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 utilized. A real-time testbed that provides end-to-edge QoS in all-IP heterogeneous wireless access networks has been employed to show QoE results that hardly could be obtained by means of simulations.**

Keywords – heterogeneous wireless 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 networks since continuous changes in the Radio Access Network (RAN) and Core Network (CN) attachment points are expected for the user throughout the session lifetime. Efficient execution of the 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 works regarding the scalability, performance and QoS management of mobility architectures and protocols in heterogeneous wireless 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 will be referred to as Quality of Experience (QoE) in this work.

A sophisticated real-time testbed has been developed within the AROMA project [6] 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, including the effect of other users, produces on a user of special interest named here as the User Under Test (UUT). Moreover, IP-based applications such as videoconference, streaming services, or web browsing can be executed to have multimedia flows for the UUT through the testbed.

In this context, the aim of this paper is to present the impact on the QoE experienced by the user of the MM strategies followed within the project. It is important to remark that the results presented in this paper 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 network (i.e., 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 AROMA 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 AROMA 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 could be interested in [11].

The AROMA testbed reproduces in a realistic way a Beyond 3G heterogeneous radio access network that includes three RANs (UTRAN-HSPA, GERAN, and WLAN), interfacing a common CN. The latter 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 incorporates the capacity to evaluate the QoS experienced by the user executing real applications.

Fig. 1 shows the functional architecture of the AROMA 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 red and blue dashed connections correspond to control plane interfaces. The UUT (the real user in the testbed) has at his disposal one stand-alone PC to run the application (application's client), and one additional stand-alone PC to run the main functionalities associated to the User Equipment (UE) – QoSClient (entity that negotiates QoS with the system) and Mobile Node (MN, that bares mobility information of the user). 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 stand-alone PC.

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 software mapping of the RANs to each IR that is set at the beginning of the testbed's execution (e.g., UTRAN is said to be 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 re-injects them in the interface of the IR to which the RAN has been configured to be connected to. 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 as well. The QoSClient is the entity that provides an interface from where 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 QoS that the UUT requests must be preserved along the RAN and CN domains and throughout the entire session's lifetime. For that purpose, the BB is the entity that handles the QoS management in the CN, by configuring the proper DiffServ filters in the IRs and 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 experienced.

In contrast, 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).

III. Mobility Management in AROMA

A. *Mobility Management Architecture*

MM is a functionality included in AROMA testbed to provide QoS-aware IP micro-mobility. Macro-mobility approaches such as Mobile IP [13] incur in excessive signalling between the 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 correspondent node. This provokes additional delays, packet loss and, obviously, 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 MN. HAWAII [17] and Cellular IP [18] are examples of these protocols.

In the AROMA 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 and 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

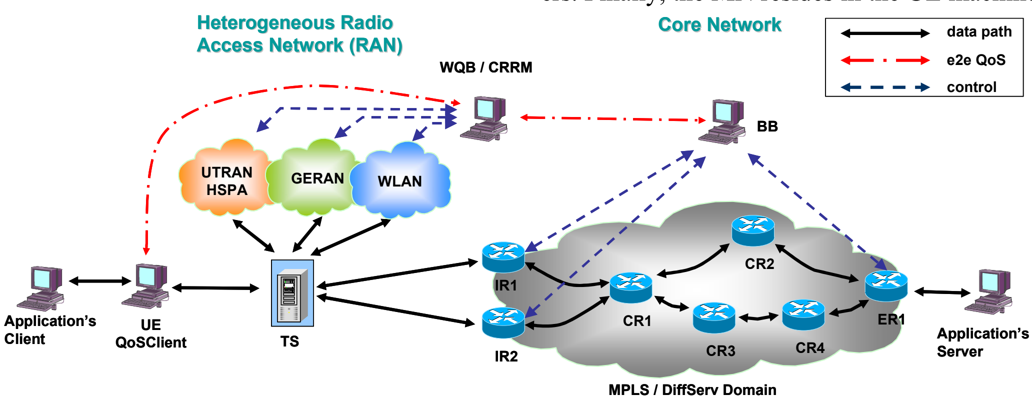

Figure 1. AROMA testbed functional architecture.

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

As the UUT moves along the scenario, different Handover (HO) types are implemented in the AROMA testbed:

- 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 of forwarding 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. To determine the IR from where to capture (downlink) or inject (uplink) UUT's packets, a mapping of the RANs to each IR is configured in TS (e.g., UTRAN is attached to IR1 while GERAN and WLAN to IR2). Each time there is a VHO that includes IR switching (e.g., from UTRAN to WLAN), 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 radio 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.B. Finally, this kind of VHO also implies an e2e QoS renegotiation between the WQB, BB and optionally QoS-Client, what gives to the mobility the proper QoS awareness. It is clear that a lack of synchronization between the MPLS tunnel switching in the CN and the VHO in the radio 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 AROMA testbed. This procedure establishes prior to a VHO (concretely, when the MN is receiving RA from both IRs), an *Inter-IR tunnel* (between IRs) to minimize packet loss during the VHO execution, as it is explained in the following sub-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 wireless path or bearer (in red[1]) is therefore established between the UUT and UTRAN. The TS physically interconnects the UUT with IR1 in the CN (in green) while the BB establishes an MPLS tunnel along the CN (in blue). 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 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 (in magenta) 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. Nevertheless, 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 forwarded to either IR1 or IR2 are captured and sent to the UUT.
2. Next, if WLAN gives better signal strength than UTRAN the CRRM requests from the WQB a VHO from UTRAN to WLAN, which 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 the signal strength from IR2 is greater than from IR1, it requests an IR/MPLS tunnel change to the ANP that forwards it to BB. Notice that the RA period (the time between two consecutive RAs) is greater than the CRRM measurements to perform VHOs and then, VHOs execute before IR/MPLS tunnel changes. Thus, the RA period highly impacts on the time interval where there is a misalignment between the radio and CN paths. Then, a new MPLS tunnel is established to the new IR, and the old MPLS tunnel is released.
4. Finally, in the case RAs from only one IR are available, the MN requests to release the Inter-IR tunnel.

In conclusion, the QoS-aware MM management procedure implemented in the AROMA testbed is able to handle mobility events while preserving the e2e QoS. Also, the Inter-IR tunnel mechanism will help in the QoS preserving during VHOs.

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[1] For readers with B/W prints please refer to legend within the figure.

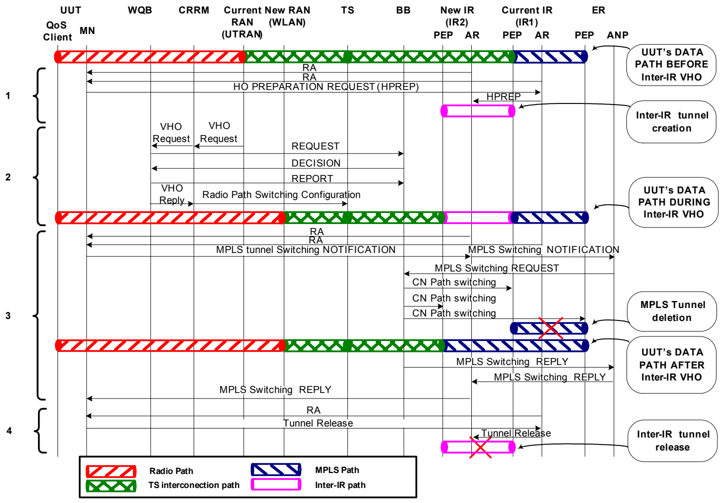

Figure 2. Signalling during an Inter-IR VHO with HO preparation.

IV. RESULTS

Different trials have been defined to test MM techniques. In the trials considered, 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, Apple Darwin Streaming Server [19] is run in the applications' server machine that 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 Video-Lan Client (VLC) [20] running in the Client machine.

In all these trials the UUT is moving within an 8 × 4 km service area with 13 UTRAN and 13 GERAN co-located base stations and 12 WLAN hot-spots. Nevertheless, GERAN is not considered in these trials because the service under test is streaming. Desired HOs are forced 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 is moving at 50 km/h and requests a streaming session 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. Thus, 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. However, 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 and no HO preparation. However, when the HO preparation is en-

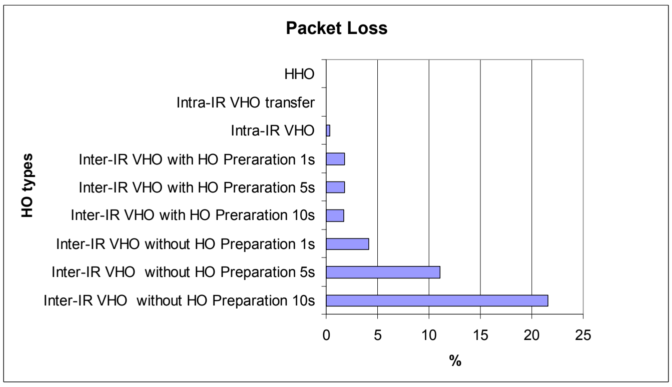

Figure 3. Average packet loss for different HO types.

abled, 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 of visualizing 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 and one of the experiments explained above is taking place. 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) represent 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 cuts are perceived in the transmitted bytes to the UUT in the left 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 original video and a not degraded copy are compared); 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 of the e2e QoS.

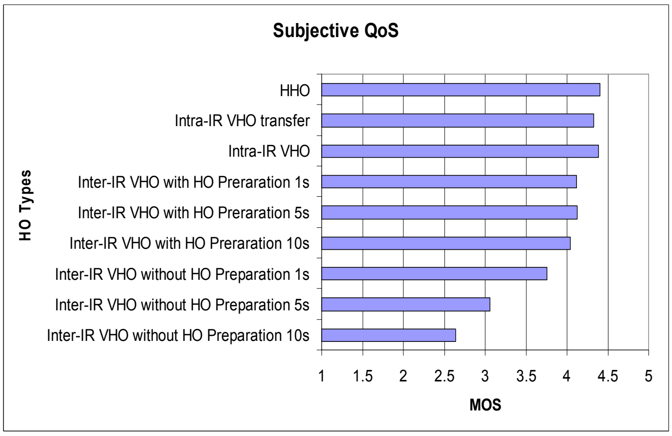

Figure 5. Mean Opinion Score for the different HO types tested

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 per-

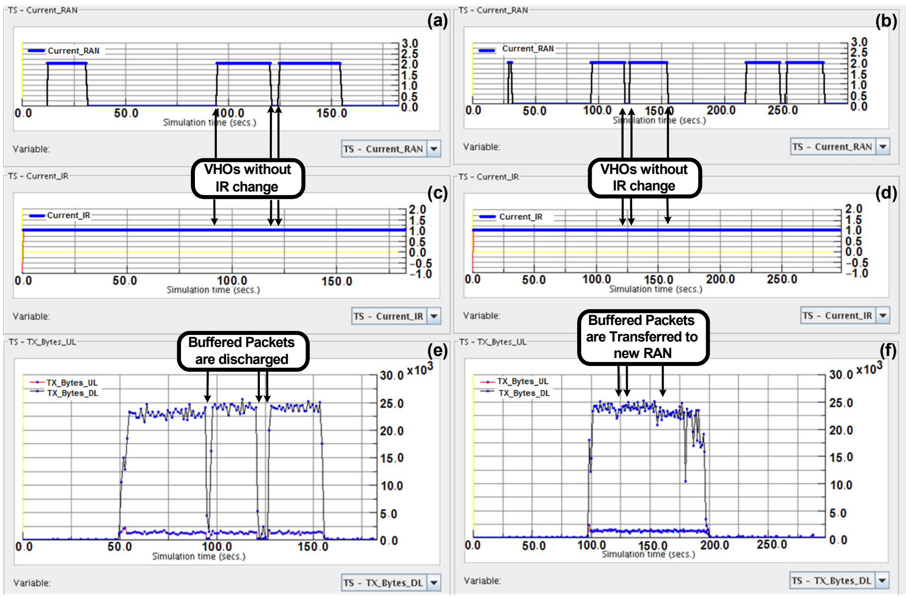

Figure 4. Intra-IR VHO without transfer policy (a), (c) and (e), and with transfer policy (b), (d) and (f)

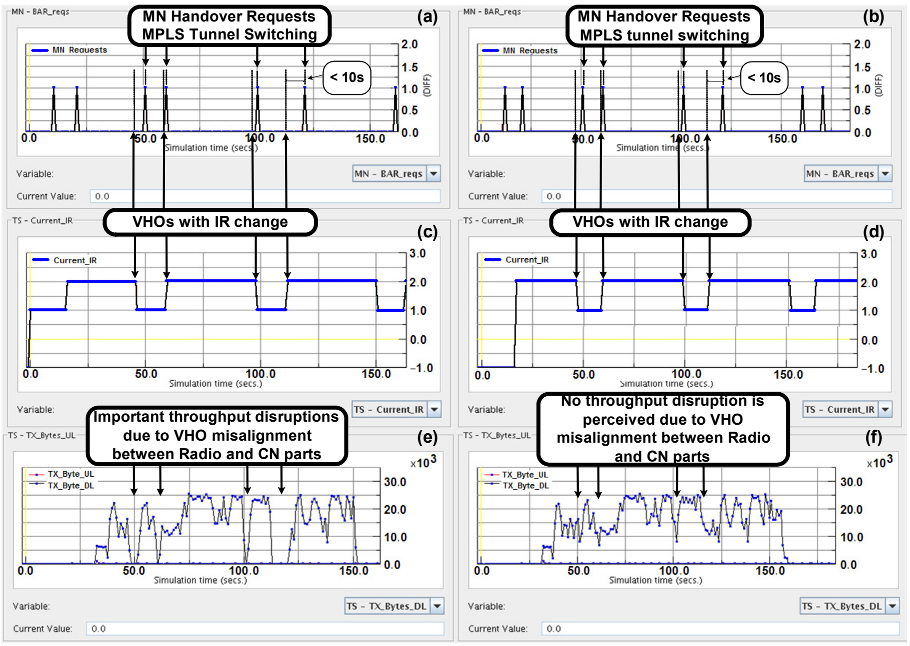

Figure 6. Inter-IR VHO with 10s of RA period, without HO preparation (a), (c) and (e) and with HO preparation (b), (d) and (f)

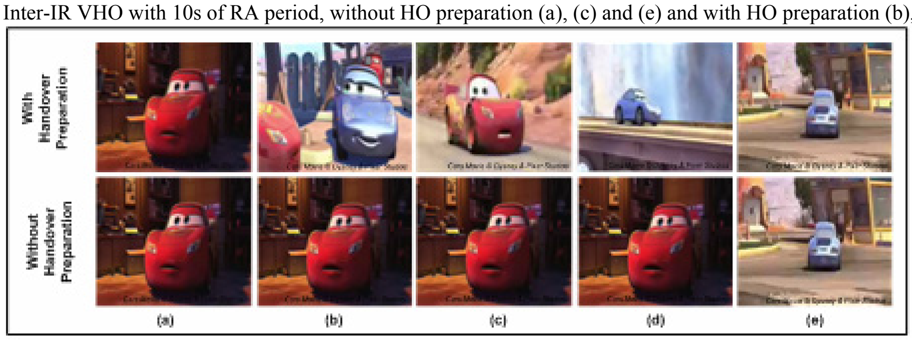

Figure 7. Example of the user's QoE with and without HO preparation

formed. 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), (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 VUT is perceived normally in the UUT's screen since streaming packets in downlink are not dropped but captured in real-time in TS from the old IR interface and delivered to the UUT after radio emulation. Finally, at (e) the VHO has terminated and the video continues normally for both trials.

V. CONCLUSION

The presented testbed constitutes a very powerful tool to perform realistic trials in the context of a heterogeneous wireless access network. Concretely, in this paper the Quality of Experience (QoE), i.e., the subjective perception the user has of the service, has been evaluated under the Quality of Service (QoS) aware mobility mechanisms developed within the AROMA project. By using real applications it has been proven that handover preparation mobility mechanisms significantly improve the QoE. In addition, intra domain mechanisms such as the transfer policy in the radio access domain improve the QoS in terms of packet loss. Thus, the AROMA testbed 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. Moreover, it has been shown that the testbed can also be used to evaluate the performance of real applications. Finally, it is worth mentioning that demonstration videos of the testbed can be found at AROMA's web page (http://www.aroma-ist.upc.edu), where the configuration procedure, execution and examples of the results that can be obtained with the testbed are shown.

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