Quality of Experience Evaluation under QoS-aware Mobility Mechanisms

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Abstract— **Next generation wireless networks will encompass a wide range of heterogeneous technologies in the radio access part. In such networks, the all-IP paradigm has been identified as a promising solution that will contribute benefits by providing IP-based transport through the radio and core network parts. However, this concept requires a precise management of the user's mobility, especially in order to preserve user's Quality of Service (QoS) throughout the session's lifetime. The aim of this paper is to evaluate the Quality of Experience (QoE) that users perceive when the different QoS-aware mobility management strategies adopted in the AROMA project are applied. A real-time testbed that provides end-to-edge QoS in all-IP heterogeneous wireless access networks has been employed to obtain QoE results that hardly could be obtained by means of simulations.**

Keywords – heterogeneous wireless access networks; mobility management evaluation; quality of experience; quality of service provisioning; real-time testbed.

I. Introduction

Mobility Management (MM) plays a crucial role in the context of all-IP [1] heterogeneous wireless access networks since continuous changes in the Radio Access Network (RAN) and Core Network (CN) attachment points are expected for the user throughout the session's lifetime. Efficient execution of handovers between RANs, in addition to efficient management of the user's flows through the CN is expected from MM. Therefore, MM strategies may severely impact the end-to-edge (e2e) Quality of Service (QoS) if not provided with proper QoS awareness and mechanisms, which align the procedures of QoS preservation executed between the RAN and CN domains.

The problem of merging QoS mechanisms with mobility is a hot research topic nowadays. Interesting work regarding the scalability, performance and QoS management of mobility architectures and protocols in heterogeneous wireless access networks can be found in [2]-[5] and references therein. However, none of the previously mentioned studies include results showing the user's subjective perception when evaluating mobility mechanisms. This evaluation is referred to as Quality of Experience (QoE) in this work.

Therefore, a sophisticated real-time testbed has been developed within the COSMOS and AROMA [6] projects with the objective of assessing a set of specific radio resource management and MM strategies that guarantee the e2e QoS in all-IP heterogeneous wireless access networks [7]. The evaluation platform emulates, in real-time, the conditions that the behaviour of the network, produces on a specially monitored user named here as the User Under Test (UUT). Moreover, real IP-based applications such as videoconference, streaming services, or web browsing are executed by the UUT to have multimedia flows through the testbed.

In this context, the aim of this paper is to present the impact on the QoE perceived by the user of the MM strategies adopted within the project. It is important to remark that the results presented in this work were obtained using real applications. Thus, our testbed enables the possibility of measuring the QoE of the user that would use those applications in a real heterogeneous wireless access network (e.g., a user with a hybrid UMTS/WLAN card installed in a laptop that starts watching a movie streaming trailer). Other applications of the testbed are performance comparison between applications [8] or testing and validation experiments of specific algorithms before putting them on the market [9][10].

The rest of this paper is organized as follows. First, section II presents a brief overview of the testbed for a better understanding of the experiments given here. Next, section III details the MM strategies implemented in the testbed. Section IV discusses the results of the trials that were conducted in the testbed in order to evaluate the user QoE under different MM mechanisms. Finally, section V summarizes the main contributions of this work and concludes the paper.

II. Brief Testbed Description

In this section, the main functionalities and entities included in testbed are briefly described to allow a better understanding of the MM strategies, trials and results given in subsequent sections. For a comprehensive description of the procedures, simulation models and implementation details the reader is referred to [11].

The testbed reproduces in a realistic way a Beyond 3G heterogeneous radio access network that includes three RANs (UTRAN, GERAN, and WLAN) interfacing a common CN, which is based is based on DiffServ/MPLS and policy-enabled networking with improved mobility aspects and a new framework for the e2e QoS management. In addition to these elements, the testbed includes the capability to evaluate the QoS experienced by the user executing real applications.

Fig. 1 shows the functional architecture of the testbed including the entities it is composed of and their inter-

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connections. Solid black connections correspond to user data paths, whereas blue dashed and red dash-dotted connections correspond to control plane interfaces.

We can distinguish two kinds of users in testbed. The emulated users are those that virtually load the RAN emulators (several PC's devoted to emulate the behaviour of different RANs). The UUT is the real user in the testbed and has at his disposal one stand-alone PC to run a real multimedia application (application's client in the figure). To test symmetric services such as videoconference and to serve multimedia applications such as web browsing or streaming, the application's server is run in another PC. Additionally, there is another PC (User Equipment – UE) that runs QoSClient software module (entity that negotiates QoS with the system).

A Traffic Switch (TS) is used to establish different interconnection configurations between the UE and the Ingress Routers (IRs) in the CN depending on the RAN the UUT is currently connected to. There is a mapping table of the RANs to each IR that is set at the beginning of the testbed's execution (e.g., UTRAN is attached to IR1 while GERAN and WLAN to IR2). Then, in uplink, the TS captures the UUT's IP packets, passes them to the appropriate RAN where the UUT is connected to (to make the real-time emulation), and after emulation re-injects them in the interface of the corresponding IR. An analogous procedure is done in downlink.

The e2e QoS management architecture is composed of the QoSClient, the Bandwidth Broker (BB), and the Wireless QoS Broker (WQB), as it can be seen in Fig. 1. The QoSClient is the entity that provides an interface from which the UUT can activate, deactivate and modify the sessions with QoS guarantees. Three service classes are available for the UUT: conversational, streaming and interactive.

The BB is the entity that handles the QoS management in the CN, by configuring the proper DiffServ filters in the IRs and Egress Router (ER) and establishing MPLS tunnels for the UUT between these routers. Depending on the UUT's traffic class [12] the MPLS tunnel is established through CR2 or, alternatively, through CR3 and CR4 where a higher delay is expected. Additionally, the WQB handles the QoS in the radio part, and tightly interacts with the Common Radio Resource Management (CRRM) entity, which is in charge of functions such as Radio Access Technology (RAT) selection and Vertical Handover (VHO). The QoS that the UUT requests is preserved along the RAN and CN domains due to the e2e negotiation that WQB and BB perform during real-time execution.

III. Mobility Management in AROMA

A. *Mobility Management Architecture*

MM is a functionality included in the testbed to provide QoS-aware IP micro-mobility. Macro-mobility approaches such as Mobile IP [13] incur in excessive signalling between the Mobile Node (MN) and its correspondent node each time the MN changes its current point of attachment and a new care-of address has to be assigned to it by the correspondent node. This provokes additional delays, packet loss and signalling overhead. Then micro-mobility protocols have been introduced to manage the IP mobility within a macro-mobility domain (i.e., within the control area of the same correspondent node).

Micro-mobility protocols can be classified into tunnel-based and host-based forwarding protocols [14]. Tunnel-based protocols follow a hierarchical architecture where the correspondent node, also referred to as Anchor Point (ANP), establishes tunnels (usually IP-in-IP tunnels) to the Access Routers (AR) or points of attachment of the MN. HMIP [15] and BCMP [16] are examples of these protocols. In contrast, in host-based forwarding protocols, each router in the path has a database whose information about the location of the MN is employed to forward packets to the MN. HAWAII [17] and Cellular IP [18] are examples of these protocols.

In the testbed, a tunnel-based micro-mobility strategy with QoS extensions has been implemented. The BCMP protocol is used, but MPLS tunnels are created instead of IP-in-IP tunnels. When compared with other micro-mobility protocols, MPLS-based micro-mobility protocols show several advantages due to the MPLS technology: simple forwarding decision based on a simple label, possibility of using constraint-based routing in order to better utilize the network resources, creation of Virtual Private Networks (VPN) and network reliability. Furthermore, MPLS has been widely adopted by operators in their access networks.

Therefore, MM is supported in the testbed by 3 entities, namely the MN, the AR and the ANP. The ANP is the master MM entity located in ER that assigns the IP care-of address to MN and communicates with BB about MM events. The BB also controls the creation, management and switching of the MPLS tunnels and closely interacts with the MM entities to know the instant the MPLS data path needs to be switched. The AR is an entity installed in each IR that broadcasts Route Advertisement (RA) messages indicating its identification to users. Finally, the MN resides in the UE machine and is the entity

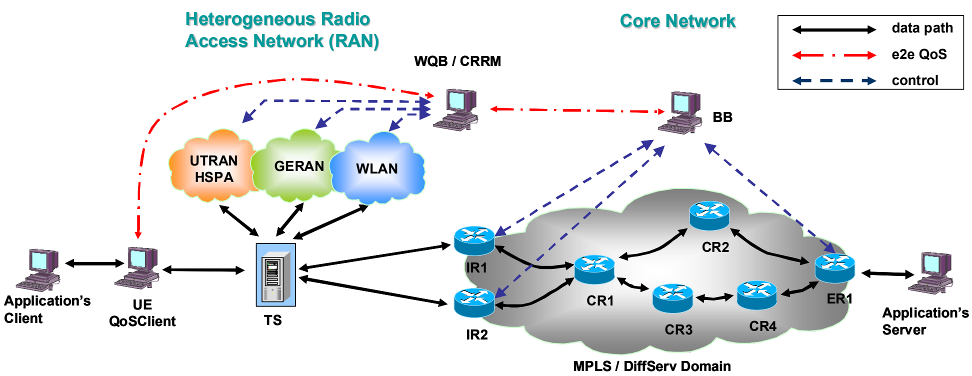

Figure 1. Testbed functional architecture.

that triggers the MPLS tunnel switching when the currently attached IR is no longer available and there is a new one (i.e., MN detects an IR's address change in the RA message), or when there is another IR whose measured received power is greater than that from currently attached IR.

B. *Mobility Management Strategies*

Different Handover (HO) types are executed in the testbed as the UUT moves along the scenario:

Horizontal Handover (HHO): It is the classical HO mechanism where an intra-RAN HO is performed (i.e., a HO between base stations of the same RAN). Its management is local to the RAN and, therefore, no e2e QoS negotiation is needed.

Intra-IR Vertical Handover (VHO): In this case the HO is performed between base stations of different RANs attached to the same IR of the CN. Its management involves CRRM. By default, all packets sent to the old RAN during the execution of the VHO are eliminated once the VHO is executed, but there is the possibility to forward those packets to the new RAN during the VHO. Hereafter we call this latter possibility the *transfer policy*.

Inter-IR VHO: In case a VHO implies an IR change then MM plays a crucial role. On the CN side, the data information of the UUT is encapsulated into MPLS tunnels from the ER to one of the IRs for downlink and vice-versa for uplink. In addition, on the radio domain, the TS filters the UUT's data packets in the UE interface (uplink) or IR interfaces (downlink) to pass them to the appropriate RAN for emulation. Each time there is a VHO that includes IR switching, the TS changes its configuration to filter packets for the UUT from its interface connected to the new IR.

It is important to remark here that VHOs (which switch the data path for the user through the RAN domain) are executed regardless of the IR/MPLS-tunnel switching within the CN domain, and always after the e2e QoS negotiation. Therefore, this situation results in a misalignment between the RAN and CN parts. The ANP informs BB about the necessity of changing the MPLS path to the new IR after receiving an MPLS tunnel change notification message from the MN as explained at the end of section III.A. Finally, this kind of VHO also implies an e2e QoS re-negotiation between the WQB, BB and optionally QoS-Client, what gives the proper QoS awareness to the mobility.

It is clear that a lack of synchronization between the MPLS tunnel switching in the CN and the VHO in the RAN part may lead to packet loss and a significant QoS degradation for the final user. Then, to avoid this situation, an advanced MM procedure called *HO preparation* is also implemented in the testbed. This procedure establishes prior to a VHO (concretely, when the MN receives RAs from both IRs) an *Inter-IR tunnel* (between IRs) to minimize packet loss during the VHO execution, as it is explained in the following section.

C. *Illustrative example*

In order to illustrate the Inter-IR VHO procedure, the signalling messages exchanged in the case of an Inter-IR VHO with HO preparation are detailed in Fig. 2. In this example, before the VHO, the UUT is connected to UTRAN through IR1. A logical *radio path* or bearer is therefore established between the UUT and UTRAN. The TS establishes an *interconnection path* that physically connects the UUT with IR1 in the CN while the BB establishes an *MPLS path* along the CN. Suppose that until the beginning of this example the UUT was only under UTRAN coverage and from that moment is also under WLAN coverage. It is worth mentioning here that if the UUT is located in an area where there is coverage of various RANs then the MN receives RAs from the IR's where the RANs are connected to. The procedures are executed as follows:

1. When the MN starts receiving RA from both IRs, it realizes that a VHO may be near to happen and then a HO preparation message is sent to the current IR. This message triggers the creation of a tunnelling mechanism between the IRs. In the testbed, the TS emulates that tunnel by connecting simultaneously the UUT to both IR's instead of physically creating a tunnel between the IR's. However, in the following we refer to this mechanism as the *Inter-IR tunnel*. Then, as long as the Inter-IR tunnel is active, data packets for-

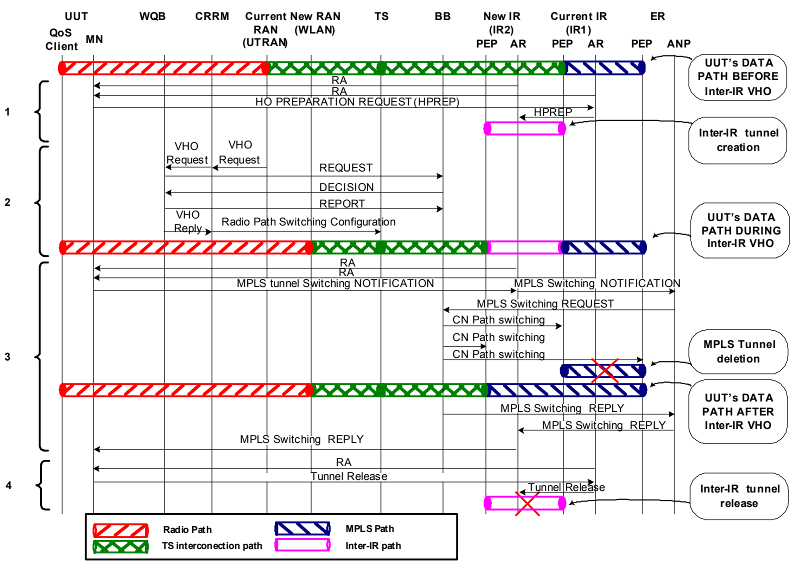

Figure 2. Signalling during an Inter-IR VHO with HO preparation.

warded to either IR1 or IR2 are captured and sent to UUT.

2. Next, if RAT selection procedures executed in CRRM determine that a VHO from UTRAN to WLAN is needed, then CRRM requests it to WQB. Then, WQB initiates an e2e QoS renegotiation that finishes with a new radio bearer established to the new RAN and the UUT connected to the new IR. However, at this moment the MPLS tunnel is not changed yet. Notice that if the Inter-IR tunnel had not been created, packet loss would have been produced until the BB is informed to switch the MPLS tunnel.
3. When MN realizes that IR2 is more convenient than IR1, it requests an IR/MPLS tunnel change to the ANP, which forwards it to BB. As a result, a new MPLS tunnel is established to the new IR, and the old MPLS tunnel is released. Notice that the RA period (the time between two consecutive RAs) is greater than the CRRM measurements to perform VHOs and then, VHOs are executed before IR/MPLS tunnel switching. Thus, the RA period highly impacts on the time interval where there is a misalignment between the RAN and CN paths.
4. Finally, once RAs from only one IR are available, the MN requests to release the Inter-IR tunnel.

IV. RESULTS

Different trials have been defined to test MM techniques. In the trials considered in this paper, the UUT requests a streaming session with a guaranteed bit-rate of 192 kbps and makes use of real applications to watch the streamed movie. Concretely, Darwin Streaming Server [19] is run on the applications' server, which contains media of different bit-rates and codecs including video and audio. For all the trials presented, a 128 kbps video sequence of approximately 120 seconds coded with a H.264 variable bit-rate video codec is used. This video (in the following Video Under Test – VUT) is requested by a VideoLan Client (VLC) [20] running in the Client machine.

In all these trials the UUT moves within an 8 km × 4 km service area with 13 UTRAN and 13 GERAN co-located base stations and 6 WLAN hot-spots. However, GERAN is not considered in these trials because the service under test is streaming. Desired HOs are produced by properly defining the UUT's trajectory between base stations and CRRM technology preference weights for RAT selection algorithms [9]. UTRAN is attached to IR1 whereas WLAN is attached to IR2 (except for the case when Intra-IR VHO is evaluated where both RATs are attached to IR1). Apart from the UUT, a total of 1000 emulated users are uniformly deployed over the scenario: 500 conversational, 300 interactive and 200 streaming users. The UUT moves along the scenario and requests streaming sessions with guaranteed bit-rates of 192 kbps in downlink.

As explained in section III, HO impact will be considered in different ways. To test HHO, a periodic HHO is produced by setting the UUT's trajectory between two UTRAN base stations. In case of a VHO trial, periodic VHOs between WLAN and UTRAN are forced. These VHOs may include IR change (Inter-IR VHO). In this case, the MPLS tunnel switching is triggered once the MN entity detects that there is a change of IR based on received RAs. Three different RA periods will be tested: 1s, 5s and 10s. In case of Intra-IR VHOs the transfer policy effectiveness will be compared with the case when no advanced policy is used.

Results are given in terms of packet loss percentage due to HOs, subjective user's QoS in terms of Mean Opinion Score (MOS) and qualitative results such as testbed's real-time statistics and video snapshots. Different levels of QoE degradation are expected depending on the HO type.

Fig. 3 depicts the average packet loss measured at the UUT's PC for the different HO types studied in this work. For testing these values, a 128 kbps constant bit-rate UDP downlink stream is sent from the applications' Server machine to the UUT. A traffic generation application was used to create the stream. Each value was obtained by averaging statistics during a period of 30 minutes when around 100 HOs occurred during that time.

No packet loss is observed with HHO whereas in the case of Intra-IR VHO it can be noticed that when the transfer policy is enabled, then almost no packet loss is perceived. Nevertheless, without the transfer policy, some packet loss is produced due to the discarding of the packets accumulated in the old RAN that will not be transferred to the new RAN. Finally, a comparison between the Inter-IR VHO with and without HO preparation is shown. In both cases, it is observed that the average packet loss is greater than in the Intra-IR VHO case due to the data path switching mechanisms in the RAN and CN parts. When HO preparation is disabled, the packet loss increases with the RA period, since longer periods of misalignment between the paths through the RAN and CN parts are given. As a result, the greatest packet loss is measured for a 10s RA period with no HO preparation. However, when the HO preparation is enabled, inter-IR tunnel allows maintaining the packet loss below 2.5% regardless of the RA period.

In order to give a qualitative validation of the HO procedures, the testbed offers the possibility to visualize in real-time the statistics of the different modules in execution. Fig. 4 shows an example of the testbed's statistics when Intra-IR VHO occurs during one of the packet loss experiments explained above. Subplots (a) and (b) depict the current RAN the UUT is attached to (UTRAN=0 and WLAN=2). Therefore, the instants where a VHO occurs can be dynamically seen in statistics. Subplots (c) and (d) show the current IR in use. It can be observed that in this kind of trials there is no IR change each time a VHO is performed. Finally, subplots (e) and (f) repre-

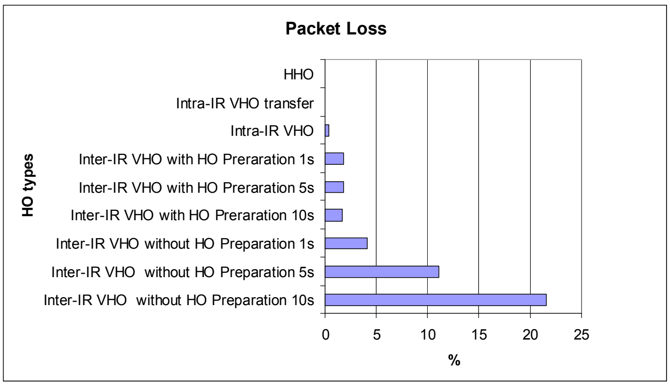

Figure 3. Average packet loss for different HO types.

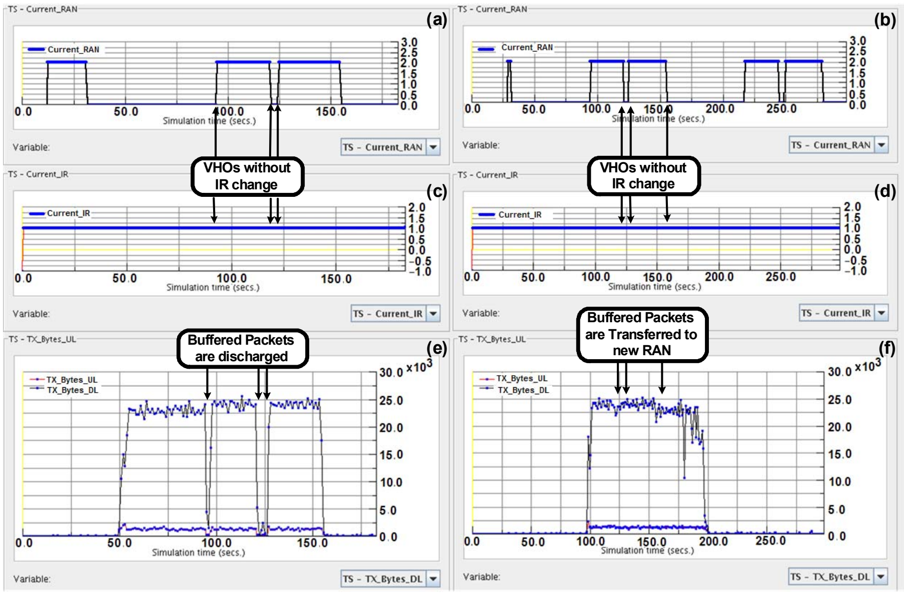

Figure 4. Intra-IR VHO without transfer policy (a), (c) and (e), and with transfer policy (b), (d) and (f)

sent the bytes transmitted to the UUT. Left hand-side subplots present the case where the transfer policy was disabled in CRRM. In this case, it can be seen that significant throughput cuts are observed each time there is a VHO. This situation may incur in packet loss and unacceptable delays. However, no throughput cut-offs are perceived in the transmitted bytes to the UUT in the right side subplots (where the transfer policy was enabled). Notice that this kind of qualitative measurements can not be done without a real-time testbed which gives an insight into the HO influence on the user's current traffic flows.

The QoE of the UUT is depicted in Fig. 5. Values represented are computed by averaging 10 repetitive tests for each HO type. The MOS values are represented for the different HO types considered in this paper. In our study we use a full-reference model-based objective metric [21] for the QoS evaluation based on ITU recommendation [22]. This kind of methods compares a reference sample of the VUT with a degraded sample obtained at the output of the system (e.g., after passing through the testbed). As a result, a satisfaction level measurement is given by the QoS evaluation method. This metric tries to express the subjective score that human beings would have given to the experiment. Then, satisfaction level is expressed as a number between 1 and 5. The satisfaction level of 5 corresponds to a perfect quality of perception (e.g., the transmitted video sequence is not degraded at all); while a score of 1 means complete loss of information. Nevertheless, these methods rarely give a degradation level equal to 5 since human perception is reluctant to give the maximum score (i.e., perfect perceived quality) even if the compared videos are equal. Again, the HO preparation mechanism considerably improves the QoE metric obtained and, independently of the RA period, the streaming session quality is good for the UUT. Thus, the HO preparation mechanism adds robustness to the user's session and helps preserving the e2e QoS.

In order to show qualitative results, Fig. 6 and Fig. 7 show the testbed's real-time statistics and snapshots of the VUT seen by the UUT respectively. These figures are obtained for the Inter-IR VHO with a RA period of 10s. For comparison purposes, the HO preparation mechanism is considered as well. Left side subplots of Fig. 6 show the statistics without HO preparation whereas right side subplots show the statistics with this functionality enabled. Fig. 6 (a) and (b) depict the instants where the MN triggers the MPLS tunnel switching, whereas Fig. 6 (c) and (d) represent the instants where a VHO is performed. It can be seen that the MN realizes it has to trigger an MPLS tunnel switching some time after a VHO is performed (because of the RA period granularity). During that time, RAN and CN paths are misaligned (i.e., the RAN part is attached to one IR and the CN part is delivering packets to the other). As a result, some disruptions of the transmitted bytes to the UUT are observed in Fig. 6 (e) when no HO preparation is performed. On the other hand, by enabling the HO preparation mechanism, Fig. 6 (f) demonstrates that, thanks to the tunnelling mechanism previously established between IRs, no throughput disruptions are perceived during the VHO procedure.

Finally, Fig. 7 shows several snapshots of the VUT when HO preparation was enabled and disabled. Instant (a) represents the VUT right before the VHO is executed. Instants (b),

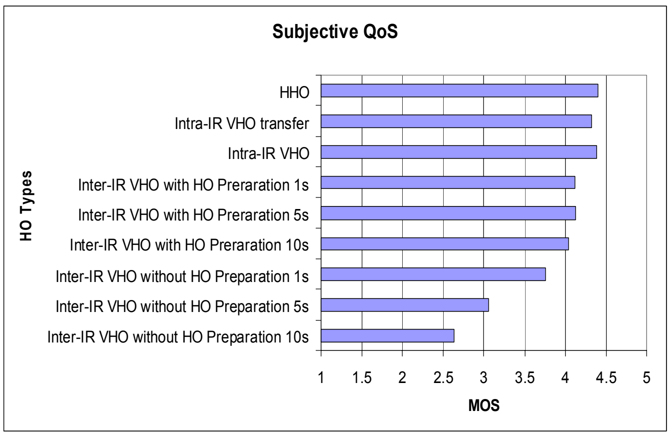

Figure 5. Mean Opinion Score for the different HO types tested

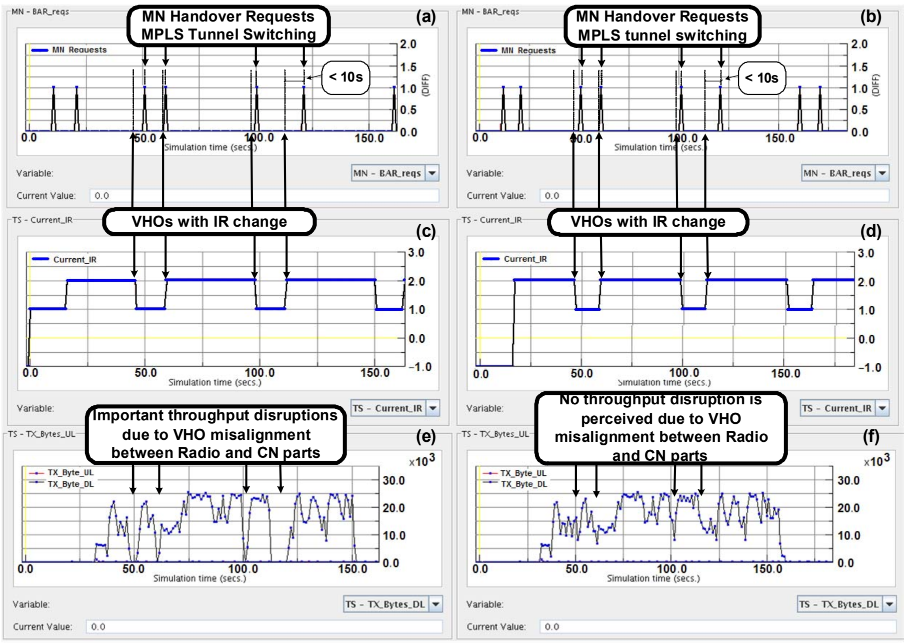

Figure 6. Inter-IR VHO with 10s of RA period, without HO preparation (a), (c) and (e) and with HO preparation (b), (d) and (f)

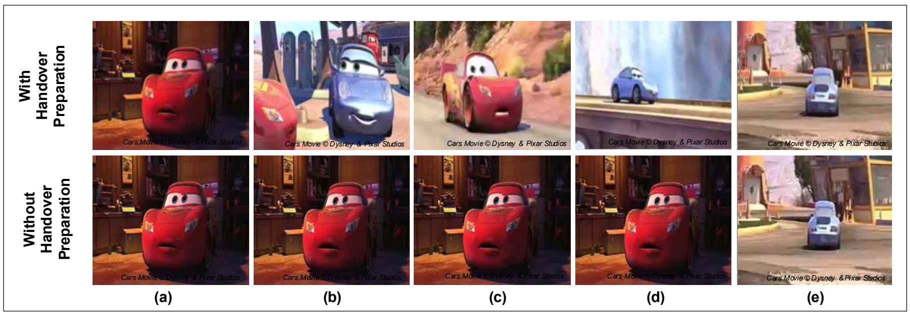

Figure 7. Example of the user's QoE with and without HO preparation

(c) and (d) show snapshots of the VUT during the VHO execution. It can be seen that when the HO preparation is disabled, the VUT remains frozen at the UUT's screen due to the throughput disruptions that incur in significant packet loss (as it can be corroborated in Fig. 3). However, if the HO preparation is enabled, then the VUT is perceived normally in the UUT's screen since streaming packets in downlink are not dropped but captured in real-time by the TS from the old IR interface and delivered to the UUT after the radio emulation. Finally, at instant (e) the VHO finishes and the video continues normally for both trials.

V. CONCLUSION

In this paper the Quality of Experience (QoE), i.e. the subjective perception that the user has of the service, has been evaluated under the Quality of Service (QoS) aware mobility mechanisms developed within the testbed of AROMA and COSMOS projects. Quantitative and qualitative results have been given to proof that the QoS-aware mechanisms implemented in the testbed could alleviate packet loss and improve subjective Mean Opinion Scores. By using real applications it has been proven that handover preparation mechanisms significantly improve the QoE. Concretely, it has been shown that an advanced Inter-IR tunnel mechanism will help in the QoS preservation during VHOs, since data packets are captured and forwarded between IRs during the VHOs, making the process insensitive to Route Advertisement periods. In addition, intra-domain mechanisms such as the transfer policy in the radio access domain improve the QoS in terms of packet loss.

To perform these tests a testbed, where the MM strategies have been implemented, has been employed. This tool constitutes a useful platform to conduct real-time experiments and accurately assess the performance of end-to-edge QoS mechanisms devised for next generation networks. Thus, the testbed enabled to obtain results that could not be easily obtained with off-line simulations. Moreover, it has been shown that the testbed can also be used to evaluate the performance of real multimedia applications or software modules before install them in real networks.

Finally, it is worth mentioning that demonstration videos of the testbed can be found at http://www.aroma-ist.upc.edu, where the configuration procedures, execution management and examples of the results that are obtained with the testbed (included the mobility management results given in this work) are shown.

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