# PERIMETER: A Quality of Experience Framework

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**Abstract.** Although Quality of Experience (QoE) is perceived as a subjective measure of a user's experience, it is the only measure that actually counts to a user of a service. For the success of the Future Internet, it is essential to identify, quantify and ultimately improve the perception of QoE for a user, in a given situation. PERIMETER pushes the boundaries to improve a user's experience by identifying a more user-centric network selection based on QoE preferences, high level rules and policies. With the fundamental focus on the user's preferences, PERIMETER will support generic QoE definition, QoE signalling, and QoE based content adaptation. This paper provides an insight into PERIMETER's QoE model and management system which are responsible for the definition, gathering, description and management of QoE-related parameters, indicators and enablers. This paper will demonstrate how PERIMETER will proceed beyond the state of the art in the QoE thematic research area and contribute to research of the Future Internet.

**Keywords:** Quality of Experience, Future Internet, User-Centric, Seamless Mobility, Always Best Connected

## 1 Introduction

Until now, the objectives of Quality of Service (QoS) have been the main area where specifications have been identified within the IETF [1] and the 3GPP [2]. QoS is a measure of performance at the packet level from the network perspective and performance of other devices involved in the service. QoS also refers to a set of technologies (QoS mechanisms) that enable the network administrator to manage the effects of congestion on application performance as well as providing differentiated service to selected network traffic flows or to selected users [3].

Quality of Experience (QoE), on the other hand, reflects the collective effect of service performances that determines the degree of satisfaction of a user with a service e.g. what a user really perceives in terms of usability, accessibility, retainability and integrity of the service. QoE is a measure of the end-to-end performance at the service level from the user perspective and an indication of how well the system meets the user's needs [3].

QoE is a concept, comprising of all the elements of a user's perception of a network and its performance and how that meets their expectations whilst QoS is intrinsically a technical concept in that it can be measured, expressed and understood in terms of networks and networks metrics [4]. QoS can be regarded as a subset of QoE. Although better QoS can lead to better QoE, it will not always guarantee user satisfaction. The ultimate goal of QoS should be to deliver a good QoE.

The major causes of user defections from a product or service are due to dissatisfaction with it, and the inability of the provider/operator to deal with this effectively. The provider/operator cannot wait for customer complaints to assess the level of its service quality. It is essential for them to devise a strategy to constantly measure QoE and improve it, as and when needed.

Furthermore, for the Future Internet to succeed and to gain wide acceptance of innovative applications and service, QoE objectives have to be met. Perceived quality problems might lead to acceptance problems, especially if money is involved. For this reason, the subjective quality perceived by the user has to be linked to the objective, measurable quality, which is expressed in application and network performance parameters resulting in QoE. Feedback between these entities is a prerequisite for covering the user's perception of quality.

PERIMETER aims to progress the QoE thematic research area by taking user-related and non-technical QoE factors into account and to provide a solid baseline for future user-centric mobility experimentation. This will be achieved through the following innovative and technological activities:

- Study of the parameters that define the "user-centric seamless mobility", resulting in new network selection algorithms for achieving QoE based Always Best Connected (ABC) paradigms.
- Development of a QoE framework that supports generic QoE definition, QoE signaling and QoE based content adaptation. As a consequence of this, proof-of-concept extensions of applications for user-centric QoE will be developed.

This paper begins with a description of current state of the art in QoE models, before detailing the approach used by PERIMETER to establish its goals. The paper concludes with a summary of the work of the PERIMETER consortium to date, before detailing its future challenges and direction in the QoE area.

## 2 QoE Model

QoE mainly relates to the subjective evaluations of service delivery by users. One of the best ways to evaluate this QoE is based on the users' feedback. For example, a user can provide simple feedback by filling in a form, or via a Living Lab methodology [5]. Since these methodologies are hard to apply, and imply a "posterior" approach, one must look at models able to *infer* the users' QoE, based not only on the feedback from them but also based on other technical parameters that can be measured by the users and on other users' preferences that can be configurable, such as cost associated to the network and/or security level.

### 2.1 QoE Model Parameters

Both technical and non-technical parameters must be considered in order to infer the QoE experienced by users. In order to have a complete QoE model, the following parameters should be considered.

- It is important that the end devices involved in the service/application are not the bottleneck of the communication; if the user is using a service that is not well dimensioned or the user's device is not able to support the application requirements, the user will not have a good QoE. Taking into account these premises, application server performance parameters, such as service setup latency and the capabilities of the users' device should be considered.
- Network performance parameters relate to the objective characteristics that can be measured in the network. The measures for IP Transfer Delay, IP Delay Variance and IP Loss Ratio should be considered [6]. The way to implement users' expectations in the network is by means of defining classes of services which allow the network operator to manage the traffic per aggregate. In order to support this decision, [6] define QoS classes of services (CoS) and take into account their network performance parameters at the IP packet level.
- An important parameter to be considered is the cost associated with the usage of a specific network. Type of charging, the cost connected to the usage of the network, restrictions related to the charging model, etc. should be factored in.
- Network access point performance parameters, such as availability, security, time to establish connections, packet loss during inter-access transition, etc must be taken into account.
- Security, such as protection against denial-of-service (DoS) attacks, reputation and the degree of privacy are also important.

### 2.2 Measuring Quality

Whilst there is not an actual standard to specify how to measure quality, [7] suggest three measurement methods as follows:

**Subjective:** Subjective approach consists on surveying people about how they perceive the quality. This provides quite accurate results. These techniques were mainly used in the evaluation of the VoIP. Most common procedure is calculating the MOS (Mean Opinion Score) obtained using the Absolute Category Rating (ACR) test that uses a 1 to 5 range. The experimenter allocates the following scores: Excellent = 5; Good = 4; Fair = 3; Poor = 2; Bad = 1. Although MOS were defined to measure audio quality, it is often used to indicate user satisfaction and is considered the QoE indicator. When the experimenter must assign values to the degradation they feel after the transmission of the media, it is called DMOS (Degradation Mean Opinion Score) and uses the Degradation Category Rating (DCR): Imperceptible = 5; Perceptible but not annoying = 4; Slightly annoying = 3; Annoying = 2; Very annoying = 1. Therefore, even though its origin was related to the subjective evaluation, the MOS metric is quite extended and there are multiple objective and subjective methods that aim to infer the MOS starting from objective measurements.

**Objective:** Objective measurement is based on using instrumental test equipment to calculate quality by analysing signals. There are techniques based on human perception such as PSQM (Perceptual Speech Quality Measure), MNB (Measuring Normalizing Blocks), and PESQ (Perceptual Evaluation of Speech Quality). There are techniques based on calculating signal parameters directly and others that correlate base signals and test signals.
**Indirect or predictive:** This consists of mapping QoS performance metrics onto user perceptible QoE performance targets. It is an on-real-time method. Steps are needed to identify the relationship between QoS parameters and QoE, and to measure QoS factors in the network to rate QoE of users.

By measuring quantifiable parameters, one can estimate the impact on the user. Based on the service classes definitions in [6], different weights are assigned to different parameter values and then QoE is calculated using a series of equations. Following this approach, an interesting model is the exponential model [8], which correlates a QoS network performance factor with the MOS value that can be considered the measurement of the QoE. In this model it is assumed that the subjective sensibility of the QoE is the more sensitive, the higher the experience quality is. Therefore the QoE depends on the current level of the QoE given the same amount of change of the QoS value. This can be expressed in the following way:

$$\frac{\partial QoE}{\partial p_{loss}} = -\beta \cdot \left(QoE - \gamma\right) \Rightarrow QoE = \alpha \cdot e^{-\beta \cdot p_{loss}} + \gamma \qquad (1)$$

This model is known as the IQX hypothesis and can be extended with more QoS network performance parameters [9]. By combining this IQX hypothesis with the most representative QoS parameters defined in [6], a specification for a QoE model can be formed.

### 2.3 Classes of Services

QoE is heavily related to the application [6]. Each application has its own associated requirements and associated users' perception of quality. For example, the parameters that influence QoE in messaging services could be delivery time, risk of non-delivery, and so forth, whilst for a streaming service it could be the initial delay, user-perceivable spatial artifacts, risk of preemption, etc. A QoE model needs to take the different CoS into consideration.

## 3 The PERIMETER Approach

One of PERIMETER's main objectives is to devise a framework based on which users are always in an ABC state. An important factor to achieve this is to gather information and generate a network switch, or handover, decision, in order to achieve the ABC goal. The ABC state is measured using QoE metrics. PERIMETER makes its decisions using information on the user's preferences, user's context (application under use, location, etc.), network performance parameters, other PERIMETER users'

QoE information and PERIMETER users' feedback. This approach is central to the user, or is deemed *user-centric*, because the handover decisions take into account all the aforementioned factors and based on that it provides the user with the best possible connection option.. The PERIMETER system architecture framework used to achieve this goal, is split into three "systems" as follows:

- The ***QoE Management System*** is responsible for handling, processing and taking decisions on the QoE-related parameters and indicators that are available at all levels from the networking infrastructure over the PERIMETER system.
- The ***QoE Delivery System (and related subsystems)***, also based on the information and decisions provided by the QoE Management System, executes all the actions necessary, such as handovers and mobility management frameworks, to achieve the QoE objectives set by the users through the expression of user policies.
- The ***PPA$^3$R system*** (Privacy Preserving AAA (Authentication, Authorization and Accounting) and Reputation) takes care of Authentication, Reputation and Charging issues and provides identity management, anonymization and pseudonimization services that will maintain users' global identity and associated preferences.

### 3.1 QoE Management System

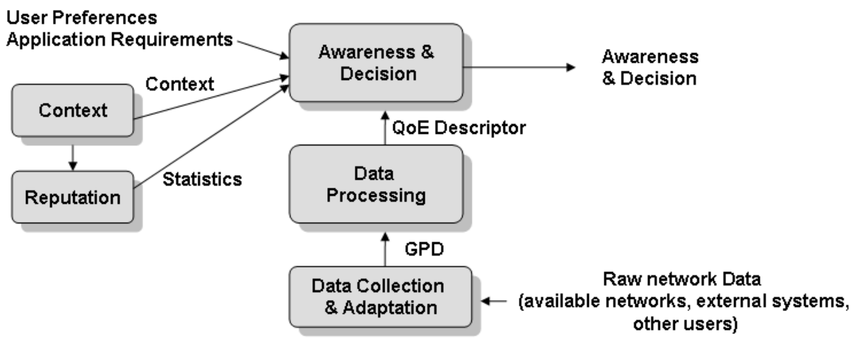


Fig. 1 QoE Management System

The PERIMETER QoE Management System, depicted in Fig. 1, is responsible for the gathering, description and management of QoE related parameters, indicators and enablers that are available at all levels from the networking infrastructure over the PERIMETER system. To achieve this, three main levels of functional entities are identified as follows: QoE Data Collection and Adaptation Function, QoE Data Processing Function and the Awareness and Decision Function.

#### 3.1.1 QoE Data Collection and Adaptation Function

The QoE Data Collection and Adaptation Function has the purpose of collecting data regarding QoE, such as QoS parameters, cost parameters, service availability, security and privacy support levels, etc., from the networks available to the PERIMETER infrastructure. An issue here is that QoE related data will be collected from heterogeneous networks and may be in different, and possibly incompatible, formats. Moreover, QoE related data is not limited to originating from the network, but also from measurement systems outside the network, as well as being communicated from other users of the network or from a community of users. Therefore, in addition to collecting the data, this function must also serve the purpose of adapting and aggregating the data making it suitable for further processing by the next functional entity. Network Specific ***Data Collection Modules*** interface with network management systems, user terminals, service databases, user communities and measurement infrastructures to collect data that have a role in providing and/or determining QoE. The collected data is classified, adapted and aggregated into a uniform common format using the ***Data Adaptation Module***. This format, known as the *Generalized Performance Data* (GPD), is necessary in homogenizing the varied information collected in order to compare them.

### 3.1.2 QoE Data Processing Function

The QoE Data Processing Function processes the input GPD to obtain homogeneously formatted information from each available access network. This homogeneously formatted information is expressed as a series of metrics, relating to the different available networking technologies, and is provided in a common PERIMETER format called the *QoE Descriptor* (QoED).

PERIMETER calculates a QoED from such information as the network performance measurements, user's context information and user's feedback. This QoED is used to take a handover action based on user's policies. Each QoED item is an aggregate and synthetic description of the quality of user's experience. It consists of a set of key parameters that summarises the QoS from a user's point of view, such as: MOS for different types of applications, cost rating, security rating and energy saving issues. The QoED MOS items are calculated from network performance measurements. Cost, security and energy saving issues are calculated from context information. The gathered information used for QoED calculation comes from the terminal running the PERIMETER middleware, as well as from QoED and performance measurements uploaded to PERIMETER by other users. A confidence value is added to each returned QoED report, to try to provide a metric on how many users contributed to it.

To specify the sources of information a QoED Query (QoEDq) must be provided. This consists of a set of optional parameters that are used to filter network performance and user's context information stored both local and globally. These filters apply to:

- Network connection, to get performance information and QoED items associated to it or to a set of networks that match a reduced set of parameters, if so specified.
- Application information, to get QoED items calculated for applications of the same class.
- Geographical location, to get QoED items calculated at the same area.
- User's ID, to get QoED items calculated by a certain user.

The QoED reports are generated in a variety of circumstances, for example: When new information appears, matching any of the conditions specified in the QoEDq, when requested by individual components of the PERMETER system or when triggered due to a deep change of network conditions like signal loss.

### 3.1.3 Awareness and Decision Function

The Awareness and Decision Function takes as input the QoE descriptors emerging from the QoE Data Processing Function and processes this information in order to take a decision that will satisfy the user's needs. Crucial to this decision making is the information derived from the Context function (information about the circumstances of the user's terminal, location, access network, application specific information, etc.) and the Reputation functions (the current user's opinion, past experiences and other users' past experiences, etc.).

The fact that the user is able to access QoE descriptors of other users which are accessing the same services from the same or different locations over different core and access networks, or different services over the same core and access networks, allows us to formulate new approaches to the Vertical Handover (VHO) management problem. More specifically, by employing ontologies that represent QoE measurements and other data such as topology, the users are able to send complex queries about the performance of the applications that it is currently using, as experienced by other users, on different times and locations. One possible decision approach that we are exploring is using semantic reasoning over this application performance data to deduce when and to which access network to initiate the VHO. This recommendation then can be compared to the user preference and context, and be executed as a decision by the QoE Delivery System.

In addition to taking decisions, this function also has the goal of providing the user with QoE awareness. This is achieved through a PERIMETER Control Graphical User Interface (GUI), which allows the user to be 'aware' of their situation, providing information such available networks and the network chosen by PERIMETER and allowing the user to rate currently running applications, thus enabling the whole system to improve its behaviour over time.

## 4 Summary and Future Work

As detailed in this paper, the central idea of PERIMETER is to provide the user with the Internet connection that is the best from the user's perspective. The technique with which this shall be achieved is applying the QoE concept, which takes the user's perspective of how well a service works into account, rather than relying on purely technical aspects. With this user-centric approach it can be guaranteed that the user always gets a connection that has a "good enough" performance regarding the currently running applications, if such a connection is available. Because PERIMETER is aware of the QoE it can provide to the user, it is also possible to let the user know if the running applications cannot be provided with an appropriate Internet connection. On the other hand, if there are different suitable connections available, PERIMETER is able to take other policies into account, such as cost or battery life for example, and choose the connection to be used based on these additional preferences set by the user. Many further technical challenges lay ahead for the PERIMETER consortium, including:

- Design and algorithms for the Decision Module: Whilst simple weighted sum models seem to work quite well for estimating QoE based on certain QoS parameters, other approaches have been successfully applied. Because the system will constantly generate new inputs as it is being used, the QoE evaluation should be able to adapt to the new user input and hence improve over the time.
- Definition of the P2P infrastructure for exchanging QoE values between users.
- Implementation of the PERIMETER system to prove the outlined concept and to facilitate the generation of concrete results.

With the Future Internet having to cope with yet unknown terminals and services, flexibility and adaptability will be considered as one of the most important design principles. This flexibility will demand different kinds of awareness both in the ends of communication in every node in the service supplying chain with users' QoE as the final objective [10] thus making the work of PERIMETER's work in the QoE sphere a timely and worthy contribution to the research of the Future Internet.

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