QoE Testbed Infrastructure and Services: Enriching the End User's Experience

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Abstract. Quality of Experience (QoE) is the subjective judgment of the satisfaction an end user perceives from an application running over a given network topology and configuration. The information provided by end users regarding their QoE preferences, experience and feedback is invaluable in providing a service that meets with their mobile activity needs within various access networks. The PERIMETER project progresses the QoE thematic research area by taking end user-related QoE factors for end user-centric mobility experimentation, thus empowering them to always have a service in which their QoE is high. This paper will detail the components of the PERIMETER framework and the user centric scenario based process adopted to implement and develop such a framework. This paper provides an insight into the federated testbed infrastructure, testing methodology and tools, operating system and applications used in the project, thus demonstrating PERIMETER's innovative advances within the QoE end user domain.

Keywords: Quality of Experience, testbeds, federation, PERIMETER, Future Internet, Always Best Connected.

1 Introduction

Quality of Experience (QoE) is a measure of the end-to-end performance at the service level from the end user perspective and an indication of how well the system meets the end user's needs [1]**.** Consideration of QoE parameters and preferences allows a more *user-centric*, rather than network-centric, approach to be adhered to in areas of seamless mobility. Enabling the end user to control the way their identity, preferences and credentials are used empowers them to be Always Best Connected (ABC) [2] in multiple access and multiple operator networks of the Future Internet.

The PERIMETER project [3] progresses the QoE thematic research area by taking user-related and non-technical QoE factors into account in order to provide a solid baseline for future user-centric mobility experimentation. This is achieved by studying the parameters that define the "user-centric seamless mobility", resulting in new

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network selection algorithms for achieving QoE based ABC paradigms and the development of a QoE framework that supports generic QoE definition, QoE signalling and QoE based content adaptation. To demonstrate such a QoE specific PERIMETER framework, a scenario based approach was adopted and a suitable federated testbed infrastructure was created to provide a valuable environment to verify the innovative QoE aspects of the PERIMETER project.

This paper gives an account of the PERIMETER middleware, before elaborating on the scenario based process used to derive the functional requirements of the system. Next, the underlying testbed infrastructure used to demonstrate and validate the middleware and its required applications is provided, in conjunction with details of the operating system used and the testing methodology employed. The results from the first round of testing are then presented. The paper concludes with a summary of the work of the PERIMETER consortium to date, before detailing its future trials in the QoE testbed infrastructure and services area.

2 PERIMETER Middleware

The PERIMETER middleware is composed of a QoE management system, QoE delivery system and PPA^{3}R (Privacy Preserving Authentication, Authorisation, Accounting and Reputation) system. These systems are supported by a Storage Layer for storing and retrieving information using a distributed peer-to-peer approach [4] and an Application Layer (which contains an Application Manager and a Graphical User Interface (GUI) that provides the end user with control over their QoE parameters, preferences and settings). The PERIMETER middleware, depicted in Figure 1, is hosted on PERIMETER aware mobile device terminals and on support nodes in the testbeds involved. Both terminals and support nodes can be directly connected to the Internet or to Virtual Private Networks (VPN) behind a Network Address Translation (NAT)/Firewall.

The central goal of PERIMETER is to devise a framework where end users are always in an ABC state. To achieve this goal, PERIMETER must gather relevant information, and make decisions on whether to generate a network switch based on the analysis of this information. The ABC state is measured using QoE metrics. PERIMETER makes its decisions using information from the end user's preferences, the end user's context (application under use, location and conclusions inferred from this), network performance parameters, other PERIMETER end users' QoE information and PERIMETER end users' feedback, which are collected in a QoE Descriptor (QoED) [5]. The Data Network Processor is responsible for computing these QoEDs. Dedicated Trust and PPA^{3}R components are employed to handle trust and security issues related to the sharing of QoEDs between the end users. The Decision Maker (DM) uses local and a selected subset of remote QoEDs to decide on the most suitable available network. The QoE delivery system performs the actual vertical handover based on the DM's analysis [6]. The QoE delivery system also conducts network measurements to aid the DM in making this decision.

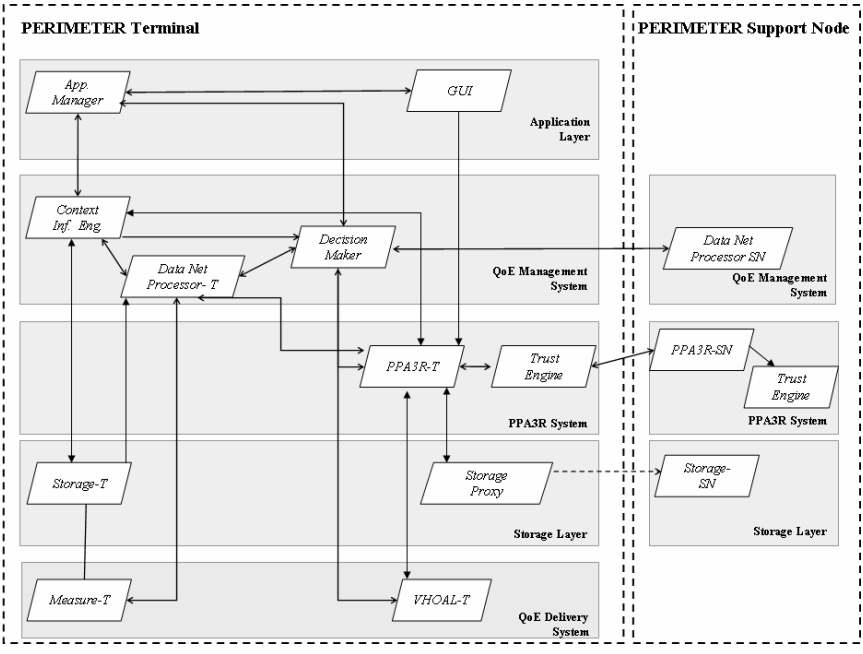

Fig. 1. PERIMETER Support Node and Terminal

3 User Centric Scenario Process

Adopting an end user scenario based process allowed the definition of a suitable federated testbed infrastructure that will be capable of supporting an end user QoE PERIMETER demonstrator. Through a scenario sub-step breakdown and component mapping activities, the PERIMETER consortium detailed the relevant component functionalities, interfaces and network technologies, therefore kick starting the process of identifying the testbed initial requirements. PERIMETER Scenario 1, entitled 'user-centric agnostic ubiquitous communication', follows the daily activity of an end user as they seamlessly roam between different technologies, connecting to services using various access technologies and devices.

A summary of the PERIMETER Scenario 1 is as follows:

Yvette is waiting for a taxi in the same room as her colleague Bob. Both have the PERIMETER system installed on their devices and are connected to the building's Ethernet network. A ***phone conference*** *starts. Bob participates with his laptop and Yvette with her handheld device. The taxi arrives and Yvette gets in. As the taxi leaves, Yvette's handheld begins to face network problems so the PERIMETER system begins searching for a suitable network to handover to Yvette's handheld has already detected a pair of Universal Mobile Telecommunications System (UMTS) networks; the PERIMETER system chooses the cheaper network. It has, in fact, analyzed a few statistics, previously cached from the PERIMETER overlay infrastructure, reporting that the majority of the end users had satisfactory experience with the*

cheaper UMTS network in that location. While in the taxi, Yvette receives an important ***video call*** *from her boss. Given its nature, the call requires high quality video parameters and a stronger confidentiality. PERIMETER scans for a network that will meet these requirements and analyses the QoE descriptors of the end users on various networks to find a suitable network. It chooses a different UMTS network and seamlessly connects to this to guarantee exceptional video call performance.*

The following work flow shows the step by step flow of actions taking into account the testbed infrastructure and the PERIMETER middleware:

- Scan for connection options and discover the nearby WLAN device. Join the phone conference.
- Monitor the active network interfaces for acceptable QoE.
- Detect changes in the location and degrading channel quality. Scan for other connection options.
- Collect QoS (Quality Of Service) data and interact with the PERIMETER Support
- Node to update QoS information of thecurrent geographic location. Collect QoE data over the PERIMETER overlay.
- Process collected data using the Decision Maker component of the system. Switch from WLAN to UMTS based on Decision Maker's decision.
- Receive the incoming call and detect QoE requirements (high quality and confidentiality).
- Probe the QoE descriptors of other users on this network.
- Select the more expensive and reliable UMTS network and switch between them.

Figure 2 conveys a high level overview of the mapping of this scenario in the PERIMETER federated testbed.

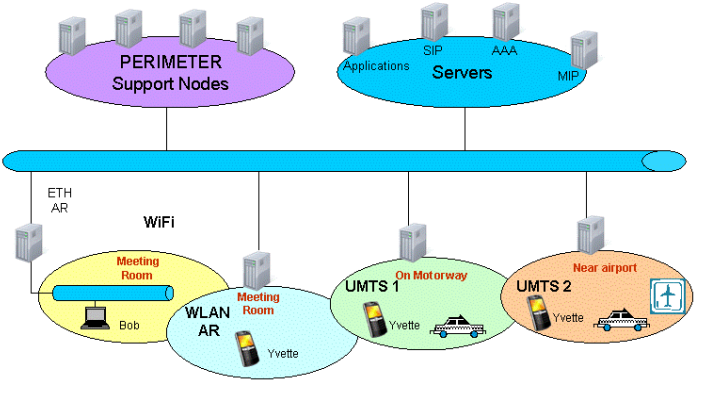

Fig. 2. Mapping Scenario to Testbed Requirements

4 PERIMETER Testbed Infrastructure and Testing

To effectively validate the results of the PERIMETER project, two main testbeds were setup to co-exist within the PERIMETER project, the first is housed at Waterford Institute of Technology (WIT) Ireland and the second main testbed is housed at Technische Universität Berlin (TUB) in Germany. The mapping of the scenario helped identify the main testbed requirements such as terminal devices (mobile and fixed), network support technology hardware and equipment and software requirements. WIT's testbed focused on the application services, while TUB's testbed focused on the network access infrastructure required to demonstrate the scenario, as illustrated in Figure 3 and Figure 4. The PERIMETER middleware requires both terminal and support nodes to be deployed in the QoE testbed infrastructure. There are four category actors in the PERIMETER system that will be part of the testbed design, User terminals, Support nodes, Network service providers and Application service providers.

WIT testbed hardware elements	TUB testbed hardware elements
• Hudson build server. • Asterisk SIP server • G1&G2 Mobile devices. • Gateway machine. • VMware server (perimeter support nodes) • Advent netbook x 2 • Wireless router, accesspoints	• Xen virtualization servers • (perimeter support nodes). • End terminal devices (laptops, netbooks, mobile devices G1/G2). • Semantic IPTV server and webcam. • gateway machine, routers, accesspoints • UMTS Femto Cells.

Fig. 3. PERIMETER Testbed Hardware

Between the two official test sites layer 3 Internet Protocol security (IPsec) interconnectivity was adopted to allow interconnection in a secure manner. The PERIMETER testbed used IPsec tools [7] such as M0n0wall [8], a complete embedded firewall package, Racoon [7] for Internet key exchange and Setkey [7] to manipulate security associations and policies within the implemented IPsec tunnel on the hosts from both testbeds.

The testbed interconnection has been designed with the following functionalities in mind:

- Service environment component integration.
- Testbed adaptation.
- Exposure, composition and redeployment of services and components.
- Horizontal Interconnection: to achieve greater scale.
- Vertical Interconnection: to support system-level testing of new Internet networking and services paradigms across layers.

The purpose of the PERIMETER testbed federation is to deliver the scenario testing, architecture validation testing, end user evaluation testing and final project demonstration for PERIMETER by interconnecting the diverse wireless network access systems and terminals and application environments which can provide a multi-faceted mobile communications environment.

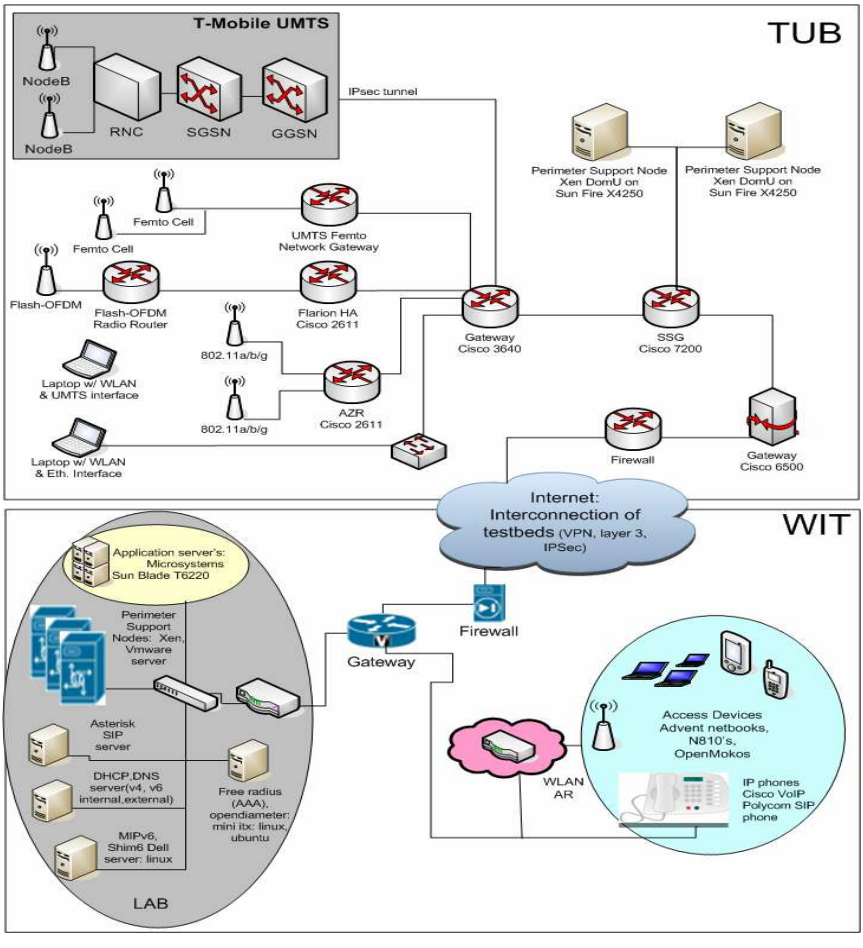

Fig. 4. PERIMETER Testbed Infrastructure

4.1 Operating System and Applications Used in the QoE Testbed

Adopting a user-centric scenario based approach incurs the need to address and have available certain applications in order to support the final end user demonstrator. In the PERIMETER scenario the two main applications required included a phone conference and a video conference application. It was agreed upon in the project to incorporate the use of the Google Android [9] operating system. This is a mobile operating system that runs on top of a Linux kernel [10].

The use of the Google Android operating system has allowed the PERIMETER consortium to invest in Android compatible mobile devices in addition to allowing the project avail of applications distributed by the Android Market. The following Google applications were initially assessed on the G1 mobile device containing firmware version 1.5, to determine their compatibility with the PERIMETER project:

1. For the phone conferencing application PERIMETER are examining **Sipdroid** [11]**.** Sipdroid is an open source SIP client implemented in Java which is capable of running on the Google Android platform.
2. For the video call application PERIMETER are investigating **Semantic IPTV** [12] provided by TUB. Semantic IPTV permits video streaming on the Android phone.

All applications used within the project must be made PERIMETER aware. This involved interfacing the PERIMETER specific Application Manager (AM). The AM's main functionality is to provide the end user with the ability to control the running applications, edit their preferences and set the network selection manually if needed.

4.2 GUI Testing Results

To validate the usability of the AM's GUI, usability tests were performed with a group of actual users from the PERIMETER consortium [13], taking into account the Living lab [13][24] methodology concepts. This step yielded important clues about the end users' acceptance of the system and their ability to grasp and utilize the functionality represented by the GUI.

As a first step for the GUI testing, a usability pre-test was initiated to evaluate statistical data of end users with different demographical (Ireland, Germany, Austria and Turkey) and technical background, with a set of interview questions. After the pre-test, the end users were provided with the Android G1 mobile phones with the PERIMETER GUI installed, shown here in Figure 5 and Figure 6. If the end user was not familiar with using an Android device, a tutorial was provided, which explained the basic tasks the end user needed to know for the tests. The end users were allowed to familiarize themselves with the phone and the operating system.

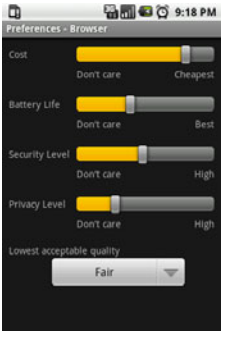

Fig. 5. Browser Preferences

Fig. 6. QoE Rating

The main feedback points were in the following areas:

- The application launcher needed to be redesigned. Functionality such as the play/pause/stop metaphor for the applications was not deemed intuitive.
- Recommendation that the privacy and security preferences, shown in Figure 5, should be merged
- The dynamic feedback, involving the 'smileys' (Figure 6) was well received.
- The meaning of the cost preference (Figure 5) was not transparent.

4.3 PERIMETER Testing and Test Tools

In order to ensure that the PERIMETER system was brought to a level where it achieved its functional and end user objectives, a development and testing methodology was applied. The Agile software methodology [14][15][16] was deemed suitable for this project as it generally promotes a project management process that encourages frequent inspection and adaptation, a set of engineering best practices, such as Test Driven Development (TDD) [17] that allow for rapid delivery of high-quality software, and a business approach that aligns development with customer and end user needs. In conjunction with these Agile and TDD processes, the testing process also took into account test management 'best practises' in testing cycles [18], to include a testing cycle of five phases, as shown in Figure 7, These phases consisted of Definition (of the functionality to be tested), Commissioning (setting up the test environment), Execution (of the tests), Reporting (of the test results) and Evaluating (of the results achieved). These steps were mapped to the PERIMETER testing procedures for unit, functional, integration and scenario testing of the code base to ensure the testing cycle was robust, scalable, interoperable and secure.

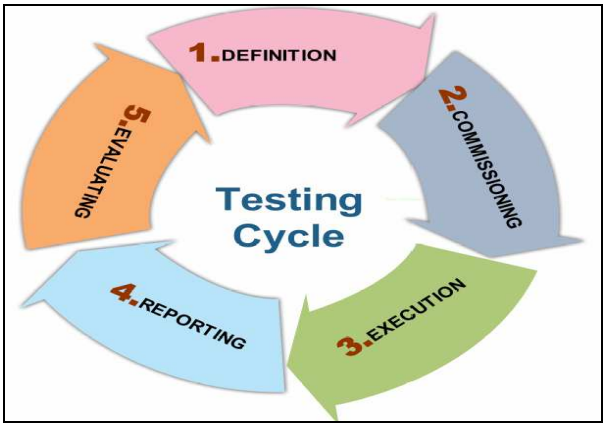

Fig. 7. PERIMETER Testing Cycle

Testing Tools are essential for team collaboration, continuous testing and structured software development. In PERIMETER, a number of supporting tools, such as Hudson [19], Trac [20] and Subversion [21] (SVN), were used to facilitate and structure the integration, validation and verification processes.

Subversion [21] was used for the code and document repository version control. ***Trac*** [20] was used for project management tasks and especially for bug tracking. ***Hudson*** [19] a continuous integration engine was used because of its flexibility and seamless integration with Subversion. In conjunction with ***Apache Ant*** [22], Hudson was configured to constantly execute builds as new or modified source code was checked in to the PERIMETER SVN.

5 Conclusions and Future Work

This paper introduced PERIMETER's approach for user-centric seamless mobility in Future Internet. The PERIMETER middleware, which manages the QoE and PPA^{3}R system and pictured the PERIMETER architecture, consisting of terminals and support nodes was described. A typical scenario for ubiquitous networking is shown that utilizes PERIMETER's overlay infrastructure with QoE based handover decisions to achieve an ABC networking environment. Within the PERIMETER project, a federated testbed was built with main sites at TUB and WIT, interconnected over the GÉANT2 research network. The testbed offers large-scale experimental facilities, sharing specialized networking infrastructure and services and enables integration and validation of the PERIMETER system in a heterogeneous and realistic environment.

On the terminal side, PERIMETER is based on the Android operating system. An Application Manager and GUI is being implemented, which allows the user to start PERIMETER aware applications, set preferences, returns QoE feedback to the user and enables the user to evaluate his QoE. The usability of the projected terminal software was evaluated in a field test, with primary focus on the GUI and the overall acceptance of the PERIMETER approach.

The PERIMETER consortium will mature the testbed activities, by progressing towards collaboration with and applying for a 'slice' of the FEDERICA [23] network infrastructure. This would enable the WIT and TUB federated testbeds to have core connectivity (layer 2) and also provide additional virtual hardware resources that can be used by the PERIMETER consortium for PERIMETER specific experimental research. Currently the PERIMETER system is being further developed in order to provide a complete system which can be used by an end user. This is being done in a user co- creation process, for which further usability and Living Labs [24] testing needs to be performed.

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