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Providing an User Centric Always Best Connection

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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. It is essential to identify, quantify and ultimately improve the perception of QoE for a user. The PERIMETER project improves the user's experience by identifying a more user-centric network selection, based on QoE calculations and user preferences. PERIMETER defines a generic QoE model which forms the basis for QoE signalling and QoE based content adaptation support. This paper provides an insight into how user centric seamless mobility is being achieved by PERIMETER, beginning with an explanation of QoE and the need for preferences. Next, more details of the complete system, including QoE management, user feedback and the final delivery, are provided. Finally, an outlook is given on PERIMETER's future plans and its contributions to research in the Future Internet.

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

I. INTRODUCTION

For the Future Internet to succeed and to gain traction in the wider acceptance of innovative applications and services certain QoE objectives have to be met.

The subjective quality perceived by the user Quality of Experience (QoE) [1] has to be linked to the objective, measurable Quality of Service (QoS) parameters to allow for a comprehensive and accurate QoE estimation. Feedback between these entities is therefore a prerequisite for covering the user's perception of quality.

The FP7 project PERIMETER's [2] architecture provides the technology to guarantee a user-centred Always Best Connection (ABC) based approach on QoE estimations and user preferences. Through this innovative architecture PERIMETER progresses towards a large-scale autonomous network for QoE aggregation and distributed ABC decision making, in order to deliver Internet connections with a good subjective quality to the user.

This paper begins with the PERIMETER definition of user centrality in the mobile network selection domain. Section III details the QoE Management System of PERIMETER. This system is responsible for determining the network which will provide the user with an ABC based on QoE calculations and their preferences. Next, it is explained how the user is involved in this process and how their preferences are taken into account by the PERIMETER system. Usability tests of the system were found to be crucial in making the users' experience of the system as uncomplicated and intuitive as possible. The details of these tests are also provided. In Section V, the PERIMETER QoE Delivery System is described. This system is responsible for the seamless handover from one network to another based on the decisions made by the aforementioned QoE management system. Finally, the paper concludes with a summary of the work that has been achieved to date and the future work and improvements ahead for the PERIMETER project.

II. DEFINING USER CENTRICITY FOR MOBILE NETWORK SELECTION

Most current portable devices offer several wireless network interfaces such as WiFi, Bluetooth and UMTS. In addition, the emergence of USB dongles containing modems, combined with flexible administration software, offer a simple-to-handle facility for changing operators. This would be required for example, in the instance where there is a lack of coverage with one operator and the user may decide to switch to another. Indeed, technically, the premise for making users "Always Best Connected" does exist, which is an important lead in maximising user QoE.

Most mobile users have had the experience where the network they are subscribed to is perhaps not always available, does not perform as well as required or is not the cheapest way of communicating [3]. As an example of ABC and a user-centric network selection, consider an everyday scenario in Hubert's life [3].

Hubert gets up in the morning and connects his laptop to his home Network via Ethernet to read the morning news on the Web. After scanning through the news, Hubert decides to check his email and connects to his email service. One of the emails contains a large file that Hubert starts downloading, but then Hubert realizes that he is late for work so he unplugs his laptop from the Ethernet Network and heads for the office. When being unplugged from Network, the laptop automatically checks for other available accesses and finds 3G coverage. The laptop then reconnects to the email service over the 3G network and continues the download Hubert initiated. The subway is delayed, so Hubert is not able to make it to the office in time for the morning meeting. Instead, Hubert participates in the meeting from the subway, using his personal digital assistant (PDA), which is connected to Hubert's corporate network over 3G, and a conferencing tool. The conferencing tool adapts to the limited capabilities of the device and access technology, and gives Hubert speech and text components only. When Hubert arrives at the office, he transfers the conferencing session from his PDA to his laptop, which is now connected to the WLAN in the building. The conferencing tool recognizes that the device and access network capabilities change, and adds a video component to Hubert's session.

In the scenario above, Hubert obtains ABC service by seamlessly using the underlying PERIMETER software where he has a predefined set of preferences selected for each application. [3] define ABC service as service that gives the user the ability to, at any point in time, get IP connectivity to a certain point on the Internet over the access network or networks that best suits their current needs. These needs could be defined, for instance, by the applications the user is running, or in a service contract between the user and the ABC service provider. To grant users connectivity over different access networks, ABC service depends on an infrastructure for authentication, authorization, and accounting (AAA). To enhance the user experience the ABC service also includes various levels of mobility support, application adaptability, and solutions for virtual private networks.

The advantage of improved QoE through network selection comes at the price of reduced QoE due to tedious manual configuration work. These scenarios put forward the need for an automated and preferably seamless solution able to preserve any ongoing transfer. In order to meet the needs of the users and maximize their QoE, the seamless communication solution has to be user-centric. The latter means that usage context, user preferences and experiences need to form the basis for taking and executing handover decisions. This is in contrast to former approaches such as [4][5], where the parameters used for the decision-making are mostly technical in nature (albeit covering performance, cost and security parameters).

The need to relieve users from forced decision-making and system-level activities, while optimizing the QoE of networked applications and services is the key driver for the PERIMETER solution. The users and their perception of quality, expectations, experiences and willingness-to-pay provide the specifications for PERIMETER's QoE

management. These specifications are correlated with observable events and measurable parameters and form the basis for taking decisions on what network connection is optimal for a given service in a given context.

III. QOE MANAGEMENT SYSTEM

The PERIMETER QoE Management System, depicted in Figure 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.

Before describing the different subparts of this system, and their functionality, a description of what QoE is, and the PERIMETER's approach to QoE determination, is provided.

Figure 1 QoE Management System

A. QoE Definition

QoE is the overall performance of a system from the point of view of the users, i.e., what a user really perceives in terms of usability, accessibility, retainability and integrity. 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. [6]. Thus, QoE can be regarded as a subjective measure of how the user perceives the actual quality delivered, which is influenced by a wide set of concepts, such as privacy, cost and QoS.

QoS, as defined by IETF [7] and the 3GPP [8], 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 [6]. QoS is intrinsically a technical concept in that it can be measured, expressed and understood in terms of networks and networks metrics [9].

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 determination of QoE is heavily related to the application in use [10]. Each application or service has its own associated requirements and associated users' perception of quality. Thus, different classes of services (COS) can be defined, each of which have their own QoS factors, user preferences and QoE related concepts. It is therefore important that any QoE estimation model should take into account the concept of different COS.

While QoS influence on QoE is a well studied matter, QoE sensitivity to privacy and cost in Internet services is a less explored field. This fact poses to the PERIMETER approach the challenge to investigate algorithms that relate QoE with cost or privacy.

B. PERIMETER's approach to QoE

Taking into account the discussion above, the PERIMETER system provides a QoE description for each Network Access Point (NAP) in the form of a set of quantities, which is called a QoE Descriptor (QoED):

$$\text{QoED} = \{ \text{CR}, \text{PR}, \text{MOS}_{\text{COS1}}, \dots, \text{MOS}_{\text{COSn}} \}$$

Where :

- CR is the Cost Rating.
- PR is the Privacy Rating.
- MOS_{COSi} is the QoE output under certain QoS conditions, for Class of Service i.

A deeper insight in each of these parameters is now provided.

1) MOS_{COSi}

This member of the set captures a quantification of the QoE perceived only due to certain QoS conditions. In order to quantify a subjective measure such as the QoE, the Absolute Category Rating (ACR) has been chosen. With ACR, different scores, ranging from 1-5 [11] are used for the less quantifiable QoE parameters. The scores are: Excellent = 5; Good = 4; Fair = 3; Poor = 2; Bad = 1. As can be seen, QoE is captured as opinion scores (OS), and, as will be seen further, due to the mathematical approach taken in its calculation, the name MOS (Mean Opinion Score) has been chosen.

A model, known as the IQX hypothesis [12] is used to correlate the various QoS network performance factors with the MOS value.

In this model it is assumed that the QoE measure is the more sensitive, the higher the quality experienced 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:

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

Where:

- QoE is a MOS metric.
- p_{loss} is the QoS parameter whose degradation influences the MOS metric. This parameter is usually a network performance metric.
- α , β and γ are the equation parameters, which must be tuned in order for the expression to be meaningful.

Typically, QoE estimation algorithms, like this one, are usually tuned from standard tests performed on a selected group of people. The PERIMETER approach addresses the personalisation issue by self-tuning the algorithms parameters with actual user's feedback (cf. Section IV), in conjunction with employing the user's contextual information.

Each PERIMETER user will have its own α , β and γ parameters, which will be tuned by the system as more feedback from them is collected.

2) Cost Rating and Privacy Rating

Inferring values for these parameters and using them to take a network switch action is an open issue within PERIMETER. Although the system's architecture has taken these factors into account, actually only a heuristic approach is taken, in which these ratings are set by hand by the user.

Although the most common approach to QoE in PERIMETER associates a QoED to a NAP, its architecture allows further associations to other factors within a specific user's context such as geographical position or application (or COS) under use. So, the system can provide, for example, a QoED associated to a specific place, no matter which networks are available at it.

One of the contributions that the PERIMETER approach adds to the QoE inference is the use of a wide user's knowledge base. A QoED is calculated, not only from the information (QoS, Cost and Privacy) collected from the user's device, but also from other PERIMETER peers, both actual and historical.

A detailed description on how these calculations are performed can be found in the next section, where the architecture behind the PERIMETER approach to QoE determination is explained.

C. PERIMETER QoE Management System Architecture

The PERIMETER QoE Management System, as previously depicted in Figure 1, consists of three main levels of functional entities as follows:

1) *QoE Data Collection and Adaptation Function*

The QoE Data Collection and Adaptation function has the purpose of collecting QoS data relevant for QoE calculation from the networks available to the PERIMETER infrastructure. This data is adapted and aggregated into a uniform common PERIMETER format, called the Generalised Performance Data (GPD) making it suitable for further processing by the next functional entity.

All the calculated GPDs are stored locally in each terminal, for other architectural entities to use them in its calculations. A time window is established to remove stale data.

2) *QoE Data Processing Function*

This function produces QoED reports. These reports can be asked on demand by other PERIMETER components (namely the Awareness and Decision functions) or can be sent as an event under certain circumstances (for example, a severe degradation in quality).

A QoED life cycle is as follows:

1. GPD data is gathered from a local repository, for the network (or context) for which the QoED is going to be calculated.
2. QoEDs for the network of interest are gathered from the PERIMETER's common repository. These QoEDs have been generated by other PERIMETER users. A trust and reputation algorithm filters them, assigning a certain weight to each of them.
3. The final QoED is calculated from a weighted sum of the other user's QoEDs and the QoED calculated from actual GPD data.

The QoE Data Processing Function works as a server for the Awareness and Decision Module triggering delivery of these QoE reports when required.

3) *Awareness and Decision Function*

The Awareness and Decision Function takes as input the QoEDs 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 PERIMETER system uses the QoEDs of other users who have accessed 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 the PERIMETER system to formulate new approaches to the Vertical Handover (VHO) management problem, which is discussed in Section V, QoE Delivery System. This function also has the goal of providing the user

with QoE awareness. This is achieved through a GUI, which allows the user to be 'aware' of their situation, discussed next in Section IV Involving the User.

IV. INVOLVING THE USER

The PERIMETER system is aiming for user centricity. As explained in the previous section, the QoE that the user perceives while using an application with a certain Internet connection is estimated by the system.

Now the question arises whether or not this estimation actually is close to how the user really feels. Thus, there needs to be a mechanism for gathering constant feedback from the user, without actually disturbing the user from using applications. PERIMETER therefore constantly shows the QoE, as it is estimated by the system, to the user in form of a smiley metaphor. There are five smileys, which are mapped to the five qualities of the MOS scale. The nonintrusive way in which the estimated QoE is presented to the user can be seen in Figure 2.

Figure 2 The QoE Feedback from the system to the user, showing the nonintrusive smiley in the left screen and the extended version on the right side.

A particularly happy smiley stands for an excellent experience, whereas a sad smiley stands for a bad experience. In case the user disagrees with the estimated rating, the QoE can be re-rated by the user. Figure 3 shows the dialog with which the user can actually input the real felt experience. This also depicts how the smileys have been mapped to the actual MOS scores. By using this two way feedback option it is possible for PERIMETER to constantly improve by learning the actual user's experience.

In order to provide user centricity beyond mapping QoS to QoE, a set of preferences is provided to the user. It is possible that there will be many access points, providers and hot-spots that can satisfy the user's needs. To provide the users with the best possible connection from those available

they can choose their specific preferences. Further decision making can be based on user's preferences such as cost, battery life or security for instance. There is a standard set of default preferences defined for PERIMETER controlled applications, which ensures the working of PERIMETER 'out of the box'. The user can use these default preferences or apply their own dedicated preference settings for applications. For instance, a user could prefer that a video call application uses secure connections and that for Internet browsing only the cheapest possible connection should be used.

Figure 3 The QoE rating input from the user to the system.

Usability tests on PERIMETER [13], including the two way feedback and preferences system, revealed that this kind of system is very much appreciated by potential users and that the two-way feedback system is well understood by the user. Also the additional preferences were evaluated to be an interesting feature. The tests have also confirmed that the user-centric ethos of PERIMETER can be maintained without actually distracting the user from their daily work.

V. QoE DELIVERY

The PERIMETER QoE Delivery System executes all the actions necessary to achieve the QoE objectives set by the users. The purpose of the QoE Delivery System is to provide fast inter-technology handover while minimally affecting the performance of ongoing services, i.e., minimize latency and packet-losses.

The QoE Delivery System consists of two main functional components: the Vertical Handover Technology Abstraction Layer and the Measurement Subsystem.

A. Vertical Handover Abstraction Layer

The Vertical Handover Technology Abstraction Layer provides the vertical handover execution functionality for PERIMETER, as well as the mobility management.

Mobility management, i.e., the virtual movement between different networks, is handled with the aid of a binary network layer protocol and is therefore technology independent. The protocol notifies users about movements of other users in the network. This is demonstrated by PERIMETER's federated testbeds housed at Waterford Institute of Technology, Ireland and the Technische Universität Berlin, Germany. This federation has been configured specifically to verify and validate the innovative QoE aspects of the PERIMETER project in a scalable manner.

The role of the HandOver (HO) Manager is to execute decisions regarding network selections. The received decisions are based upon combined policies established by the QoE Management System and derived from measurement results and event notifications. The latter might require immediate action (e.g., in case of a link failure) on a short time scale, while policies imply a strategic choice of a suitable network on a longer time scale. Thus, the QoE Management System needs to prioritise according to the importance of the criteria; finally, the HO Manager provides the switch command to the HO execution that will relay the connection streams.

Communication between mobile end-nodes is established over UDP tunnels. Vertical Handover is then realised by relaying the User Datagram Protocol (UDP) tunnel over another interface. This is transparent to user-space applications as they are bound to the virtual interface of the tunnel. The virtual interface state does not change during the uptime of the device. This way the user-space applications are decoupled from the mobile environment.

Furthermore, a Location Service is used to keep track of users in the virtual landscape. The Location Service maintains a mapping of which users are active on what IP addresses. As interfaces can appear and disappear in an unpredictable sense, a Location Service is necessary. The Location Service can be established as a pure distributed database or a centralized variant. The Location Service for PERIMETER is located on a support node.

B. Measurement Subsystem

The Measurement Subsystem provides the QoE Management System with quantifiable information for use in the decision making process. As packet-loss and one-way delay-jitter have a significant impact on QoE [14], these metrics are essential for predicting the satisfaction of the users. The data collected is sent to the database system maintained by the Storage Layer. Additionally, the Measurement module provides an event generation mechanism that notifies registered PERIMETER modules

for arbitrary network events, e.g., link-failure, exceeded bandwidth threshold, etc. Events are of particular interest for the QoE Management System. The measurement subsystem is designed in such a way that it allows to be easily extended by new network technologies.

Two types of information are collected in different manners: general physical network interface statistics and connection statistics. The interface statistics are often stored by interfaces in a unified manner and are easily retrievable by user-space applications. Examples of these statistics are: transmitted and received bytes, number of erroneous packets, and number of dropped packets.

On the other hand statistics about ongoing connections are collected. This is essential when ABC is to be maintained. Three metrics are observed; one-way delay-jitter, packet drop rate, and packet reordering rate. These metrics are computed with the help of values located in the tunnel's header. The minimum required fields are a timestamp and a sequence number. These two fields are appended as 32bit fields to the UDP tunnel header.

The one-way delay-jitter is computed by comparing the difference of consecutive departing timestamps with the difference of consecutive receiving timestamps. The amount of reordered and dropped packets can be derived from the sequence number. An in-kernel dedicated algorithm computes these metrics. It is shown that in-kernel algorithms are preferred above user-space measurement systems as they yield better performance and higher accuracy [15].

VI. SUMMARY AND FUTURE WORK

As outlined throughout 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. In order to achieve this we apply the QoE concept and extend it with user preferences and context information as opposed to previous methods where only the technical details were taken into consideration. We call this concept *user-centric* because the handover decisions take into account all factors that are of interest for the user.

Currently the PERIMETER system is being further developed in order to provide a complete system, which can be exploited by a user. This is being done in a user co-creation process, for which further usability and Living Labs [16] testing will need to be performed. Testing is mostly done in two inter-connected testbeds, one located in Waterford, Ireland and one in Berlin, Germany. The tests in these testbeds will provide experimental results on the PERIMETER solution.

Flexibility and adaptability are some of the most important design principles for the Future Internet as devices and component architectures are not yet finalised. This flexibility will demand different kinds of awareness in every node in the service supply chain with users' QoE as the final objective [17]. Thus, PERIMETER's work in the QoE

sphere is a timely and worthy contribution to the research of the Future Internet.

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