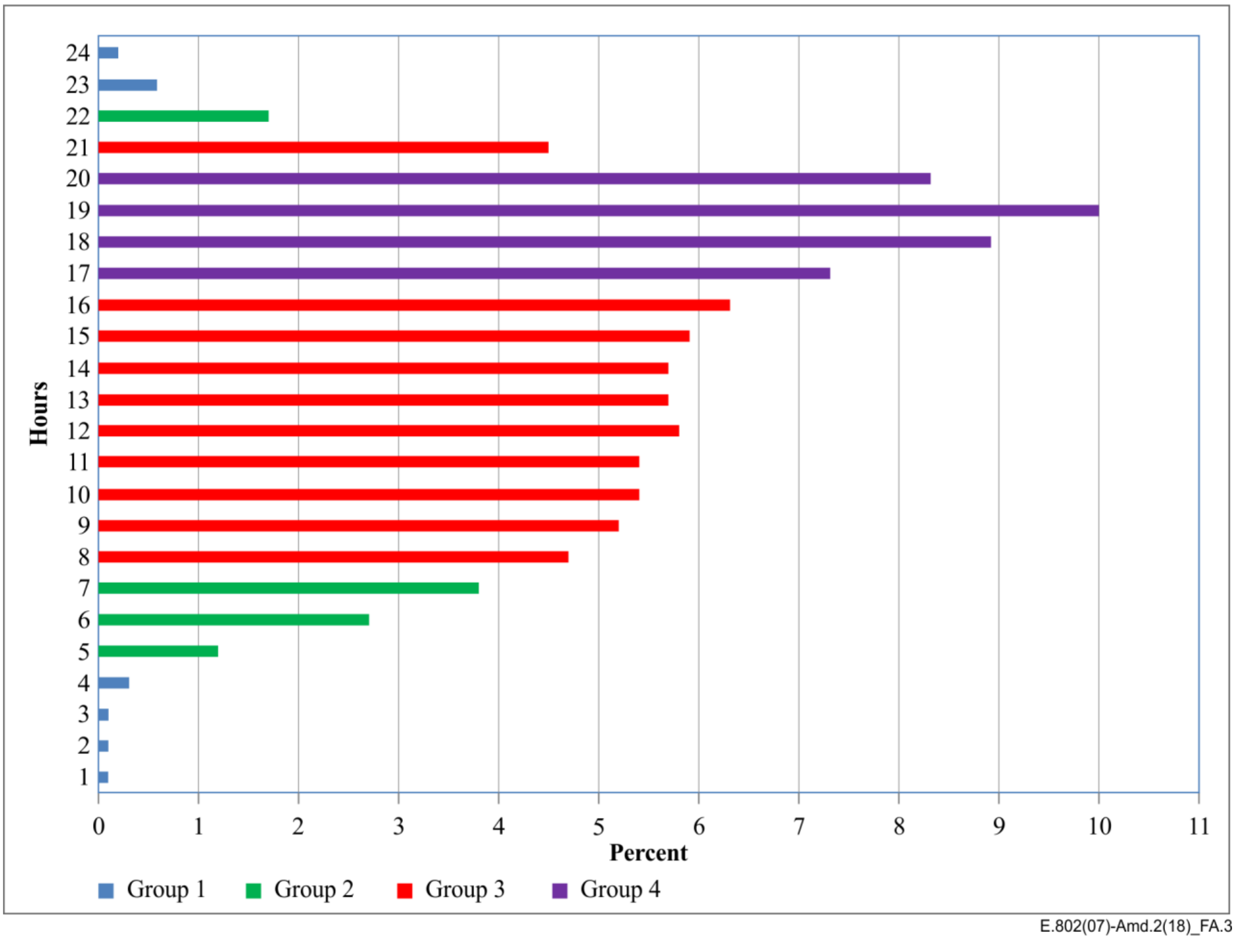


Figure A.3 – Four distinct groups in the 12-month hourly traffic

NOTE – The resulting QoS parameter from measurement should be based on all observations of the sample, e.g., all 96~100 observations as calculated from Equation (1) in this example, not on observations within any one single group. It should also be noted the assumptions of normality on which Equation (1) is based will hold when the total sample size calculated is 30 or greater. This is why it is important not to confuse measurements/number of observations within the groups for the total calculated sample size and to maintain the whole calculated sample in decision making.

Since traffic in each group is not significantly different, the time at which sample measurements are taken within a group will not affect the results; for example, the two measurements in Group 1 can be done at any time during the six hours available for measurement.

Appendix I

References for the development of QoS metrics and examples of QoS parameters

(This appendix does not form an integral part of this Recommendation.)

This appendix provides references to standards that are either ready to use QoS parameter definitions and measurement methods or useful for the elaboration of adequate parameters.

The intention is not to provide a comprehensive list of QoS parameters and measures but to assist parties in determining parameters for QoS measurements and reporting.

I.1 Examples of QoS parameters

Table I.1 gives a list of QoS parameters that are currently available in standardization:

Table I.1 – Examples of QoS parameters

Service	QoS parameter	Reference
Applicable to any service	Supply time for fixed network access Supply time for Internet access Proportion of problems with number portability procedures Fault report rate per fixed access lines Fault repair time for fixed access lines Response time for operator services Response time for directory enquiry services Response time for admin/billing enquiries Bill correctness complaints Prepaid account credit correctness complaints Bill presentation quality Frequency of customer complaints Customer complaints resolution time Customer relations Professionalism of help line	ETSI EG 202 057-1
Voice telephony (and voiceband related services like fax, data transmission and SMS)	Unsuccessful call ratio Call setup time Speech connection quality Fax connection quality Data rate of dial-up access to the Internet Successful SMS ratio Completion rate for SMS End-to-end delivery time for SMS	ETSI EG 202 057-2

Table I.1 – Examples of QoS parameters

Service	QoS parameter	Reference
Mobile services	(Voice telephony parameters as listed above also apply) Unsuccessful call ratio Dropped call ratio Coverage	ETSI EG 202 057-3
Internet access	Login time Data transmission speed achieved Unsuccessful data transmissions ratio Successful log-in ratio Delay (one-way transmission time)	ETSI EG 202 057-4

I.2 Development of QoS metrics

A comprehensive and detailed analysis of existing standards, terms and concepts can be found in the [ITU-T Hdbk QoS]. The references given there provide a sound basis for the development of QoS metrics and parameters. Important network performance related parameters, terms and concepts and other measures that are useful to develop the necessary measurement methods are listed.

For specific guidance on measures for emerging packet-based networks and technology, the following ITU-T Recommendations provide substantial information: [ITU-T G.1020], [ITU-T G.1030], [ITU-T G.1040], [ITU-T G.1050], [ITU-T O.211], [ITU-T Y.1540] and [ITU-T Y.1541].

Appendix II

Quality objectives

(This appendix does not form an integral part of this Recommendation.)

This appendix provides quality objectives for various telecommunication services where available. These values are not normative but represent commonly accepted quality requirements for end-to-end services that are achievable when using state-of-the-art technology.

Guidance on specific performance and QoS parameters for various telecommunication services that can be used as a reference for determining minimum quality requirements and objectives is given below.

NOTE – Most reference values given cover aspects of information transfer and connection establishment and release. In order to ensure adequate performance of services over interconnected networks, there are several Recommendations dealing with these aspects. But for operational and maintenance aspects of the end user access to the service, e.g., availability, fault rate and billing, there are no generally recommended limits as it is up to the network/service operator to decide on performance levels.

II.1 Voice telephony and voiceband services

Since voice services are very sensitive to variations in delay and transmission quality (information loss and transmission impairments), special care needs to be taken to ensure an adequate quality.

ITU-T Rec. G.109 defines five categories of speech transmission quality from mouth to ear for 3.1 kHz handset telephony across networks in terms of "user satisfaction". These categories are tied to the so-called R-values of the E-model, a transmission rating model for assessing the combined effects of variations in several transmission parameters that affect conversational quality of 3.1 kHz handset telephony.

Table II.1 – Definition of categories of speech transmission quality (from ITU-T Rec. G.109)

R-value range	Speech transmission quality category	User satisfaction
$90 \le R < 100$	Best	Very satisfied
$80 \le R < 90$	High	Satisfied
$70 \le R < 80$	Medium	Some users dissatisfied
$60 \le R < 70$	Low	Many users dissatisfied
$50 \le R < 60$	Poor	Nearly all users dissatisfied
NOTE 1 – Connections with R-values below 50 are not recommended. NOTE 2 – Although the trend in transmission planning is to use R-values, equations to convert R-values into other metrics, e.g., MOS, %GoB, %PoW, can be found in Annex B/G.107.		

Detailed information on delay requirements specific to voice telephony can be found in ITU-T Rec. G.114. Guidance on one-way delay for voice over IP is given in Appendix II/G.114.

ITU-T Rec. G.114 provides guidance on the effect of end-to-end one-way delay (sometimes termed latency), and an upper bound one-way network delay. While it is recommended that a one-way delay of 400 ms should not be exceeded for general network planning, it is important to appreciate that highly interactive tasks (e.g., many voice calls, interactive data applications, video conferencing) can be affected by much lower delays. The effects of delays below 500 ms on conversational speech are estimated using a curve derived from the E-model (ITU-T Rec. G.107).

For mixed traditional telephony and VoIP based services over IP and PSTN architectures, [ITU-T E.470] should be consulted.

II.2 Services over packet-based networks

[ITU-T G.1010] defines a model for multimedia quality of service (QoS) categories from an end-user viewpoint. By considering user expectations for a range of multimedia applications, eight distinct categories are identified, based on tolerance to information loss and delay. These categories form the basis for defining realistic QoS classes for underlying transport networks, and associated QoS control mechanisms.

[ITU-T G.1010] can be used to determine quality objectives for services provided over packet-based networks. The basic performance objectives of [ITU-T G.1010] are reproduced in Tables II.2 and II.3.

Table II.2 – Performance targets for audio and video applications (transported from Table I.1/G.1010)

Medium	Application	Degree of symmetry	Typical data rates	Key performance parameters and target values			
				One-way delay	Delay variation	Information loss (Note 2)	Other
Audio	Conversational voice	Two-way	4-64 kbit/s	< 150 ms preferred (Note 1) < 400 ms limit (Note 1)	< 1 ms	< 3% packet loss ratio (PLR)	
Audio	Voice messaging	Primarily one-way	4-32 kbit/s	< 1 s for playback < 2 s for record	< 1 ms	< 3% PLR	
Audio	High quality streaming audio	Primarily one-way	16-128 kbit/s (Note 3)	< 10 s	<< 1 ms	< 1% PLR	
Video	Videophone	Two-way	16-384 kbit/s	< 150 ms preferred (Note 4) < 400 ms limit		< 1% PLR	Lip-synch: < 80 ms
Video	One-way	One-way	16-384 kbit/s	< 10 s		< 1% PLR	

NOTE 1 – Assumes adequate echo control.

NOTE 2 – Exact values depend on specific codec, but assumes use of a packet loss concealment algorithm to minimize effect of packet loss.

NOTE 3 – Quality is very dependent on codec type and bit-rate.

NOTE 4 – These values are to be considered as long-term target values which may not be met by current technology.

Table II.3 – Performance targets for data applications (transported from Table I.2/G.1010)

Medium	Application	Degree of symmetry	Typical amount of data	Key performance parameters and target values		
				One-way delay (Note)	Delay variation	Information loss
Data	Web-browsing – HTML	Primarily one-way	~10 KB	Preferred < 2 s /page Acceptable < 4 s /page	N.A.	Zero
Data	Bulk data transfer/ retrieval	Primarily one-way	10 KB-10 MB	Preferred < 15 s Acceptable < 60 s	N.A.	Zero
Data	Transaction services – high priority e.g., e-commerce, ATM	Two-way	< 10 KB	Preferred < 2 s Acceptable < 4 s	N.A.	Zero
Data	Command/ control	Two-way	~1 KB	< 250 ms	N.A.	Zero
Data	Still image	One-way	< 100 KB	Preferred < 15 s Acceptable < 60 s	N.A.	Zero
Data	Interactive games	Two-way	< 1 KB	< 200 ms	N.A.	Zero
Data	Telnet	Two-way (asymmetric)	< 1 KB	< 200 ms	N.A.	Zero
Data	E-mail (server access)	Primarily one-way	< 10 KB	Preferred < 2 s Acceptable < 4 s	N.A.	Zero
Data	E-mail (server to server transfer)	Primarily one-way	< 10 KB	Can be several minutes	N.A.	Zero
Data	Fax ("real-time")	Primarily one-way	~10 KB	< 30 s/page	N.A.	$< 10^{-6}$ BER
Data	Fax (store & forward)	Primarily one-way	~10 KB	Can be several minutes	N.A.	$< 10^{-6}$ BER
Data	Low priority transactions	Primarily one-way	< 10 KB	< 30 s	N.A.	Zero
Data	Usenet	Primarily one-way	Can be 1 MB or more	Can be several minutes	N.A.	Zero

KB kbyte
MB Mbyte
NOTE – In some cases, it may be more appropriate to consider these values as response times.

Appendix III

Examples for the usage of the three models

(This appendix does not form an integral part of this Recommendation.)

This appendix provides examples for the usage of the three models. The examples are tentative. They do not claim to be outright; other parties may come to different results and conclusions when applying the models.

III.1 Universal model

Usage of the universal model for a mobile telephony service:

	Quality components and criteria			
	Performance criteria	**Aesthetic criteria**	**Presentational aspects**	**Ethical aspects**
Functional elements				
1) Hardware (terminal equipment)		Ergonomic design of handset usability		Disposal and ecological aspects
2) Service usage	Connection set-up and release Transmission quality Fault repair time Service availability		Customization of service features Customization of billing and payments Bill presentation quality	Security features
3) Contract	Supply time			
4) Customer relations	Hotline availability Response time Complaint resolution			Disabling mobile set when reported stolen

Performance criteria are further elaborated in III.2 by means of the performance model.

III.2 Performance model

Usage of the performance model for a mobile telephony service:

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

III.3 Four-market model

Usage of the four-market model for music streaming and download service:

Content creation:

- suitability of content;
- technical quality of original content;
- popularity of content and artists;
- repurposing of original content to a specific codec format (e.g., Ogg Vorbis) with minimum distortion;
- piracy and IPR aspects.

Service provision:

- ease of navigation to required music;
- security;
- fair contracts;
- pricing (value for money) and method of charging;
- customer care.

Service transport:

- bandwidth;
- latency;
- jitter and error;
- contention;
- round-trip delay [server + application + network];
- distortion.

Customer equipment:

- ease of selection and playback;
- ease of navigation and downloading;
- storage capacity;
- quality of playback;
- ergonomic considerations of devices.

Appendix IV

Sample calculator

(This appendix does not form an integral part of this Recommendation.)

IV.1 Sample calculator – R implementation

This clause demonstrates a sample calculator that readily implements the sampling methodology of clause A.2. This calculator code is in clause IV.2 and the code files that need to be saved on the user's computer can be found in the electronic attachment to this Recommendation.

First install the R base program and then install its GUI (graphical user interface) called RStudio. Here are the links to the two programs respectively:

1. R Base Program
https://cran.r-project.org/bin/windows/base/
(For MS Windows users. R also runs on a wide variety of UNIX platforms and MacOS)

2. RStudio
https://www.rstudio.com/products/rstudio/download/

After installing RStudio, launch it. On the R console, type **getwd()** to see the current working directory and/or **setwd()** to set the directory to the one in which you've downloaded the files. (*Note that folder name on Windows will use either forward slashes or double back slashes as shown in Textbox 6-2). Once the working directory is known, unzip the zip folder that contains Sample Calculator program files and save them in that directory. While still connected to the internet, on the console type: **install.packages("lattice")**. This is a graphics package used to draw bar charts, which will be used to analyse traffic variations (traffic patterns) of the service provider for which QoS is to be verified.

IV.1.1 Distribution of total network traffic

To determine the particular traffic (e.g., calls) pattern of a network to be verified, save a 12-month traffic data as a csv file, in the same folder as the sample calculator files. The calculator has been programmed to read data organised as in Figure IV.1. Mock data (sampletraffic.csv) used for demonstration in this appendix has also been provided with the sample calculator files to get the user started.

YEAR	MONTH	DAY	HOUR	EVENT	EVENT COUNT	VOLUME

Where

- YEAR: base year from which to determine traffic variations on the network
- MONTH: month in which event occurred
- DAY: day of month of event
- HOUR: hour of day in which event occurred
- EVENT: event on the network, e.g., call, SMS or data event
- EVENT COUNT: number of events (calls, SMSes, data sessions) in that Hour
- VOLUME: for calls – the unit of measure should be seconds, for SMS – SMSes made in that hour, and for data – the unit of measurement should be bytes.

Figure IV.1 – Organisation of 12-month traffic data for determination of traffic variations

To begin analysis of the traffic pattern on the calculator, on the R console, type **getwd()** to see the current working directory and/or **setwd()** to set the directory to the one in which the program files have been saved. To execute the calculator type **source("main.r")**<Enter>, followed by **main()**<Enter> and then follow prompts (see Figure IV.2).

```
> getwd()
[1] "C:/Users/officer/Documents"
> setwd("C:\\Users\\officer\\Documents\\E802\\SampleCalc")
> source("main.r")
> main()
```

Figure IV.2 – Extract 1 from R console

The text in Figure IV.3 has been extracted from the R console and displays part of what will be visible as the user follows the prompts. For example, it will ask the user whether this is the first time run of the program, and whether to print both outputs and commands as the calculation continues. Further down in the next interactive session **>specs <-uspec(),** it will prompt the user to type in the name of the file that contains traffic data to analyse (one saved as a csv file, e.g., sampletraffic.csv), and the Event to analyse (e.g., calls) – this is the variable which will be used to compute the QoS parameter to verify.

```
Enter 1 for 1st-time/clean run of program, 2 for a re-ru
n & q to quit: 1
Enter 1 to print outputs & commands, 2 to print outputs
only & q to quit: 1

> specs <- uspec();
Starting Interactive Session!!
Enter data file name: sampletraffic.csv
Enter datagroup identifier: calls
Enter chart title: 12 Month Traffic (calls) Distribution
Enter chart x-axis label: percent traffic
Enter chart y-axis label: hours
Ending Interactive Session!!
```

Figure IV.3 – Extract 2 from R console

The result, which is the traffic pattern of a service provider over a 12-month period, will appear in the bottom right area as a plot; see Figure IV.4.

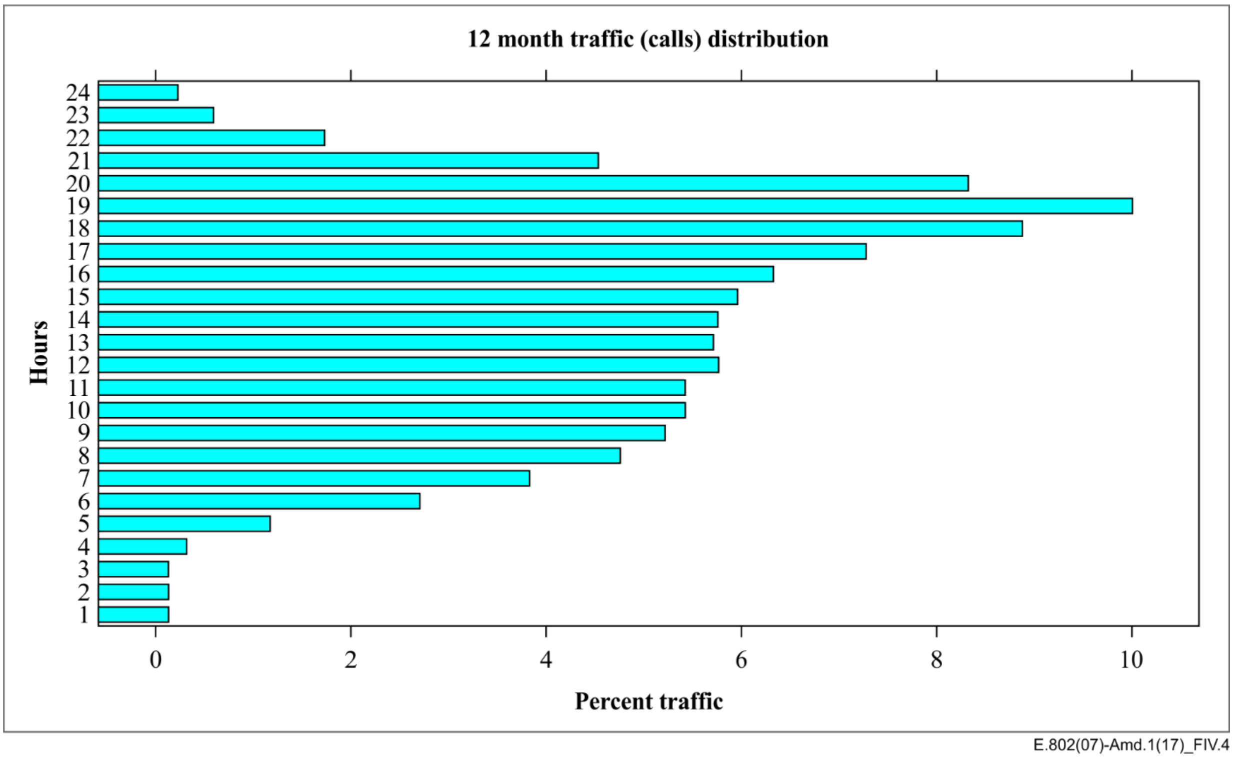


Figure IV.4 – 12-Month hourly traffic pattern

IV.1.2 Calculations and distribution of sample measurements

The calculator will by default calculate a sample from which the QoS parameter to be verified will be measured at 95% confidence level, ±10% level of precision and 50% level of variability. The calculator will however prompt the user to specify different parameters, if say a smaller precision level (i.e., sampling error) is preferred. To determine the distribution of sample measurements during a verification campaign, the calculator will perform the same binning algorithm to reveal the resulting groupings. Figure IV.5 displays the four distinct groups which will guide the distribution of sample measurements.

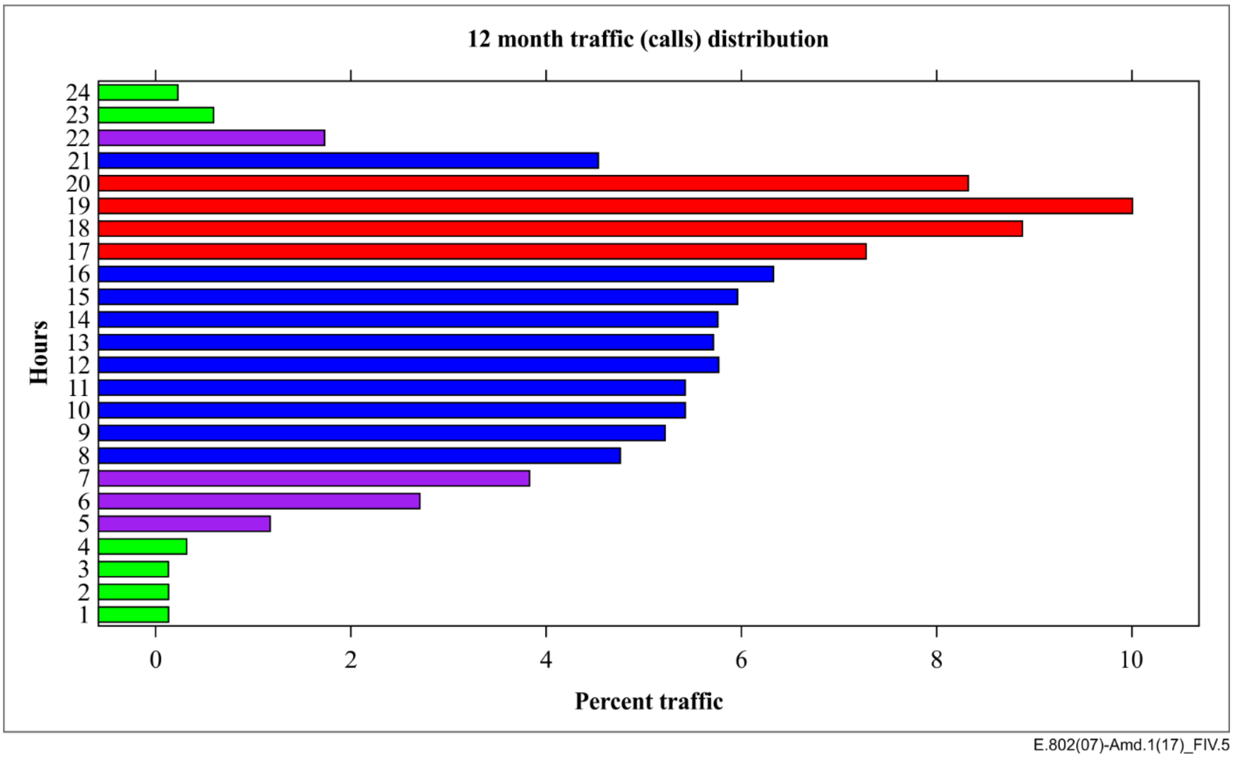


Figure IV.5 – Four distinct groups in the 12-month voice traffic

The resulting distribution of the 97 (which is approximately equal to the 96 calculated in clause A.2, save for rounding up) sample measurements are then distributed by the calculator as in Table IV.1. This table will appear on the calculator and also as an excel csv-file saved following prompts on the calculator. The last column, "Sampling Interval", simply provides a guide on the time intervals within which measurements can be taken. It should however be noted that, as stated in clause A.2.3, since traffic within each group is not significantly different, measurements can be taken at any time within each group.

Table IV.1 – Distribution of sample measurements

Group	Range.of.Hours	No. of. hours	Sample	Sampling.Interval
1	8:01 am - 5:00 pm & 9:01 pm - 11:00 pm	10	53.07611434	11 minutes
2	5:01 pm - 9:00 pm	4	33.39798809	7 minutes
3	5:01 am - 8:00 am & 10:01 pm - 11:00 pm	4	9.130179897	26 minutes
4	11:01 pm - 5:00 am	6	1.395717669	258 minutes
Total sample measurements			**n = 97**	

The QoS measurements which will be computed from samples calculated following the methodology specified in Annex A will be representative of the service provider's performance, with an acceptably small margin of error of ±10. In using QoS measurements computed from sampled data to monitor the network for quality trends and for comparing service providers, care should also be taken to consider if the differences in measurements computed are statistically significant (see Appendix V).

IV.2 Sampling algorithm – R implementation

The R programming language was used to implement the sampling methodology developed in Annex A. Several subroutines performing different tasks were written and called from the main script **sampling.r** (client code) or **rerun.r** (client code to rerun a portion of **sampling.r**).

The program was written in a modular fashion, with several subroutines (or functions) performing distinct tasks. These are then "sourced" and "called" (i.e., made available/usable), at a time when they are needed, from the client code. An immediate benefit of this approach is that the client code is very clean and streamlined and enhances code reusability. Another benefit is that, when a subroutine is modified to improve functionality, efficiency etc. this results in little or no change to the client code. Moreover, this building-block approach makes it easier to test the code extensively because each can be error-checked separately, greatly reducing bugs and run-time (execution-time) errors. One key feature of the program is that there is virtually no hard-coding, consequently improving reusability/adaptability for other uses. The program is also interactive, which has among other things, eliminated possibilities for hard-coding. This will therefore allow users to enter unique data during execution of the program, for example, chart labels and colours.

To use this program, the user must place all program and data files in the current working directory. The client code can then be executed in the following way:

- Navigate to the R console, type **source("main.r")**<Enter>, followed by **main()**<Enter> and follow the prompts.

Non-graphical outputs are redirected to a text file **output.txt** in the current working directory. In addition to these basic outputs, the sampling procedure is output into an editable **csv-file**. The relative sample sizes for each group are written correct to several decimal places. This leaves it up to the user to round these up as they wish and update the total sample size. Following this paragraph is the code used to implement the program is shown. The subroutines are shown in the order of appearance from top to bottom in the client code with **main.r** placed at the end to emphasize the importance of the client code, **sampling.r**.

sampling.r – Main script/client code for implementing the sampling methodology

```
sink("output.txt", append=FALSE, split=TRUE) #send output to output.txt
# 1. Load Required R Packages -----------------------------------------

# Ensure packages are installed first
library(lattice) #Load graphics package
rm(list=ls(all=TRUE)) #Clear workspace

#make main() available for a re-run of the program
source("main.r")

# 2. Enter global user specifications ---------------------------------
source("make.csv.r")
source("uspec.r")
source("changespec.r")
cat("\nFiles in the working directory\n")
list.files(getwd()) #display files in the working directory
specs <- uspec();
specs <- changespec();
attach(specs)

# 3. Initial Data Summarization and Visualization -----------------------

source("dataprep.r")
data <- dataprep(address,datagroup); attach(data)
par(ask=TRUE)
barchart(hours~traffic, main = title, xlab = xlabel, ylab = ylabel)

# 4. Extract Data Groups, Color-code and Visualize ----------------------
```

```
# (a) Prepare/Extract distinct groups
source("grouping.r")
group <- grouping(traffic)

# (b) Enter color specs on console and visualize data
source("colcd.r"); cols <- colcd(hours,group)
par(ask=TRUE)
barchart(hours~traffic, col = cols, main = title,
         xlab = xlabel, ylab = ylabel)

# 5. Sample Calculation and Distribution --------------------------------

source("samplecalc.r")
source("parscalc.r")
# Compute proportions of sample allocated to each group
gprop <- lapply(group,function(x) sum(traffic[x])/100)
gprop <- as.vector(gprop,mode="numeric")
sampledist <- parscalc()*gprop


# 6. Results Presentation/Tabulation ------------------------------------

source("tabfun.r")
cat("\nHour groupings\n")
group  #display groupings
cat("\nNote: There are",length(group),"groups\n")
res <- tabfun(group,sampledist)
cat("\nSampling procedure\n")
res # display table on console

sink() #close output file output.txt

#remove used objects from search path
detach(data); detach(specs)

# Export table to excel csv-file in the current working directory
filename <- readline("Enter output csv filename(e.g. file.csv): ")
filename <- make.csv(filename)
write.csv(res,file=filename,row.names=FALSE)
shell.exec(filename) # open file to view table
```

uspec.r - Specdata input/modification

```
uspec <- function(){
# USAGE:
#   Interactive subroutine that takes in user-specified data.
#   These specs will determine the datagroup/factor selected and
#   how graphics will be labelled.
# SYNTAX:
#   specs <- uspec()
# INPUT(S):
#   data file name  - name of the datafile
#   datagroup ID    - a unique ID to select a specific dataset/factor
#   chart title     - main title for bar chart
#   x-axis label    - label for the bar chart x-axis
#   y-axis label    - label for the bar chart y-axis
#
# Example:
#   Entering specs for the firs time?[y/n] y
```

```
#   Enter data file name: datafile.csv
#   Enter datagroup identifier: smses
#   Enter chart title: Network Traffic - SMEs
#   Enter chart x-axis label: SMS Traffic
#   Enter chart y-axis label: Hours
# OUTPUT(S):
#   specs    - list of user specifications

  alarm() #invoke system beep (might not work on RStudio)
  message("Starting Interactive Session!!")

  A <- readline("Enter data file name: ")
  A <- make.csv(A) #ensure correct filenaming
  A <- gsub(" ","",paste(getwd(),"/",A))

  #Print part of dataset for user to view
  cat("\nFirst 6 lines of the dataset. ",
      "Check datagroups under \"EVENT\".\n\n")
  show(head(read.csv(A))); cat("\n")

  B <- toupper(readline("Enter datagroup identifier: "))

  message("Specifications for traffic distribution chart")
  C <- readline("Enter chart title: ")
  D <- readline("Enter chart x-axis label: ")
  E <- readline("Enter chart y-axis label: ")

  message("Ending Interactive Session!!")

  return(list(address=A,datagroup=B,title=C,xlabel=D,ylabel=E))
}
```

make.csv.r – Text processor (adds .csv to file names)

```
make.csv <- function(fName){
# USAGE:
#   Subroutine for reading in a file name, verifying
#   that it has the .csv file extsion, coercing it
#   to the .csv file extension if needed, and outputing it.
# SYNTAX:
#   filename <- make.csv(fName)
# INPUT(S):
#   fName     - a text string
# OUTPUT(S):
#   filename  - file name with a csv file extension
#   read file name and break into char vector

  fAlias <- strsplit(fName, "")

  #determine if the .csv file extension is entered
  n <- length(fAlias[[1]])
  fEnd <- fAlias[[1]][seq(n-3,n,1)]
  checkVar <- sum(c(".","c","s","v")==fEnd)

  if(checkVar < 4){ #fix the file name
    fName <- gsub(" ", "", paste(fName,".csv"))
  }
  return(fName)
}
```

changespec.r – Specdata modifier

```
changespec <- function(){
# USAGE:
#   Interactive subroutine for modifying specific user-specified data.
# SYNTAX:
#   specs <- changespec()
# INPUT(S):
#   A decision prompt on whether to modify user-specified data or not
#   followed by prompts on the data to modify.
# Example:
#   Do you wish to change a spec/specs?[y/n] y
#   spec names: datafile,datagroup,title,xlabel,ylabel,or q to quit
#   Enter spec to change: datagroup
#   Enter new datagroup: voice
#   spec names: datafile,datagroup,title,xlabel,ylabel,or q to quit
#   Enter spec another to change: q
#   Once q is entered, the program terminates and modifies specs.
# OUTPUT(S):
#   specs    - list of user specifications
# DETAILS:
# It is a time-efficient way to modify user-specified data obtained
# through uspec(), without having to enter all the data required by
# uspec() each time. Also, one may want a re-run of the main script,
# sampling.r, for the other datagroups/factors without re-entering
# the entire user-specified data all over again.

  alarm() #invoke system beep (might not work on RStudio)
  message("Starting Interactive Session!!")

  decision <- readline("Do you wish to change a spec/specs?[y/n] ")

  if(decision=="y"){
    message(
      "spec names: datafile,datagroup,title,xlabel,ylabel,or q to quit")
    c.spec <- readline("Enter name of spec to change: ")

    while(c.spec != "q"){

      if(c.spec=="datafile"){
        dfile <- readline("Enter new datafile name: ")
         dfile <- make.csv(dfile)
        specs[[1]] <- gsub(" ","",paste(getwd(),"/",dfile))
      }else if(c.spec=="datagroup"){
        specs[[2]] <- toupper(readline("Enter new datagroup/factor: "))
      }else if(c.spec=="title"){
        specs[[3]] <- readline("Enter new chart title: ")
      }else if(c.spec=="xlabel"){
        specs[[4]] <- readline("Enter new x-label: ")
      }else if(c.spec=="ylabel"){
        specs[[5]] <- readline("Enter new y-label: ")
      }else if(c.spec=="q"){
        break
      }else{
        message("Error: Invalid spec name!!")
      }
     message(
      "spec names: datafile,datagroup,title,xlabel,ylabel,or q to quit")
```

```
      c.spec <- readline("Enter name of another spec to change: ")
    }
    message("Ending Interactive Session!!")
    return(specs)

  }else if(decision=="n"){

    message("Ending Interactive Session!!")
    return(specs)

  }else{
    stop("Wrong input! Enter y or n.")
  }
}
```

dataprep.r – Telecomms Traffic Data aggregator

```
dataprep <- function(address,datagroup){
# USAGE:
#   Subroutine for aggregating daily hourly data over the
#   time period covering the dataset.
# SYNTAX:
#   data <- dataprep(address,datagroup)
# INPUT(S):
#   address     - directory where a .csv data file is stored. Put
#                 the data file in the current working directory.
#   datagroup   - a unique ID to select a specific data set
# OUTPUT(S):
#   data        - aggregated hourly data (stored in a list)

  #Import and prepare the dataset
  lca <- read.csv(address, header = TRUE);
  attach(lca)

  data <- (EVENTS_COUNT[EVENT==datagroup])/1000 #Scale data to '000s

  #Data Summarization (Relative Frequencies)
  traffic <- rep(0,24)
  for(j in 1:24){
    traffic[j] <- 100*sum(data[seq(j,length(data),by = 24)])/sum(data)
  }

  #re-order hours from 1:00 a.m. to midnight
  traffic <- c(traffic[2:24], traffic[1])
  hours <- head(HOUR[EVENT==datagroup], 24L)+1
  sumdata <- list(traffic=traffic,hours=hours)
  detach(lca) #remove "lca" from search path
  return(sumdata)
}
```

grouping.r – Traffic-specific grouper

```
grouping <- function(traffic){
# USAGE:
#   Subroutine for grouping hours of similar traffic together.
#   The grouping criteria is to find data 1, 2 and >2 std
#   deviations in both directions from the mean
# SYNTAX:
```

```
#   group <- grouping(traffic)
# INPUT(S):
#   traffic - Hourly traffic levels
# OUTPUT(S):
#   group   - list of data groupings by hours

  #Determining cutoff points (1sd, 2sd & 3sd from mean)
  limit <- matrix(nrow = 3, ncol = 2)
  for(j in 1:3){
    limit[j,] <- c(mean(traffic)-j*sd(traffic),
                   mean(traffic)+j*sd(traffic))
  }

  #Intermediate Overlapping Groupings
  x <- list(rep(0,24),rep(0,24),rep(0,24),rep(0,24),
            rep(0,24), rep(0,24),rep(0,24),rep(0,24))

  for(i in 1:8){

    #Above-average traffic (1sd, 2sd & 3sd from mean)
    if(i==1){x[[1]] <- which(traffic>=mean(traffic))}

    if(i>1 & i<=4){x[[i]] <- which(traffic>=limit[i-1,2])}

    #Below-average traffic (1sd, 2sd & 3sd from mean)
    if(i==5){x[[5]] <- which(traffic<mean(traffic))}

    if(i>5){x[[i]]<-which(traffic<=limit[i-5,1])}
  }

  #Compute Distinct Groups
  group <- list(rep(0,24),rep(0,24),rep(0,24),
                        rep(0,24),rep(0,24),rep(0,24))
  for(j in 1:6){
    group[[j]] <- setdiff(x[[j]],x[[j+1]])
  }

  #exclude empty vectors
  group <- group[lapply(group,length)>0]
  return(group)
}
```

colcd.r – Color coder

```
colcd <- function(hours,group){
# USAGE:
#   Interactive subroutine for dynamic color-coding for
#   lattice bar charts. Takes as additional inputs the
#   outputs of the grouping() function.
# SYNTAX:
#   cols <- colcd(hours,group)
# INPUT(S):
#   group   - groupings by std deviations from mean
#   hours   - hours of the day (from 1 a.m.)
#   sl      - prompt on whether to input colors (y=yes,n=no)
#   clr     - a list of colors entered on the console separated
#             by comas or selected randomly (if sl==n);
#             e.g. green,yellow,black,red
# OUTPUT(S):
```

```
#   cols    - colors for each of the groups

  alarm() #invoke system beep (might not work on RStudio)
  message("Starting Interactive Session!!")

  decision <- readline(
         "Do you wish to select your own colors?[y/n] "
         )
  n <- length(group)
  if(decision=="y"){
    clr <- as.character() #initialize clr
    if(n==4){ #the case of 4 groups

      while(length(clr) != n){
        clr <- readline(
              "Enter colors for groups 1-4(comma-separated): "
              )
        clr <- strsplit(gsub(" ", "",clr,fixed = TRUE),",")[[1]]
        if(length(clr) < length(group)){ #error-checking
          message("Too few colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }
        if(length(clr) > length(group)){
          message("Too many colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }      }
      cols <- ifelse(hours%in%group[[1]], clr[1],
                     ifelse(hours%in%group[[2]],clr[2],
                            ifelse(hours%in%group[[3]],clr[3],clr[4])))

    }else if(n==5){ #the case of 5 groups

      while(length(clr) != n){
        clr <- readline(
              "Enter colors for groups 1-5(comma-separated): "
              )
        clr <- strsplit(gsub(" ", "",clr,fixed = TRUE),",")[[1]]
        if(length(clr) < length(group)){ #error-checking
          message("Too few colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }
        if(length(clr) > length(group)){
          message("Too many colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }
      }
      cols <- ifelse(hours%in%group[[1]], clr[1],
                  ifelse(hours%in%group[[2]],clr[2],
                      ifelse(hours%in%group[[3]],clr[3],
                          ifelse(hours%in%group[[4]],clr[4],clr[5]))))

    }else{# the case of 6 groups

      while(length(clr) != n){
        clr <- readline(
              "Enter colors for groups 1-6(comma-separated): "
              )
        clr <- strsplit(gsub(" ", "",clr,fixed = TRUE),",")[[1]]
        if(length(clr) < length(group)){ #error-checking
```

```
          message("Too few colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }
        if(length(clr) > length(group)){
          message("Too many colors. There are ",n, " groups. ",
                  "Enter ",n," colors.")
        }      }
      cols <- ifelse(hours%in%group[[1]], clr[1],
                  ifelse(hours%in%group[[2]],clr[2],
                      ifelse(hours%in%group[[3]],clr[3],
                         ifelse(hours%in%group[[4]],clr[4],
                           ifelse(hours%in%group[[5]],clr[5],clr[6])))))
    }

  }else if(decision=="n"){ #select random colors

    sst <- c(26,47,51,84,116,120,134,153,259,400,502,552,653)
    clr <- colors()[sample((sst),n)]

    if(n==4){ #the case of 4 groups

      cols <- ifelse(hours%in%group[[1]], clr[1],

                         ifelse(hours%in%group[[2]],clr[2],
                           ifelse(hours%in%group[[3]],clr[3],clr[4])))

    }else if(n==5){ #the case of 5 groups

      cols <- ifelse(hours%in%group[[1]], clr[1],
                  ifelse(hours%in%group[[2]],clr[2],
                     ifelse(hours%in%group[[3]],clr[3],
                         ifelse(hours%in%group[[4]],clr[4],clr[5]))))

    }else{# the case of 6 groups

      cols <- ifelse(hours%in%group[[1]], clr[1],
                  ifelse(hours%in%group[[2]],clr[2],
                     ifelse(hours%in%group[[3]],clr[3],
                        ifelse(hours%in%group[[4]],clr[4],
                           ifelse(hours%in%group[[5]],clr[5],clr[6])))))
    }

  }else{
    stop("Wrong input! Enter y or n.")
  }

  message("Ending Interactive Session!!")
  return(cols)
}
```

samplecalc.r – Sample-size Calculator

```
samplecalc <- function(cl=0.95,tol=0.1,prop=0.5){
# USAGE:
#   Subroutine for calculating sample size.
#   Based on Cochran (1963) sampling procedure.
#
# SYNTAX:
#   size <- samplecalc()  #uses default values
```

```
#   size <- samplecalc(input=...)
#   size <- samplecalc(cl,tol,prop)
# INPUT(S):
#   cl    - confidence level (proportion out of 100)
#   tol   - error tolerance level
#   prop  - proportion of attribute present in population.
#           The highest is prop = 0.5
# DETAILS:
#   Inputs may be scalars or arrays and defaults are
#   cl = 0.95, tol = 0.05 and prop = 0.5.
#
#   If one or two input values are specified the rest
#   will be assigned default values. e.g. for
#   samplecalc(tol=0.01), cl and prop will be defaults.
# OUTPUT(S):
#   size  - sample size

  size <- (qnorm((1+cl)/2)^2)*prop*(1-prop)/tol^2
  return(ceiling(size)) #rounded up (by convention)
}
```

parscalc.r – Interactive implementer of samplecalc()

```
parscalc <- function(){
# USAGE:
#   Subroutine for facilitating sample size calculation
#   through interactive sampling parameter specification
#
# SYNTAX:
#   size <- parscalc()
# INPUT(S):
# prompts - console prompts on how to calculate the sample
# See samplecalc() documentation for inputs
# DETAILS:
#   Inputs may be scalars or arrays and defaults are
#   cl = 0.95, tol = 0.05 and prop = 0.5.
#
#   If only one or two input values are specified the rest
#   will be assigned default values. e.g. for
#   samplecalc(tol=0.01), cl and prop will be assigned defaults.
# OUTPUT(S):
#   size  - sample size

  alarm() #invoke system beep (might not work on RStudio)
  message("Starting Interactive Session!!")
  decision <- readline(
         "Specify sampling parameters?[y-specify,n-defaults]"
         )

if(decision=="y"){

    message(
         "Input values in [0,1], or leave blank to use default(s)"
         )

    s.cl <- as.numeric(readline("Enter confidence level: "))
    s.tol <- as.numeric(readline("Enter error tolerance rate: "))
    s.prop <- as.numeric(
      readline(
```

```
          "Enter proportion of attribute present in population: "
               )
          )

    message("Ending Interactive Session!!")

    if(all(!is.na(c(s.cl,s.tol,s.prop)))){
      return(samplecalc(cl=s.cl,tol=s.tol,prop=s.prop))
    }else if(is.na(s.cl) & !is.na(s.tol) & !is.na(s.prop)){
      return(samplecalc(tol=s.tol,prop=s.prop))
    }else if(!is.na(s.cl) & is.na(s.tol) & !is.na(s.prop)){
      return(samplecalc(cl=s.cl,prop=s.prop))
    }else if(!is.na(s.cl) & !is.na(s.tol) & is.na(s.prop)){
      return(samplecalc(cl=s.cl,tol=s.tol))
    }else if(is.na(s.cl) & is.na(s.tol) & !is.na(s.prop)){
      return(samplecalc(prop=s.prop))
    }else if(is.na(s.cl) & !is.na(s.tol) & is.na(s.prop)){
      return(samplecalc(tol=s.tol))
    }else if(!is.na(s.cl) & is.na(s.tol) & is.na(s.prop)){
      return(samplecalc(cl=s.cl))
    }else{
      return(samplecalc())
    }

  }else if(decision=="n"){
    message("Ending Interactive Session!!")
    return(samplecalc())

  }else{
    stop("Wrong input! Enter y or n.")
  }
}
```

tabfun.r – Sampling Methodology Summarizer

```
tabfun <- function(group,sampledist){
# USAGE:
#   Subroutine for generating sampling procedure summary table.
#
# SYNTAX:
#   dframe <- tabfun(group,sampledist)
# INPUT(S):
#   hour ranges - text strings (semicolon-separated) of ranges
#                         of hours for each group. Based on group list
#                  from grouping()
# Example:
# Enter ranges of hours(semicolon-separated list): 09:01-10:00,
# 18:01-19:00,22:01-23:00;
# 06:01-09:00 & 19:01-22:00;23:01-06:00,10:01-12:00,
# 16:01-18:00;12:01-16:00
# N.B. Make sure commas are used only to separate different hour
# groupings.

# OUTPUT(S):
#   dframe      - a dataframe summarizing sampling procedure

  alarm() #invoke system beep (might not work on RStudio)
  message("Start Interactive Session!!")
```

```
  roh <- readline(
         "Enter ranges of hours(semicolon-separated list): "
         )
  roh <- gsub("; ",";", roh, fixed = TRUE)
  roh <- c(strsplit(roh,";")[[1]],"")
  n <- length(group)

  while(length(roh)-1 != n){#catch and fix errors
    message("Error: Too many or too few ranges! ",
    "There are ",n," groups. Enter ",n," ranges.")
    roh <- readline(
         "Enter ranges of hours(semicolon-separated list): "
         )
    roh <- gsub("; ",";", roh, fixed = TRUE)
    roh <- c(strsplit(roh,";")[[1]],"")
  }
  message("Ending Interactive Session!!")

  # Synthesis of Data
  smpl <- c(sampledist,sum(sampledist))
  grpno <- c(1:n,"Total")
  hrsavail <- c(as.vector(lapply(group,length),mode="numeric"), 24)
  intvl <- c(round(60*hrsavail[1:n]/sampledist),"")
  dframe <- data.frame(Group=grpno,Range.of.Hours=roh,
                       No.of.Hours=hrsavail,Sample=smpl,
                            Sampling.Interval=intvl)
  return(dframe)
}
```

rerun.r – Ancillary client code to **sampling.r**

```
sink("output.txt", append=FALSE, split=TRUE) #send output to output.txt
#This is alternative client code to sampling.r with slightly different
#user specs and avoid re-entering all of the data required by uspec()
#As such, it commences with changespec() and runs essentially the same
#code as sampling.r beyond that and appends the new output to #"output.txt"

# 1 & 2. Enter global user specifications -------------------------------

source("changespec.r")
specs <- changespec();
attach(specs)

# 3. Initial Data Summarization and Visualization -----------------------

source("dataprep.r")
data <- dataprep(address,datagroup); attach(data)
par(ask=TRUE)
barchart(hours~traffic, main = title, xlab = xlabel, ylab = ylabel)

# 4. Extract Data Groups, Color-code and Visualize ----------------------

# (a) Prepare/Extract distinct groups
source("grouping.r")
group <- grouping(traffic)

# (b) Enter color specs on console and visualize data
source("colcd.r"); cols <- colcd(hours,group)
par(ask=TRUE)
```

```
barchart(hours~traffic, col = cols, main = title,
         xlab = xlabel, ylab = ylabel)

# 5. Sample Calculation and Distribution --------------------------------

source("samplecalc.r")
source("parscalc.r")
# Compute proportions of sample allocated to each group
gprop <- lapply(group,function(x) sum(traffic[x])/100)
gprop <- as.vector(gprop,mode="numeric")
sampledist <- parscalc()*gprop

# 6. Results Presentation/Tabulation ------------------------------------

source("tabfun.r")
cat("\nHour groupings\n")
group  #display groupings
cat("\nNote: There are",length(group),"groups\n")
res <- tabfun(group,sampledist)
cat("\nSampling procedure\n")
res # display table on console

sink() #close output file output.txt

#remove used objects from search path
detach(data); detach(specs)

# Export table to excel csv-file in the current working directory
filename <- readline("Enter output csv filename(e.g. file.csv): ")
filename <- make.csv(filename)
write.csv(res,file=filename,row.names=FALSE)
shell.exec(filename) # open file to view table
```

main.r – Client code executor

```
main <- function(){
# USAGE:
#   Subroutine for executing the client code sampling.r
#   or rerun.r. It includes a feature for choosing how
#   to handle printing of outputs and commands.
# SYNTAX:
#   main()
# INPUT(S):
#   a decision prompt to choose what to display in the output
# OUTPUT(S):
#   objects output by sampling.r

  doquit <- function(){ #subfunction to handle quitting main()
    dec <- readline(
      "Are you sure you want to quit the program?[y/n] "
    )

    if(dec=="y"){#if user decides to quit
      message("User has aborted program!")

    }else{#if user reneges from quitting
      main2() #restart main()
    }
```

```
}

main.opt <- function(opt){
  #subfunction to implement main() options
  script <- c("sampling.r", "rerun.r")
  message(
    "Print Options:",
    "\n1 - to print outputs & commands",
    "\n2 - to print outputs only",
    "\nb - go back to program execution options",
    "\nq - to quit"
  )

  decision0 <- readline("Enter print option or quit: ")

  if(decision0=="1"){ #print outputs & commands

    source(script[as.numeric(opt)], echo=TRUE)

  }else if(decision0=="2"){ #print outputs only

    source(script[as.numeric(opt)], print.eval = TRUE)

  }else if(decision0=="b"){#for changing program execution

    main()

  }else if(decision0=="q"){

    doquit()

  }else{#error-checking for decision

    stop("Wrong input! Enter 1, 2, b and q.")

  }
}

#Beginning of execution of main()
message(
  "Program Execution Options:",
  "\n1 - for 1st-time/clean run of program ",
  "\n2 - for a re-run",
  "\nq - to quit"
)

decision <- readline("Enter program execution option or quit: ")

if(decision=="1"){ #if first-time/clean re-run preferred

  main.opt(decision)

}else if(decision=="2"){ #if not firs-time run/re-run preferred

  main.opt(decision)

}else if(decision=="q"){ #quitting/continuing program execution

  doquit()
```

```
  }else{#error-checking for decision

    stop("Wrong input! Enter 1, 2 or q.")
  }
}
```

Appendix V

Minimum required number of measurements for statistically significant QoS parameter evaluations

(This appendix does not form an integral part of this Recommendation.)

This appendix provides useful information on how to use QoS parameters calculated from samples instead of population data/real traffic data as the samples in Annex A.

V.1 Comparison of QoS parameters for benchmarking and quality trends

It is important to monitor if the quality thresholds have been met as well as to evaluate if the network performance degradation or improvements are statistically significant over time.

Therefore, it is recommended to use statistical significance for these kinds of comparisons, against a predefined quality threshold (QoS parameters) or to evaluate degradation or improvement trends. An example can be found in [b-ITU-T P.1401], which describes tests on statistical significance differences between proportions, which in Annex A would be between QoS achieved in different periods of verification.

V.1.1 Significance of the difference between proportions

Events representing proportions such as failures or success/completion ratios are described by binomial distributions of parameters (p, 1-p), where p is defined by the probability of failure or success/completion.

The analysis should be performed per each QoS time group. Let's assume that day 1, for example, the probability of success is $p1$ and day 2 it is $p2$. On each day $N1=N2=N$ samples have been collected.

The distribution of the differences of proportions from two binomially distributed populations with parameters ($p1$, 1-$p1$) and ($p2$, 1-$p2$) (where $p1$ and $p2$ correspond to the two compared proportions) can be approximated by a normal distribution for $N1=N2=N$ >30 [b-Spiegel] with the mean:

$$\mu_{(p1-p2)} = \mu(p1) - \mu(p2) = p1 - p2 = 0 \tag{1}$$

and standard deviation:

$$\sigma_{p1-p2} = \sqrt{\frac{\sigma(p1)^2}{N} + \frac{\sigma(p2)^2}{N}} \tag{2}$$

The null hypothesis in this case considers that there is no statistically significant difference between the population parameters $p1$ and $p2$, respectively $p1=p2$. Therefore, the mean, Equation (1), is zero and the standard deviation, Equation (2), becomes Equation (3):

$$\sigma_{p1-p2} = \sqrt{p \times (1-p) \times (\frac{1}{N1} + \frac{1}{N2})} \text{ = sqrt (2* p * (1-p) / N)} \tag{3}$$

where $N1=N2=N$ represent the total number of samples of the compared proportions $p1$ versus $p2$.

The variable p is defined by Equation (4):

$$p = \frac{N1 \times p1 + N2 \times p2}{N1 + N2} = (p1 + p2) / 2 \tag{4}$$

The normalized statistics Z_N is calculated as:

$$Z_N = \frac{p1 - p2 - \mu_{(p1-p2)}}{\sigma_{(p1-p2)}} \quad (5)$$

and compared to the tabulated z value of normal distribution for the 95% significance level of the two tailed test. If the calculated $Z_N > z$, then the compared proportions $p1$ and $p2$ are statistically significantly different, with a 95% significance level.

In the case in which the statistical significance test needs to be applied for a comparison against a predefined quality threshold, $p1$ can play the role of evaluated proportion (e.g., call set-up failure ratio) and $p2$ the role of the threshold (maximum allowed call set-up failure ratio).

V.1.2 Significance of the difference between means

Continues metrics such as call set-up time, signal strength, voice/video QoE can be described by normal distribution. Therefore, in this case the comparison is between the mean values of QoS metric.

Let's assume that day 1 the mean QoS = $m1$ is measured and day 2 the mean $m2$. The same number of samples $N1=N2=N$ have been collected on both days, and the standard deviations each day are $sd1$ and respectively $sd2$.

The distribution of the difference of the two means coming from two normal distributions is a normal distribution as well [b-Spiegel] with

$$M\,(m1\text{-}m2) = 0 \quad (6)$$

$$\text{Stdev}\,(m1\text{-}m2) = \text{sqrt}\,(sd1\text{^}2 + sd2\text{^}2)\,/\,N)$$

With mean M=0 for null hypothesis, meaning no statistical difference.

The normalized statistics Z_N is calculated as:

$$Z_N = (m1\text{-}m2 - M)/\ \text{Stdev}\,(m1\text{-}m2)$$

As in clause V.1.1, Z_N is compared to the tabulated z value of normal distribution for the 95% significance level of the two tailed test. If the calculated $Z_N > z$, then the compared means $m1$ and $m2$ are statistically significantly different, with a 95% significance level.

In the case in which the statistical significance test needs to be applied for a comparison against a predefined quality threshold, $m1$ can play the role of evaluated QoS mean (e.g., throughput) and $m2$ the role of the threshold (minimum required throughput).

Bibliography

[b-ITU-T E Suppl.9] ITU-T E-series Recommendations – Supplement 9 (2013), *Supplement 9 to ITU-T E.800-series Recommendations (Guidelines on regulatory aspects of QoS)*.

[b-ITU-T P.1401] Recommendation ITU-T P.1401 (2012), *Methods, metrics and procedures for statistical evaluation, qualification and comparison of objective quality prediction models.*

[b-ETSI EG 202] ETSI Guide 202 057-3 V1.1.1 (2005), *Speech Processing, Transmission and Quality Aspects (STQ); User related QoS parameter definitions and measurements; Part 3: QoS parameters specific to Public Land Mobile Networks (PLMN).*

[b-Ardilly] Pascal Ardilly (April 2006), *Les techniques de sondage*.

[b-Cochran] Cochran, W.G. (1963), *Sampling Techniques*, 2nd edition. New York: John Wiley and Sons, Inc.

[b-Rice] Rice, J.A. (2006), *Mathematical Statistics and Data Analysis*, 3rd edition, Thomson Brooks/Cole.

[b-Spiegel] Spiegel, M. (1998), *Theory and problems of statistics*, McGraw Hill.

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Printed in Switzerland
Geneva, 2017