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D20

Trial results and algorithm validation

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Abstract:

This report contains the results obtained in the execution of the test plan elaborated to perform the trials. An analysis of results is also done comparing them with those expected to be obtained, in order to evaluate and validate activity carried out within the project.

Keyword list: Trials results, test bed.

DISCLAIMER

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EXECUTIVE SUMMARY

The aim of this document is to provide the results of the trials described in deliverable “D15 – Trials Description”. Different scenario demonstrations have been performed in the AROMA testbed for testing and validating the proposed RRM/CRRM/BB algorithms, E2E QoS strategies and mobility mangement.

As described in D15 those trials are focusing in five main areas, going from Quality measurements with applications to the test of some RAT selection/CRRM algorithms, E2E QoS strategies, Admission Control algorithms in the BB and finally with QoS and mobility.

In each area several demonstrations are defined, and obtained results and its analysis have been done for each one.

The testbed definition and presentation is not the intent of this deliverable. That information has been presented in “D07 - Testbed Specification”, (30-6-2006) document that should be used as reference to understand the testbed architecture and available functionalities.

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1 INTRODUCTION

This deliverable is devoted to present the results of the different demonstrations proposed in deliverable D15 - Trials Description [1]. Different scenario demonstrations have been performed in the AROMA testbed for testing and validating the proposed RRM/CRRM/BB algorithms.

As described in D15 those trials are focusing in five main areas, going from Quality measurements with applications to the test of some RAT selection/CRRM algorithms, E2E QoS strategies, Admission Control algorithms in the BB and finally with QoS and mobility.

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The testbed definition and presentation is not the intent of this deliverable. That information has been presented in “D07 - Testbed Specification”, (30-6-2006) document that should be used as reference to understand the testbed architecture and available functionalities.

The document is organized as follows. Firstly the QoS perception measured with real applications is evaluated in area 1. Then the Radio Access Technlogies selection/CRRM algorithms are analyzed in area 2. Next the proposed strategies for providing e2e QoS management are evaluated in area 3. After this, test to show the admission control algorithms in the Bandwidth Broker are included in area 4. And area 5 close with the QoS and mobility tests devoted to analyse the IP handover delay. Finally, overall conclusions are presented.

2 AREA 1: QUALITY MEASUREMENTS WITH APPLICATIONS

The QoS perception has been defined as one of the goals in the AROMA testbed [2]. The demonstrations under this area have been defined with aim to evaluate the variation in perceived QoS experienced by a user running multimedia applications when changing QoS management policies or algorithms.

The primary requirement for the applications that should be used in perceptual QoS evaluation is to be widely available. Both commercial and open source applications, that coupe with this, are considered. Depending on the specific behaviour in the network that is tried to be evaluated, some of the applications that may be used are given in Table 1. The rest of this chapter will explain under which circumstances (network conditions) are those applications used to evaluate the perceived QoS.

To evaluate the perceived QoS, the application needs to be captured on the user’s side. The modified (degraded) multimedia contents are compared to the reference contents (originals). The applications used should respect the recommendations of QoS metrics [3][4][5][6] and be in accordance with the input file types (audio, speech or video).

Table 1- Applications involved in QoS measurements.

End to End Service	End to End Application		Capturing Application
	Server	Client	
Video Streaming	Darwin Streaming Server[7]	QuickTime Pro[11]	Camtasia Studio Recorder[13]
		VLC[12]	
Audioconference	RAT[8]	RAT	Microsoft Sound Recorder
	NetMeeting[9]	NetMeeting	
Videoconference	VIC[10]	VIC	Camtasia Studio Recorder
	NetMeeting	NetMeeting	

The general objective is to make the quality measurements with several applications in order to test the QoS perceived by the user under test (UUT) in different network (end-to-end) conditions.

Different actions (like horizontal handover, vertical handover, core network rerouting, etc.) and different CRRM algorithms or QoS policies are meant to be implemented in different scenarios to test the QoS perceived by the UUT in the testbed. At the same time, the user's application may be varied as well. In particular, the objective QoS could be measured when applications like video streaming or videoconference are run with distortion in communication due to handovers, limited bandwidth or congestion, causing packet loss or delay. However, detailing in this document exhaustive demonstrations for all the applications given above will be repetitive. Then, the streaming applications have being selected as representative for the demonstrations given in this section.

Concretely, Darwin Streaming Server is run in the Server machine and it contains media (videos) of different bitrates and codecs, including video and audio. For all the experiments presented here a video sequence of approximately 120 second of 128kbps coded with H.264 video codec and an acc audio codec has been used. Then, the mean source bitrate is 128kbps but the instantaneous source bitrate might be above and below that value. This video (in the following Video Under Test – VUT) is requested by a client streaming application run in the Client machine. Two streaming clients have been used in the demonstrations, Apple QuickTime 7.0 (QT) and open-source VideoLan Client (VLC). Then, the testbed can also be used to evaluate the performance of real applications and compare them. Although, AROMA project has no interest in highlight an application over others, the results presented in this section are given for both QT and VLC in order to stress that not only the network conditions impact the QoS experienced by the user but also the application in use.

Finally, both quantitative (packet loss, delays, etc.) and qualitative (Mean Opinion Score) results are given in addition to specific testbed statistics to explain the obtained behaviour.

2.1 Demonstration 1: Bandwidth assignment

2.1.1 Description

With this kind of test, the sensitivity of the applications to bandwidth limitation will be measured. The objective is to compare the behaviour (in terms of QoS perception) of the applications when the bandwidth of the channel is limited as it is common in wireless networks, while having variation in streaming.

For example, QT application seems to implement buffers (i.e., at the beginning of the streaming session QT tries to retrieve the whole video making use of all the available bandwidth), that will directly influence the resistance of the streaming process to different types of constrains introduced in the intermediate IP models. VLC streaming technology does not implement buffers and has a packet-by-packet behaviour. This means that VLC is more sensitive to channel bandwidth than QT.

In this demonstration, the UUT is static and located near a WLAN base station. Then the CRRM policies are configured to serve the UUT through WLAN when a streaming session is requested. Values for the requested guaranteed bandwidths in different trials are 64kbps, 128kbps, 192kbps and 256kbps. Recalling that the VUT streamed is 128kbps in average, then, poor results are expected for 64kbps bandwidths while increasingly improved results are expected for the rest of bandwidths.

2.1.2 Results – Analysis and Validation

Figure 1 shows the behaviour of QT with increasing guaranteed bandwidths. Leftmost of the figure depicts the UUT's transmitted bits through WLAN for both Downlink (DL) and Uplink (UL) directions. Rightmost shows the UUT's buffer occupancy in the base station in the radio interface. Several conclusions could be extracted from Figure 1:

1. QT tries to retrieve the movie from the server in the client side as soon as possible making use of all available bandwidth. Then, a flat and non-bursty behaviour is shown in the DL transmitted bits when the bandwidth is less or equal the VUT source rate, and the transmission of packets lasts until the end of the movie (~120s after the streaming starts). However, when the bandwidth available is above the VUT bitrate, QT at the beginning of the session downloads the video until a buffer in the client side is full and from that moment, only video packets are transmitted as long as the buffer is being empty.

2. The bits transmission duration is shortened when the guaranteed bitrate is above the source video bitrate thanks to the client buffer as is shown in Figure 1. This property makes QT more robust to some disruptions in the radio interface since the lost packets during the disruption might be stored in the buffer some time before the disruption and in consequence, the user does not perceive the packet loss. However, this dependence on buffering the packets would have negative behaviour as it will be shown in next sections.

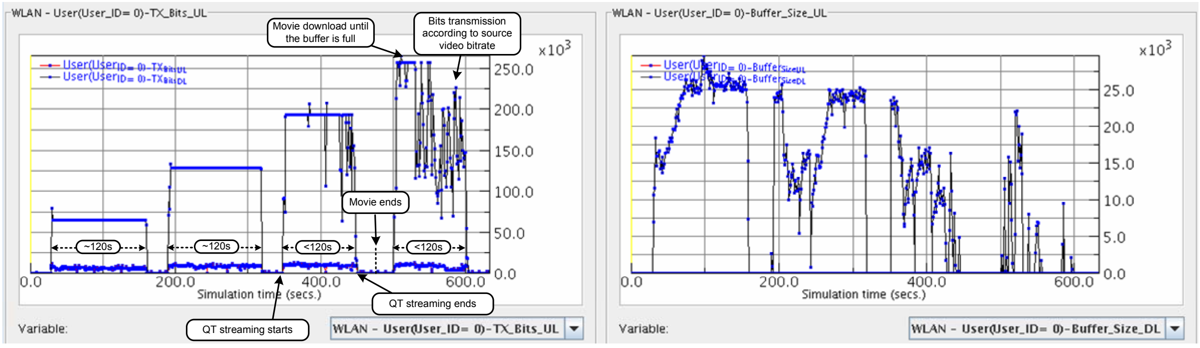


Figure 1 - QT behaviour for different guaranteed bandwidths

Figure 2 shows the VLC behaviour for different guaranteed bitrates. VLC manages the streaming differently as QT does. VLC streaming client retrieves packets from the server as long as they are needed depending on the source video encoding. Then, the transmission bits graphic shows a bursty behaviour, where if the instantaneous video rate is below the guaranteed bandwidth then the packets are transmitted without problems, but if the video rate is above the guaranteed bandwidth, then the packet is stored in the radio buffer and a 'flat' behaviour is shown. This will cause delays in the transmitted packets and since VLC does not implement any buffer in the client application, then the perceived QoS is directly impacted. In all cases (from 64 to 256kbps) the bits transmission lasts the same as the movie duration meaning that until the last second VLC is retrieving packets to show them to the user.

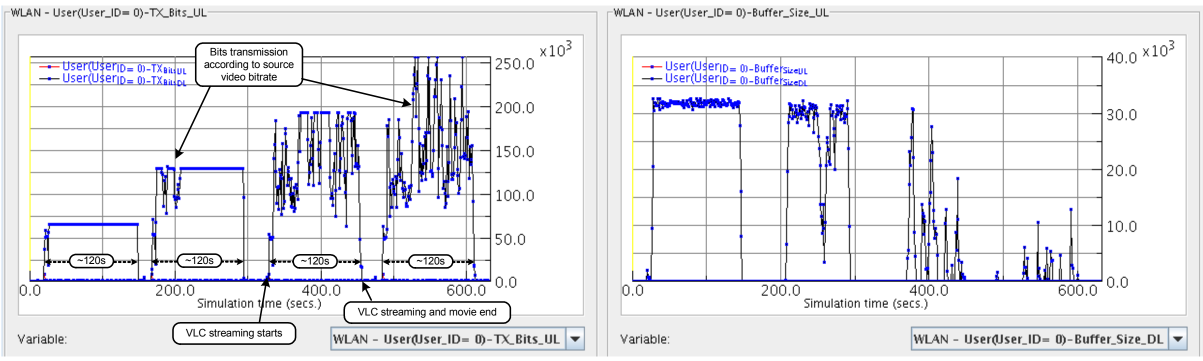


Figure 2 - VLC behaviour for different guaranteed bandwidths

In the following, the perceived QoS is measured and reported. Table 2 shows the objective Mean Opinion Score (MOS) for VUT streamed with both QT and VLC when different guaranteed bandwidths were requested. Two MOS scale are presented, the classic [1-5] scale where a score of 1 is the worst situation and a normalized scale [1-0] where again 1 is the worst situation and a score of 0 means total satisfaction. Values that pass the test (above 3 in classic scale and below 0.5 in normalized scale) are highlighted in green in Table 2, whereas they are marked in red otherwise. Then, as expected, a guaranteed bandwidth of 64kbps was insufficient for streaming the video and the test fails for both QT and VLC. As long as the guaranteed bitrate is increasing, the MOS score is also increasing or maintained in overall. Comparing, QT and VLC, QT obtains greater values since the application buffer allows to show the video to the user cleaner that VLC does. Due to bandwidth constrains, VLC loses some packets and then poor videos with frozen images periods are shown to the user.

Table 2 - MOS comparison for QT and VLC and different guaranteed bitrates

Video QoS objective values								
Guaranteed BitRate	64		128		192		256	
QoS Scale	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]
QT	1,73	0,82	4,48	0,13	4,6	0,10	4,68	0,08
VLC	1,58	0,90	4.31	0,17	4,47	0,13	4,46	0,14

As an illustrative example of the visual QoS experienced by the user, Figure 3 shows a sample frame taken during the tests for different bandwidths and each streaming client. It can be seen that for bandwidths above the streaming video rate the frame is ‘clean’ as whereas for the rest of the bandwidths that concrete sample frame was blurry, frozen or merged with previous frames.

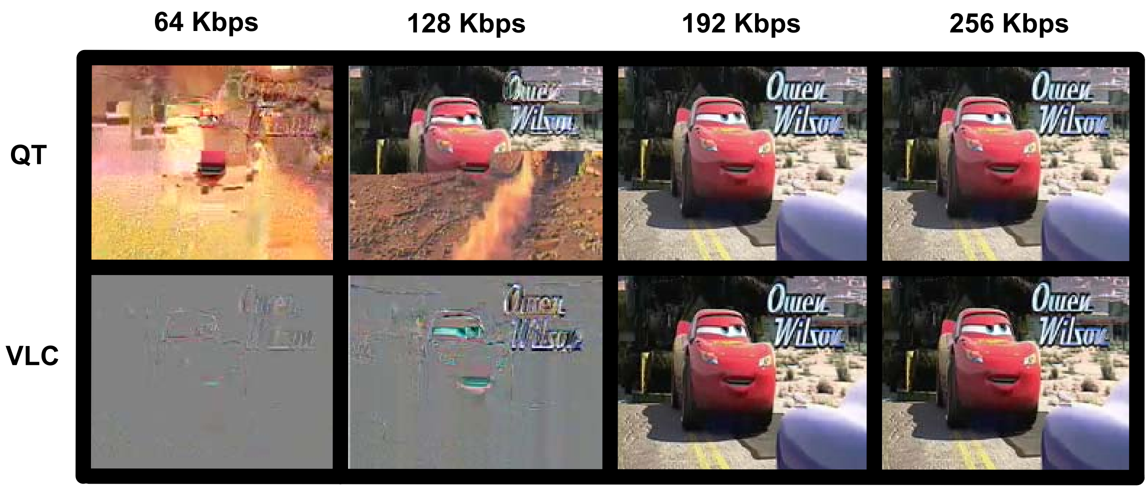


Figure 3 - Illustrative example of the visual effects of bandwidth constrains in the streamed video[1]

Finally, quantitative values of the QoS, obtained with Ethereal [14] of the Real Time Protocol (RTP) captured streams in the client side, are presented in the following. Figure 4 depicts the packet loss for different bandwidths for both QT and VLC. Figure 5 and Figure 6 show the mean packet delay between packets for QT and VLC respectively and Figure 7 and Figure 8 show the delay cumulative distribution function (CDF) which gives an idea of the mean jitter. In all figures the expected behaviour is obtained, where better values are obtained as long as the bandwidth increases and both client applications behave similar.

[1] Note that illustrative results in the figure correspond to the ending of the movie – when the bandwidth limitations that contribute distortion accumulate. This is to give emphasis to the level of distortions that may occur. However, the movie may be passing with significantly higher image quality in other instances in time, and result in quite higher marks (like in Table 2 – the movie samples compared are from the first half of the video).

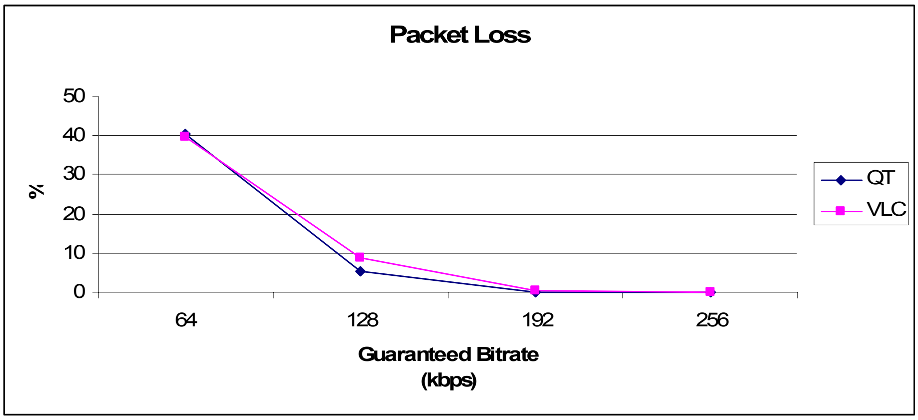


Figure 4 - Packet loss for each streaming application and different guaranteed bitrates

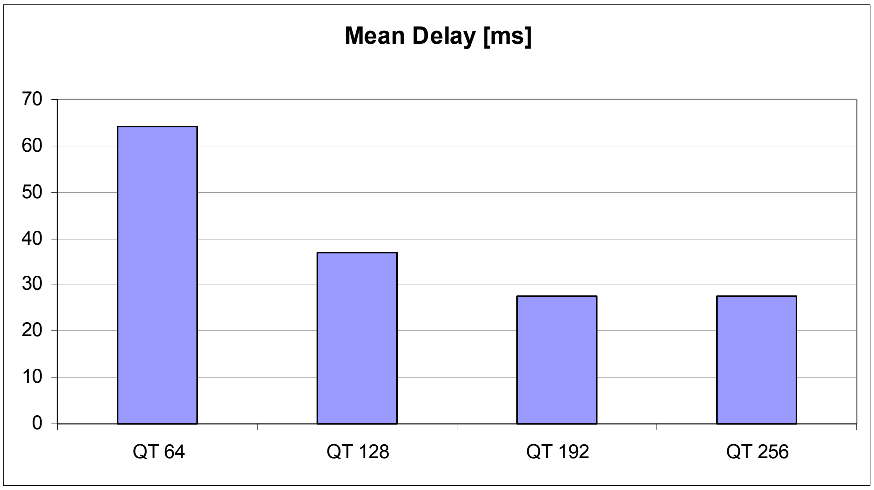


Figure 5 - Mean packet delay for QT and different guaranteed bitrates

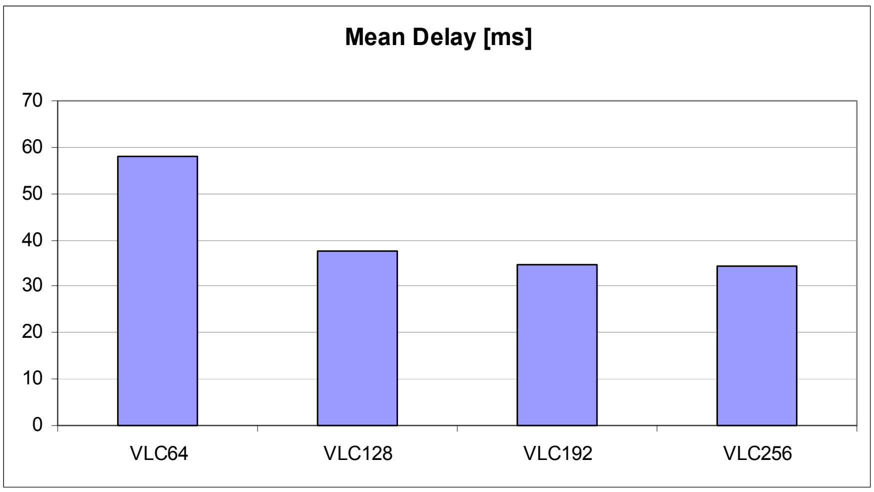


Figure 6 - Mean packet delay for VLC and different guaranteed bitrates

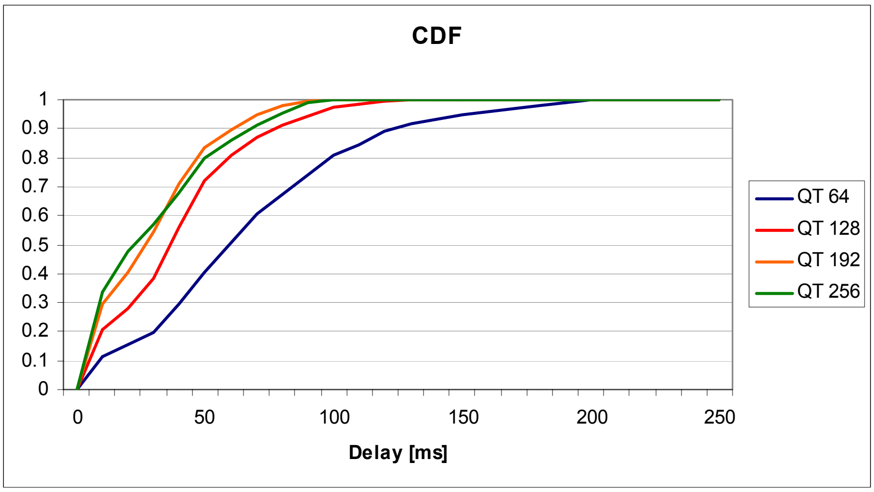


Figure 7 - Delay CDF for QT

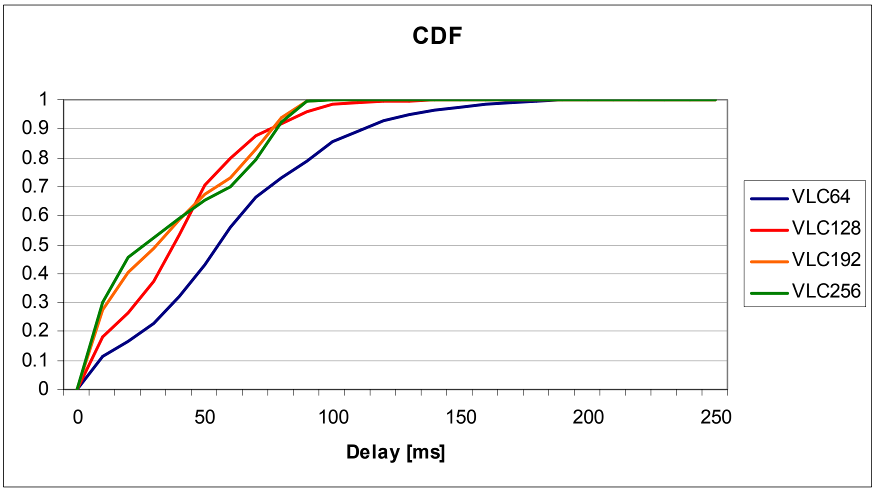


Figure 8 - Delay CDF for VLC

2.2 Demonstration 2: Handover impact

2.2.1 Description

In this demonstration the UUT is moving between base stations in order to force the UUT to have the desired HO, by defining the mobile's trajectory and technology preference weights (RAT selection) properly depending on the service under test. Then, the UUT is requesting a videostreaming session and during the session the handovers are produced.

Handover impact will be considered in four different ways. Those HO should introduce different levels of loss and delay that will influence the connection:

1. Horizontal HO.
   An Horizontal HO (HHO) is produced between two UTRAN base stations. This type of handover should produce low distorsion in the streaming since the neither RAN nor IR change is produced.

A periodic Vertical HO (VHO) between WLAN and UTRAN is produced in the rest of the tests. These VHO can include IR change or not.

2. Vertical HO without IR change.
   VHO without IR change means that the distorsion due to disruption is produced only in the Radio part since MPLS tunnels through the CN are maintained to the same IR. There is an advanced policy in CRRM to minimize the packet lost during the VHO that transfer the radio buffered packets in the old RAN to the new one. Then tests are conducted with or without the transfer policy.

3. Vertical HO with IR change.
   A VHO that includes the change of IR will introduce more service distortion. With change of IR, the duration of the HO will be longer as the e2e QoS renegotiation should be done. Also, change in IR changes the point of attachment of the UUT on the CN (i.e., it needs a MPLS tunnel switching from the old to the new IR). The MPLS tunnel switching is triggered once the Mobility Management entities detect that there is a change or IR. The MN is the Mobility management entity in charge of detecting those IR changes by receiving the Route Advertisement (RA) micromobility information periodically sent by IRs. As soon as a new RA is detected by MN, it triggers a L3 VHO requests that will provoke the MPLS tunnel switching. However, the L2 VHO (the radio VHO) is not coordinated with the L3 VHO, then some misalignments between the radio switching and the MPLS switching might appear leading to packet loss (because, for example, the radio part is trying to transmit the packets that arrive trough the new IR and the CN is still tunnelling packets to the old one). In order to test this, different RA periods are defined including 1s, 5s and 10s. Logically, the greater the RA period the grater the time that the radio and the CN parts might be misaligned.

4. Vertical HO with IR change and IP mobility management handover preparation.
   In this case, an enhancement called the handover preparation stage is introduced to the IP mobility management. In this, an IP-in-IP tunnel is established between the IRs just before the actual IP handover happens. This enhances the performance of the network by reducing the packet loss because the packets that arrive the old IR are duplicated and tunneled to the new one until the MPLS CN tunnel is switched from the old to the new IR following the same signalling explained above.

Then, different levels of service degradation depending of the HO are expected. That is, the higher the distortion introduced by HO is, the lower mean opinion score metric will be obtained. The distortion will depend on HO type, packet loss and delay. The robustness of the application and codecs in use to the aforementioned constraints may also vary the final results.

2.2.2 Results – Analysis and validation

All the results were obtained by streaming the VUT over a guaranteed bandwidth of 192kbps that previous section showed us that is not constraining the video streaming. Then the UUT is moving between the desired base stations in order to force the desired HO.

2.2.2.1 Horizontal HO results analysis and validation

Figure 9 and Figure 10 show for QT and VLC respectively the statistics collected in AGMT for three streaming session where the VUT was streamed. The UUT was moving between UTRAN base stations 2 and 3 in the scenario, and thus HHO handovers were produced between base stations. In figures, it can be seen that the current RAN the UUT is attached is UTRAN (lower left side), the active set of the UUT showing the current connected base station (lower right side), the UTRAN radio buffer occupancy in bytes (upper left side) and the transmitted bytes through UTRAN (upper right side).

Figures apparently do not show any distortion due to HHO. This has sense since the HHO management only depends on the RAN (is an intra-RAN procedure) and then is executed quickly and seamlessly to be detected by the user. This is corroborated with the perceived QoS results presented in section 2.2.2.5.

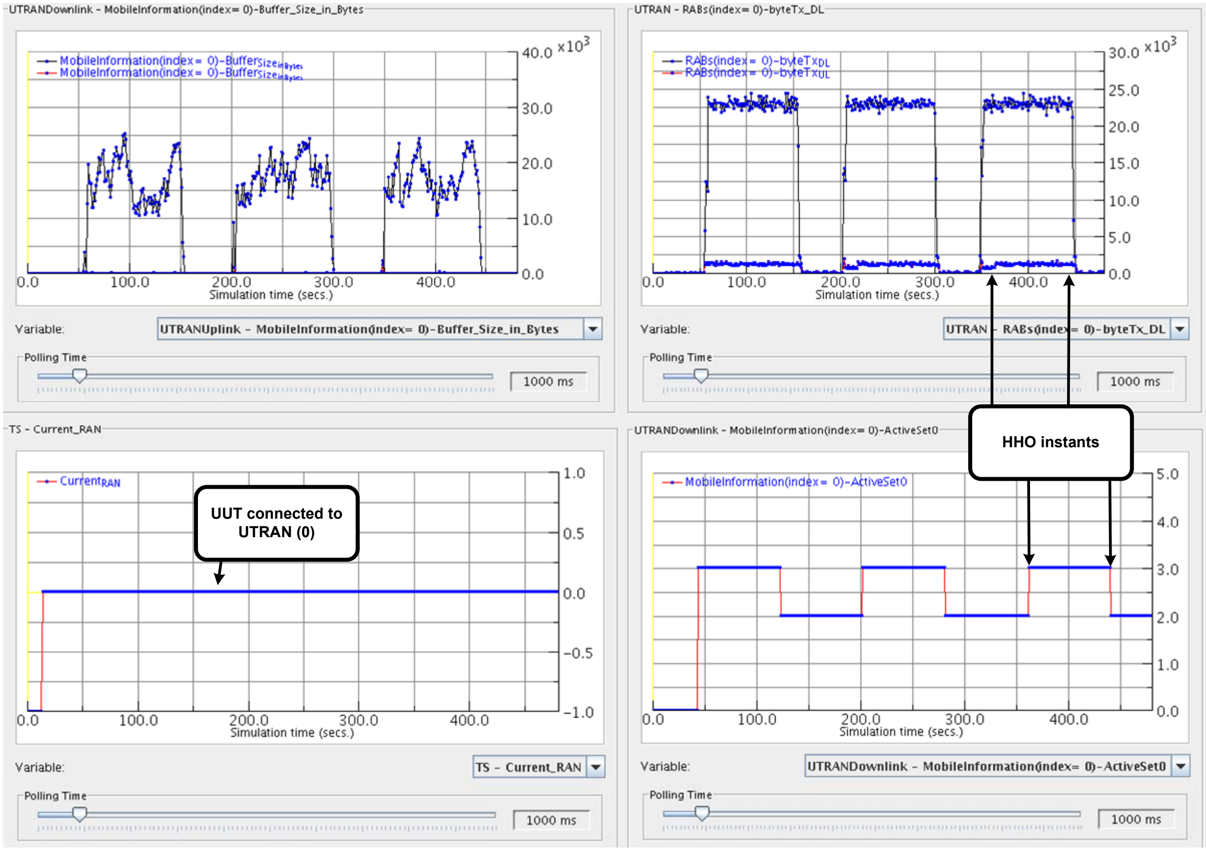


Figure 9 - HHO statistics for QT

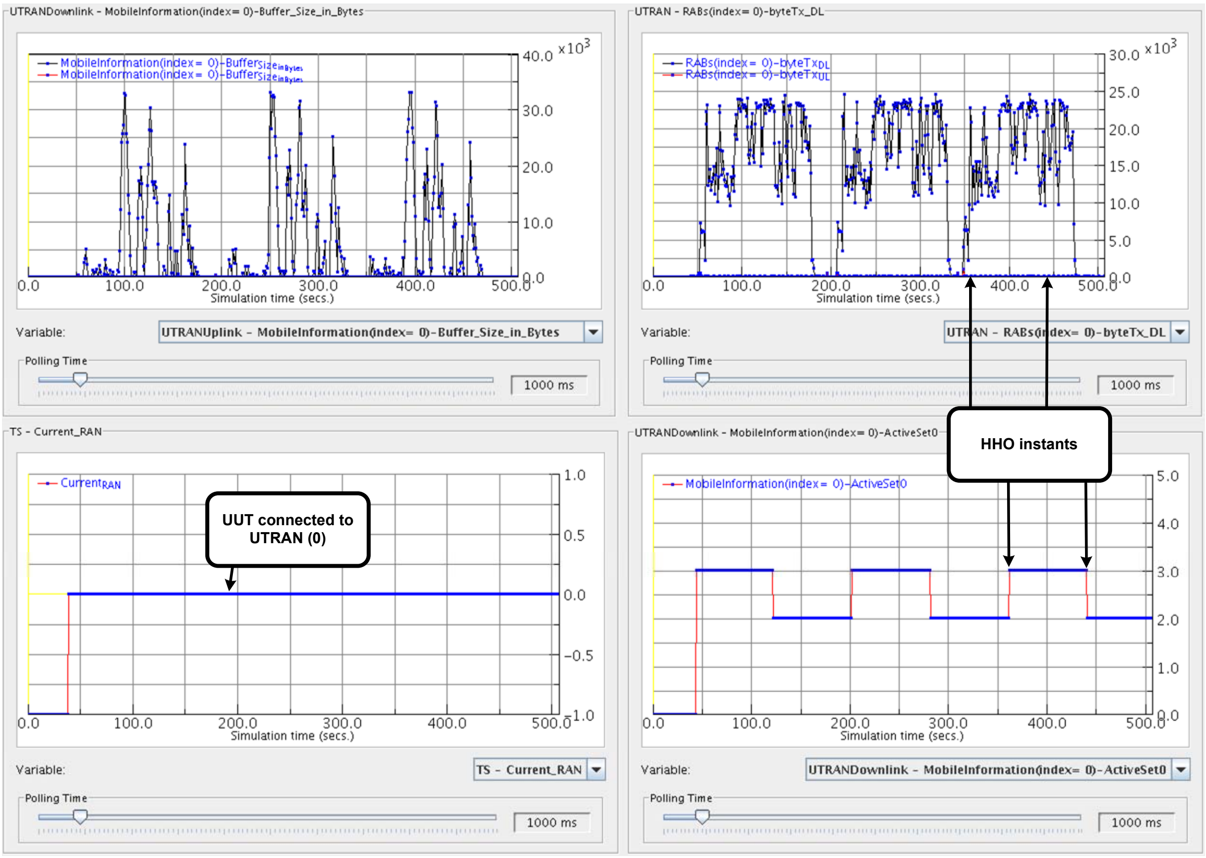


Figure 10 - HHO statistics for VLC

2.2.2.2 Vertical HO without IR change results analysis and validation

Figure 11 and Figure 12 show respectively the statistics captured in AGMT when a QT streaming session is executed without and with the CRRM VHO policy of transferring the packets accumulated in the radio buffer for the user from the old to the new RAN after a VHO. The two graphics in the lower left corner show the current RAN (UTRAN = 0, WLAN = 2) and the current IR. In this set of trials, both WLAN and UTRAN are configured to be attached to IR1 so, whenever there is a VHO between these RANs there is no change of the point of attachment to the CN. Upper left graphic and upper right graphic show the transmitted bit through WLAN and UTRAN respectively (actually, UTRAN information is represented in bytes). Finally, the lower right graphic shows the bytes transmitted to the user. In this figure we can observe the difference from using or not the VHO advanced policy of transmitting bytes to new RAN. When the policy is disabled some apparent disruption of the flow through the user is detected whereas when the policy is enabled no disruption is perceived. This is because QT is greedy demanding RTP packets that fill the buffer for the user in the RAN, so if no policy is used those packets are discarded and then a disruption is observed. Also packets are discarded in UL what also obligate QT to ask for those packets. However, when the policy is enabled, then the packets stored in buffer are transferred to the new RAN and no apparent disruption is detected.

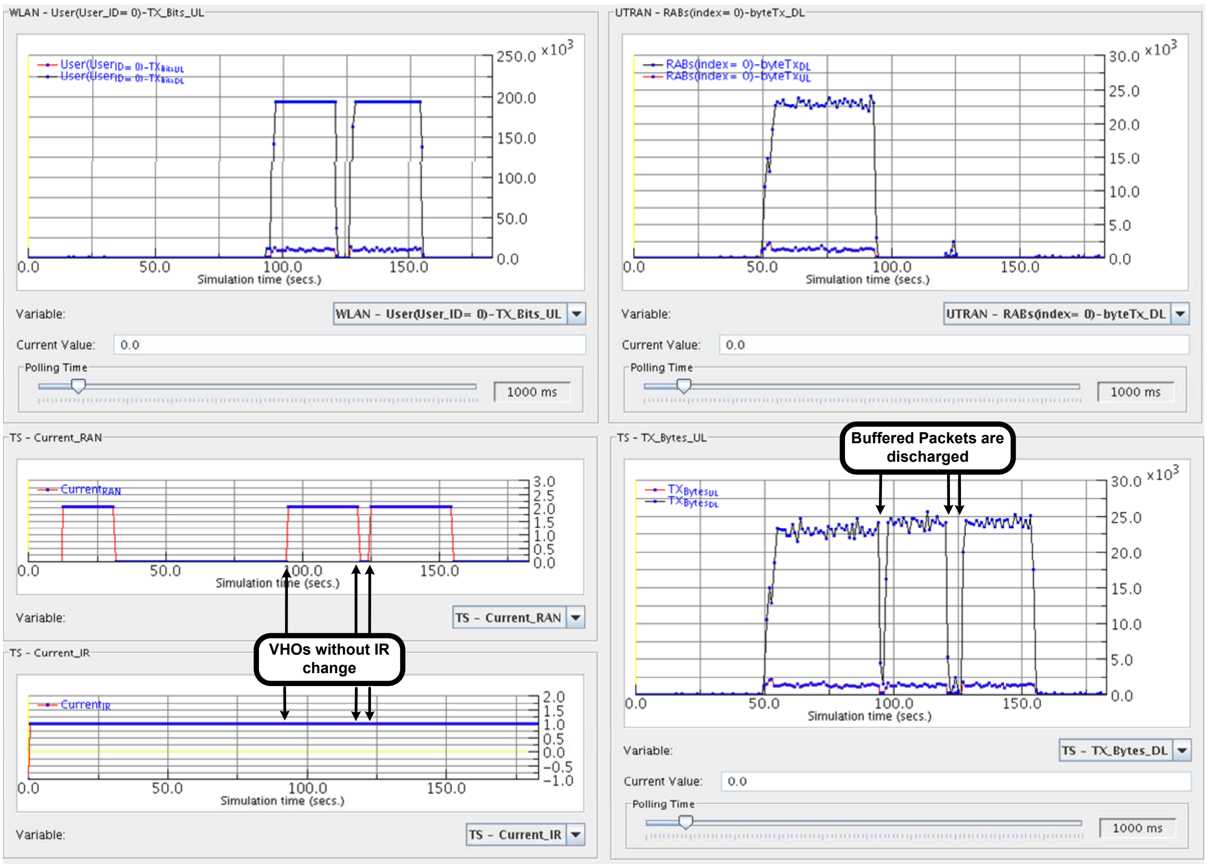


Figure 11 - AGMT statistics for QT streaming with packet transfer policy to new RAN disabled

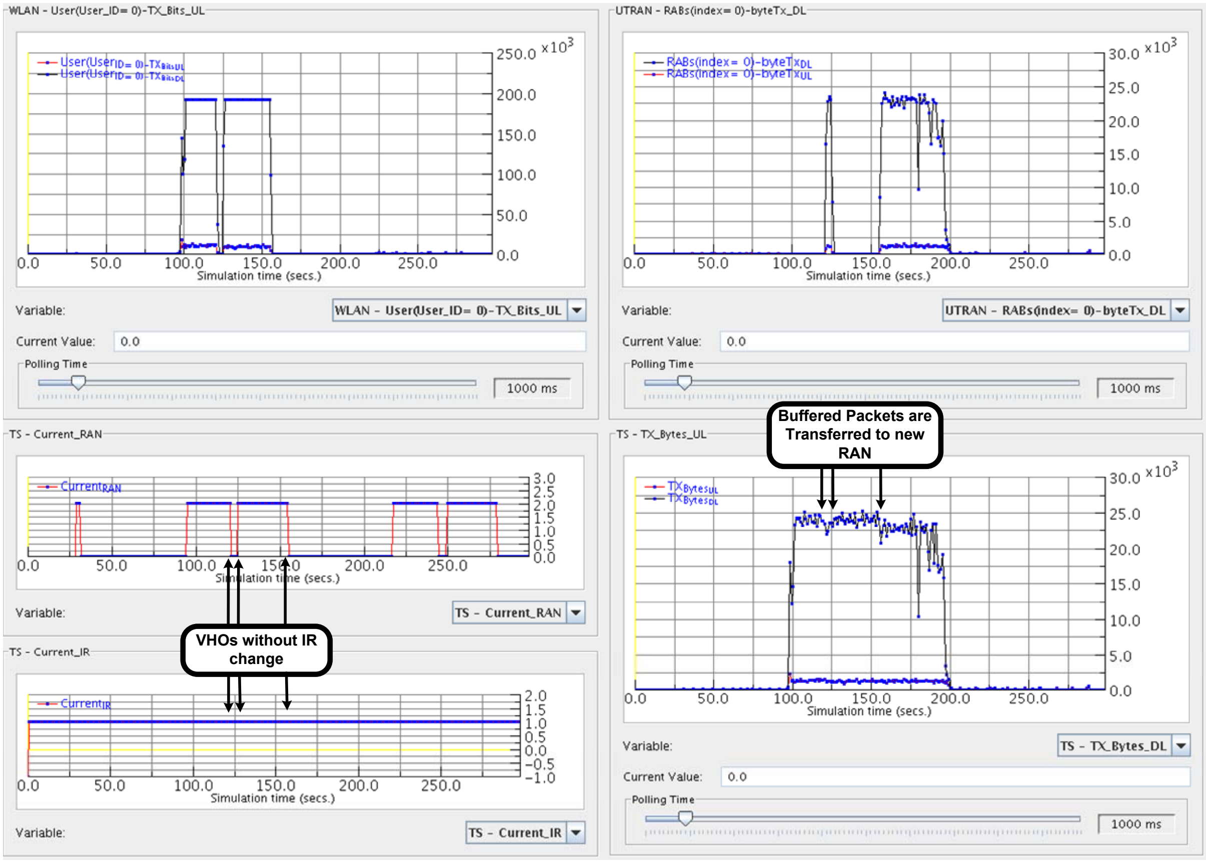


Figure 12 - AGMT statistics for QT streaming with packet transfer policy to new RAN enabled

Figure 13 sums up the aforementioned trial for VLC. Only graphics related with the VHO instants and the bytes tranmitted to the user are shown. Differently for QT, there is no difference between using or not the transfer policy. The explanation is that the 'packet-by-packet' behaviour of VLC makes that in the VHO instant low bytes are stored in the radio buffers, and thus, low improvement is obtained.

Again, section 2.2.2.5 summarizes the perceived QoS results for this sort of VHOs

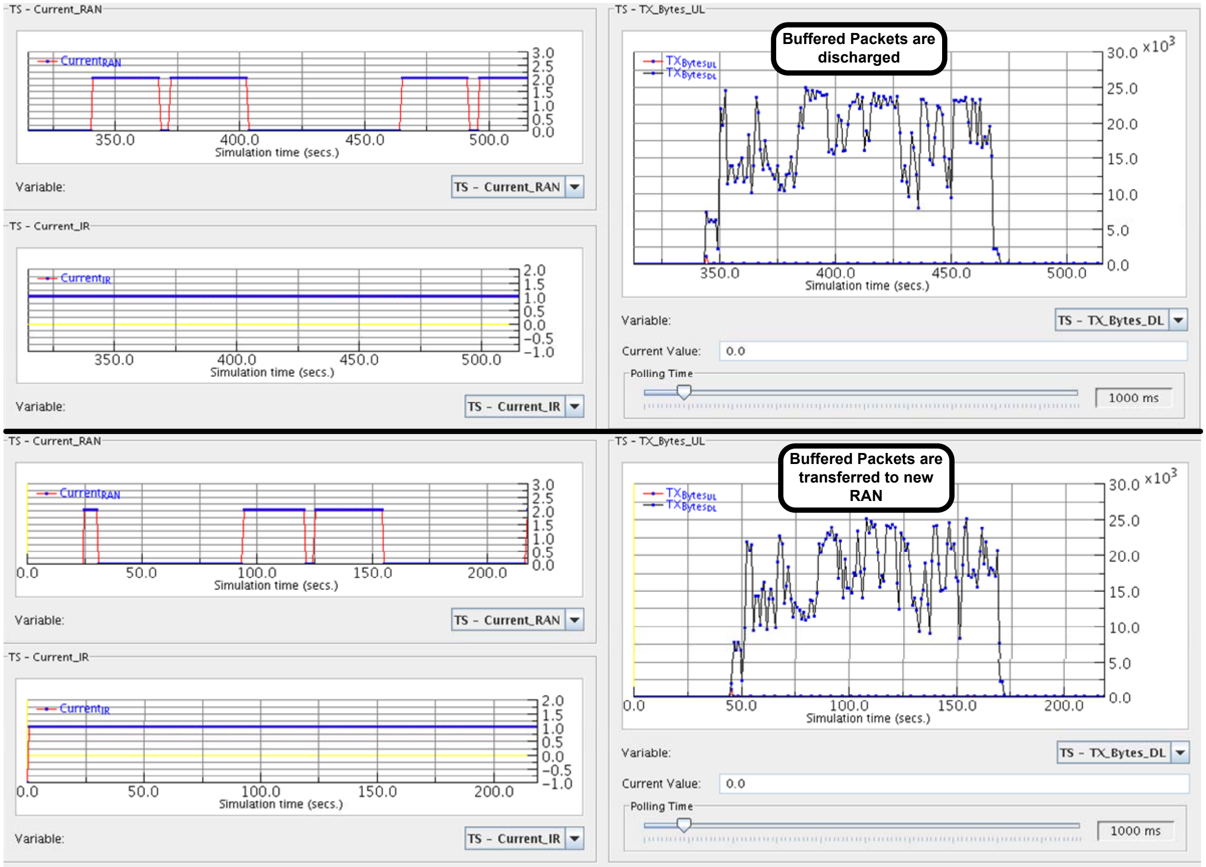


Figure 13 - AGMT statistics for VLC streaming with transfer policy disabled (upper) and enabled (lower)

2.2.2.3 Vertical HO with IR change results analysis and validation

In this set of trials, WLAN is configured to be attached to IR2 while UTRAN is configured to be attached to IR1 so, wherever there is a VHO between these RANs there is a change of the point of attachment to the CN.

Figure 14 and Figure 15 show the AGMT statistics for QT (VLC ones are similar) for Route Advertisement periods of 1s and 10s respectively. Recalling that the RA period determines the instants where the MN (the mobility management entity located in UE) receives notifications about the presence of a new IR which triggers a L3 VHO. Left side of the figure shows from bottom to top the current IR where the UUT is connected, the current RAN and the instants where the MN triggers the L3 VHO. It can be seen in both figures that the gap between the instants where a L2 VHO (radio VHO) and the MN triggers is less or equal to the RA period.

On the other hand, right side of the figure shows from top to bottom, the transmitted bits through WLAN, the transmitted bytes through UTRAN and the total amount of bits transmitted to the UUT. It can be clearly noticed that the greater the RA period, the greater the loss of packets due to the misalignment between the switching in the Radio and CN parts.

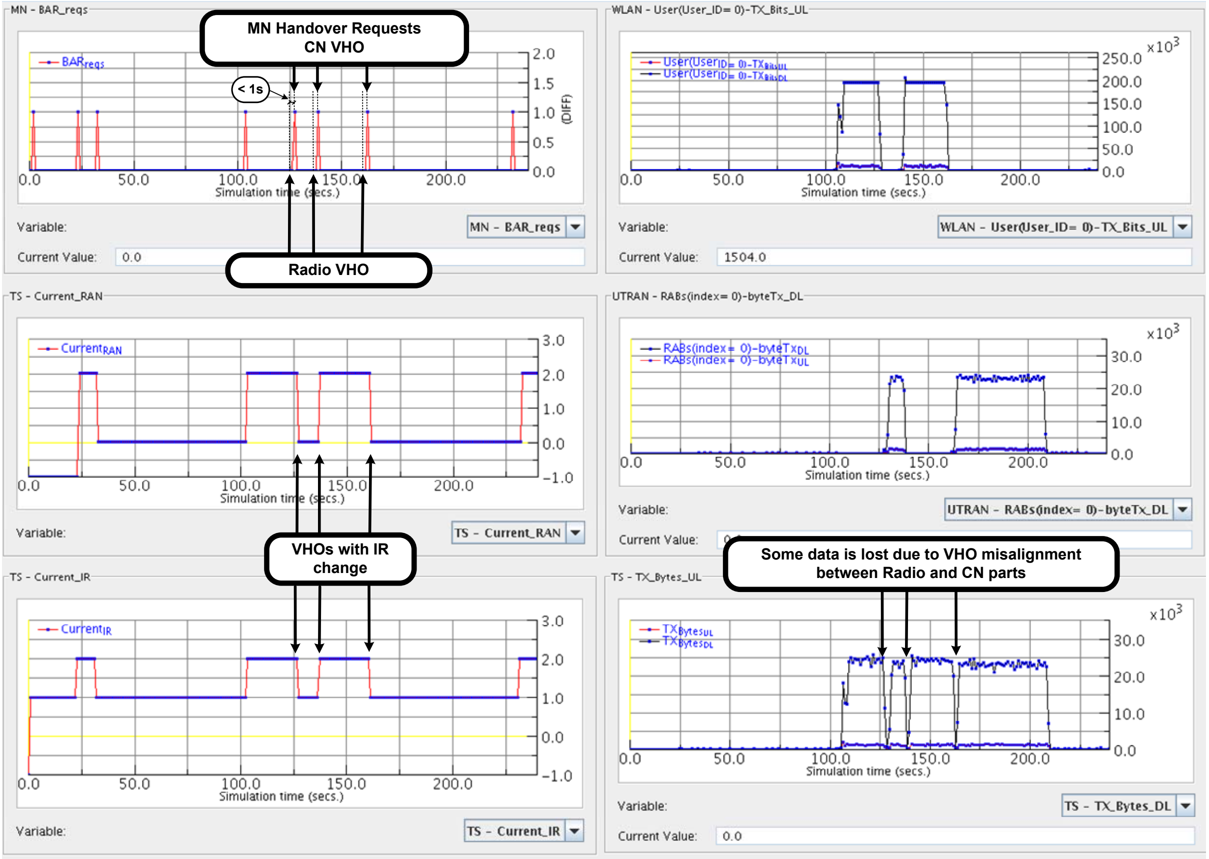


Figure 14 - VHO with IR change and 1s of Route Advertisement period

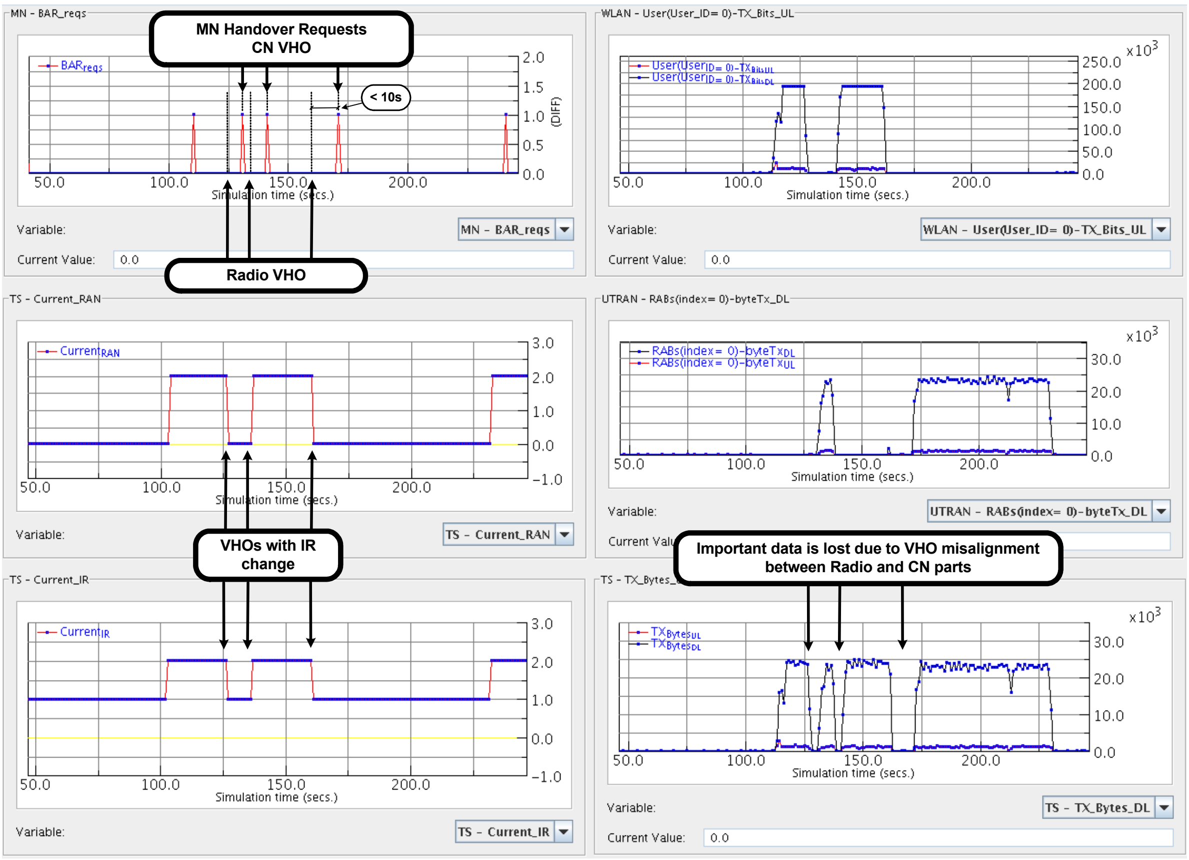


Figure 15 - VHO with IR change and 10s of Route Advertisement period

2.2.2.4 Vertical HO with IR change and Handover Preparation results analysis and validation

Figure 16 and Figure 17 show the AGMT statistics for the VHO with IR change and HO preparation. It is expected that the HO preparation stage reduces the packet loss of the streaming during VHO. This is thanks to an IP-in-IP tunnel between IRs that preserves the packets to be dropped. However, comparing Figure 16 and Figure 17 with Figure 14 and Figure 15 (where HO preparation was disabled) no improvement is apparently seen.

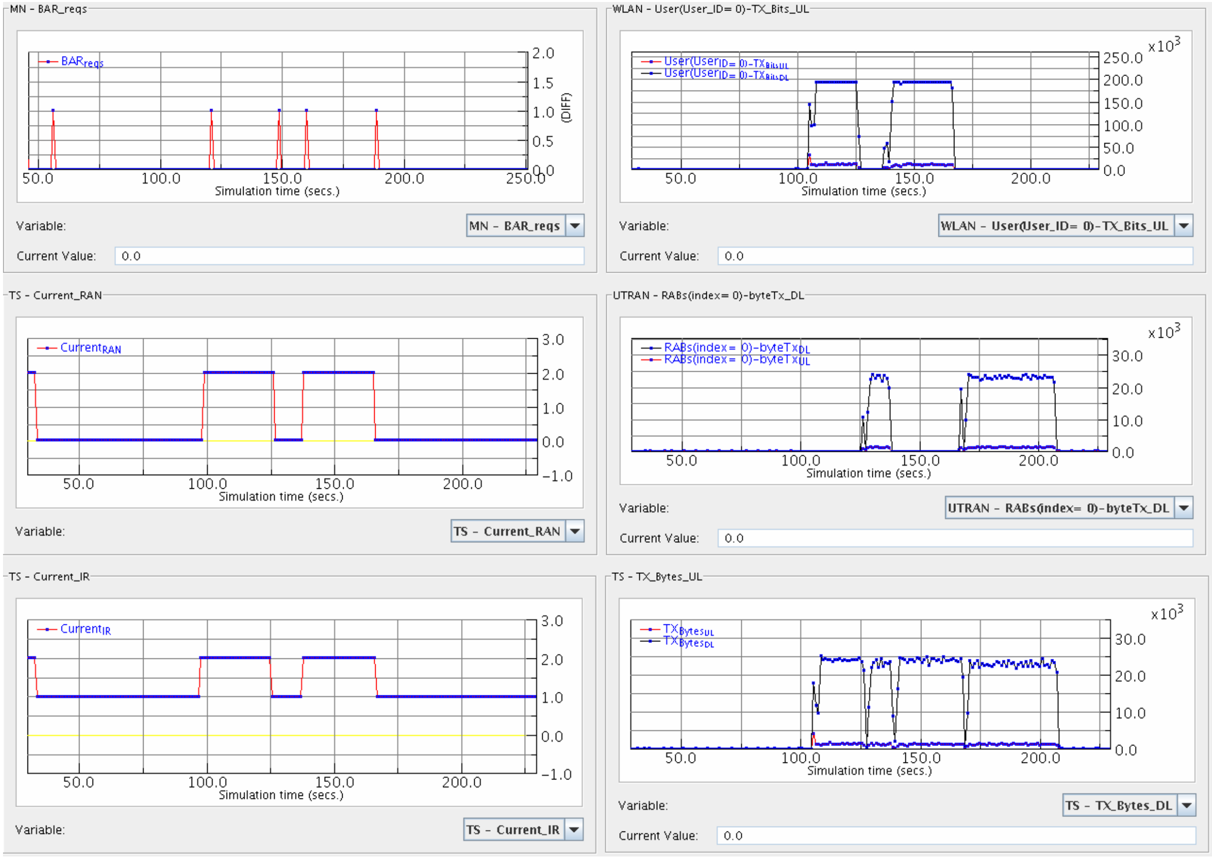


Figure 16 - VHO with IR change and HO preparation and 1s of Route Advertisement period

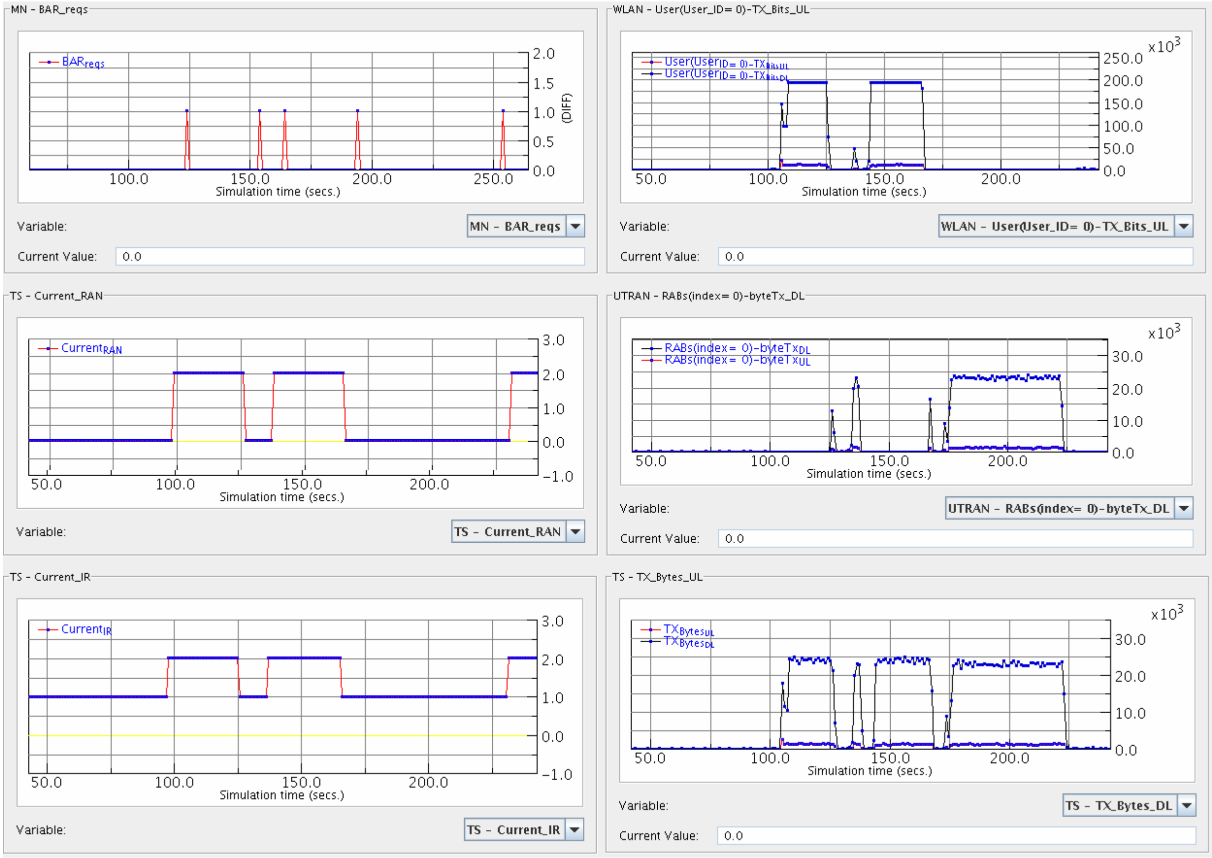


Figure 17 - VHO with IR change and HO preparation and 10s of Route Advertisement period

2.2.2.5 Perceived QoS results for all types of handovers studied

In this section, MOS values for all the HO types studied are presented. Table 3 shows the results for HHO and VHO without IR change handovers. Also, the CRRM VHO packet transfer policy between RANs has been included. As it can be seen, HHO obtains the best values for both QT and VLC. In addition little difference is observed between using the transfer policy or not. In the case of QT this is in first instance shocking if we remit to Figure 11 and Figure 12, where some packet losses were detected when the policy was disabled. The idea is that the packets that were lost were packets that QT was retrieving in advance from the server. Then, the loss of those packets was not affecting the UUT perception as long as there were packets in the application buffer to display to the user. That is the reason why the QoS perceived is still good. In case of VLC was detected that the transfer policy had small effect so the values are also similar. Finally, note that the values of HHO and VHO are quite similar, what infers us that CRRM HO algorithms are quite seamless to the user regardless the type of HO (Horizontal or Vertical).

Table 3 - MOS values for HHO and VHO without IR change handovers

Video QoS objective values						
Type of HO	HHO		VHO w/o IR change		VHO w/o IR change & transfer policy	
Scale	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]
QT	4,67	0,08	4,66	0,08	4,65	0,09
VLC	4,4	0,15	4,39	0,15	4,33	0,17

Table 4 comprises the MOS values for the different VHO with IR change evaluated. It can be seen that trials up to 5s were passed. Again the CRRM transfer policy was also evaluated, but although not presented, in this case a disruption in the data flow to the UUT was always detected since the 1s misalignment between the radio part and the CN in the path switching was impossible to overcome.

Note that the values obtained here are lower that those in Table 3, meaning the even a 1s disruption is some how affecting the UUT. In case the RA was set to 10s, then the disruptions are too heavy and then poor QoS is experience by the UUT.

Table 4 - MOS values for VHO with IR change and different RA period values

Video QoS objective values								
Type of HO	VHO with IR change							
	1s		1s Transfer policy		5s		10s	
Scale	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]
QT	4,45	0,14	4,4	0,15	3,64	0,34	2,92	0,52
VLC	3,76	0,31	3,73	0,32	3,06	0,48	2,64	0,59

In addition, Table 5 shows the QoS perceived values in case HO preparation is enabled.

Table 5 - MOS values for VHO with HO preparation and different RA period

Video QoS objective values						
Type of HO	VHO with IR change and HO Preparation					
	1s		5s		10s	
Scale	[1-5]	[1-0]	[1-5]	[1-0]	[1-5]	[1-0]
QT	4.44	0.14	4.6	0.09	2,81	0,63
VLC	3.82	0.29	3.4	0.48	2,78	0,42

Finally, Figure 18 shows the packet loss statistic obtained from the RTP stream with ethereal. It can be seen that QT in all cases shows very low percentage of loss in comparison with VLC. Also an increasing behaviour is regarded with increasing RA periods.

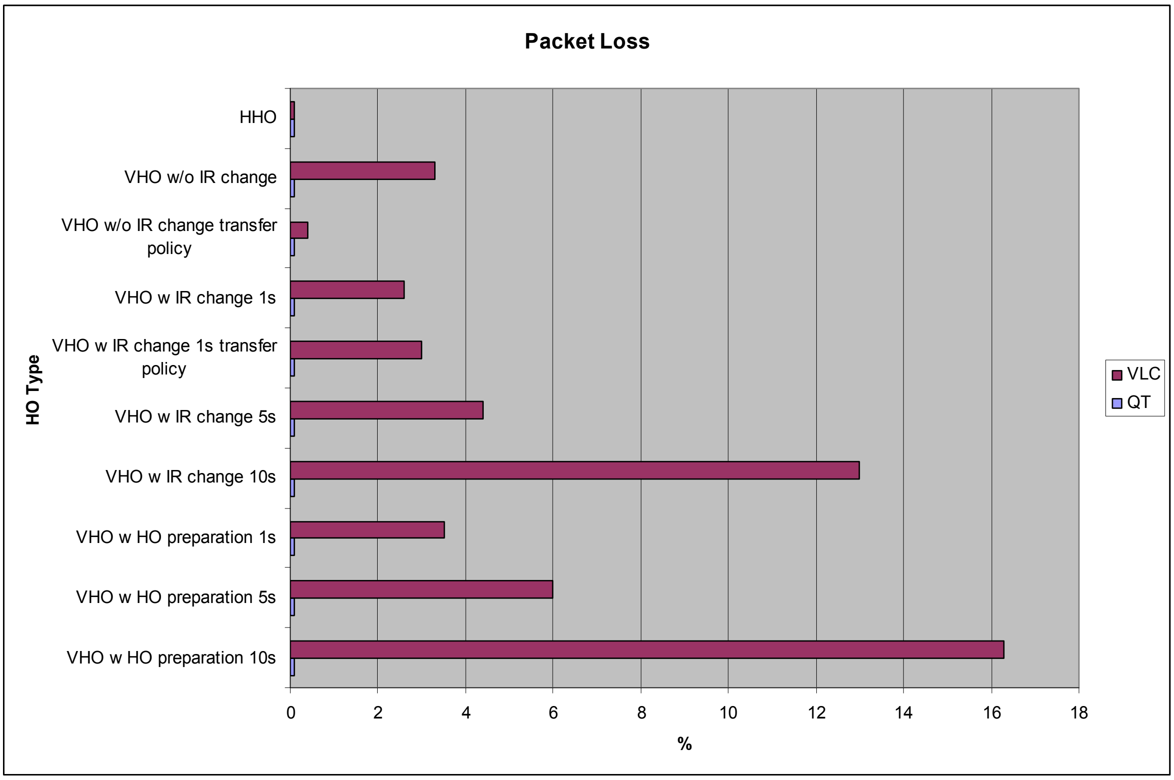


Figure 18 - Packet loss for different HO types

2.3 Demonstration 3: Network Congestion

2.3.1 Description

Network congestion, caused in radio or core network part, can introduce significant delays and losses in the delivery of IP packets that may affect the performance of real time applications. Moreover, relevant variations of the delay may occur. The influence of the congestion on the quality perception will depend on the application and will be measured.

The reflection of the congestion to QoS degradation is expected to be obvious. Variations in load level will cause increase in loss and delay, and confirm this. The robustness of the application and codecs in use to the aforementioned constraints may also vary the final results.

In this trial, the user is static and located under UTRAN coverage. Then a streaming session of 192kbps of guaranteed bitrate is requested. Right after the user starts to stream the video (with QT or VLC) the CN is congested with an artificial load entering the CN through IR1 (the one where UTRAN is configured to be attached). Then, the streaming is affected by this situation, provoking some bluring and jerkiness in the video.

2.3.2 Results – Analysis and Validation

Figure 19 and Figure 20 show the behaviour of QT and VLC respectively when CN is congested. Right after the streaming is started, the CN is congested by injecting a high data rate flow in IR1 (around 80Mbps) as can be seen in bottom subfigure, which shows the IR1 link occupancy. In case QT, Figure 19 shows that some difficulties are found in transmitting through UTRAN. This is because QT at the beginning is asking for a high bandwidth in order to retrieve the movie as soon as possible. Then QT perceives more the network congestion since the CN cannot satisfy its bandwidth requirements. On the other hand, VLC has the packet-by-packet behaviour that in this case is quite beneficial since VLC is only requesting some few packets that can be transmitted through the CN even if there is congestion. Then in Figure 19, QT shows some cuts in the transmitted bandwidth whereas VLC does not.

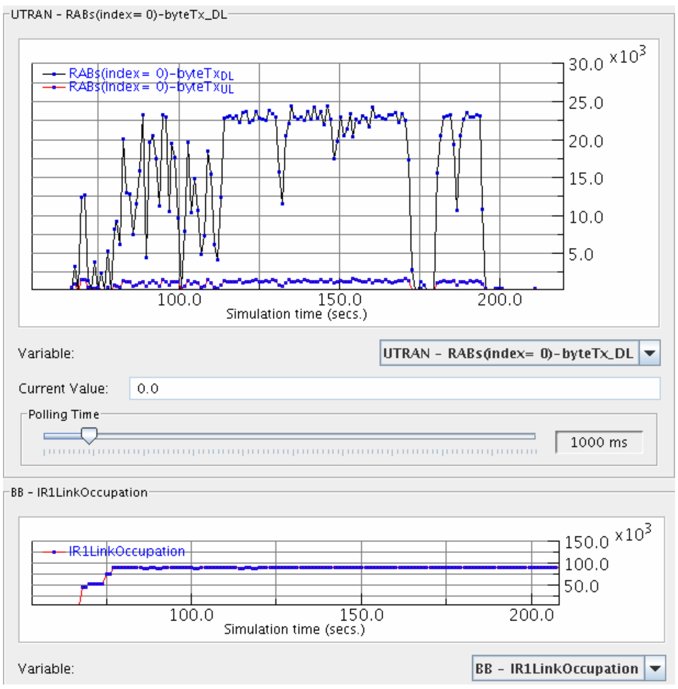


Figure 19 - QT behaviour with congestion in CN

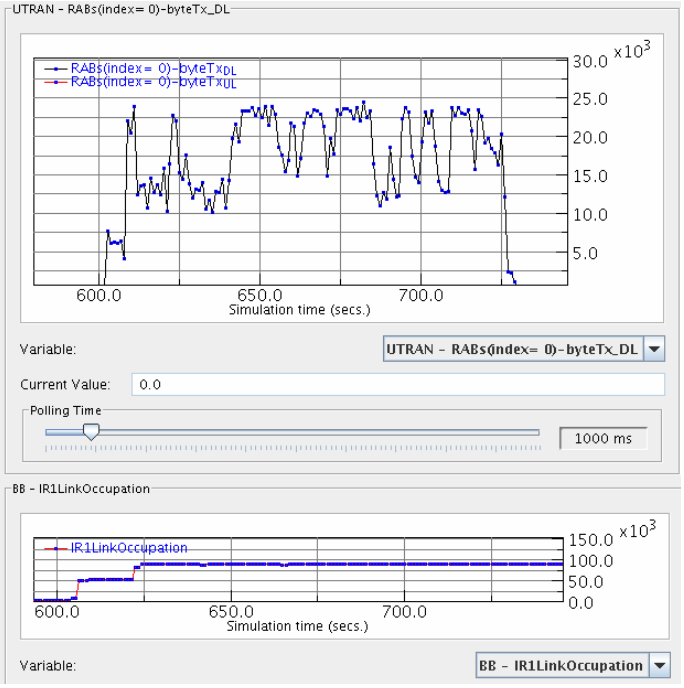


Figure 20 - VLC behaviour with congestion in CN

Finally, Table 6 shows the Perceived QoS comparison between QT and VLC. In this case, VLC shows a performance superior to QT.

Table 6 - QT and VLC

Video QoS objective values		
Scale	[1-5]	[1-0]
QT	3.48	0.43
VLC	4.54	0.12

3 AREA 2: RADIO ACCESS TECHNOLOGY (RAT) SELECTION / COMMON RADIO RESOURCES MANAGEMENT (CRRM) ALGORITHMS

The objective of these trials is to check the coherence between the results achieved in simulations of Radio Access Technologies (RAT) selection algorithms presented in WP3 conceptual studies [15], and the implementation incorporated in the AROMA real-time testbed. The RAT selection algorithms implemented in the testbed are employed to decide the optimum RAT for a given user at session activation as well as the optimum RAT during the session lifetime, triggering a Vertical Handover (VHO) whenever it is required. In particular, the two following RAT selection algorithms were implemented in the testbed and will constitute the scope of these trials:

- ***Network-Controlled Cell-Breathing (NCCB)***: The main idea of the Network-Controlled Cell-Breathing algorithm, as presented in [16] and [17], is to take the advantage of the coverage overlap that several RATs may provide in a certain service area in order to improve the overall interference pattern generated in the scenario for the CDMA-based systems and, consequently, to improve the capacity of the overall heterogeneous scenario. The goal of the tests related to the NCCB algorithm is to evaluate the initial RAT selection process as well as the RAT selection process during an on-going VHO in a heterogeneous scenario.

- ***Fittingness factor based algorithm***: As mentioned in [18], fittingness factor is a generic CRRM metric that facilitates the implementation of cell-by-cell RRM strategies by reducing signalling exchanges and aims at capturing the multidimensional heterogeneity of beyond 3G scenarios within a single metric. The goal of the tests related to the fittingness factor based algorithm is to evaluate the RAT selection process during an on-going Vertical Handover (VHO) in a heterogeneous scenario. The RAT selection process consists of a two-step procedure that incorporates monitoring period (step 1) and the triggering part (step 2). The algorithm is expected to reflect the suitability of allocating a given RAT to a given user (UUT) of a certain profile, according to the created metrics.

The specific real-time evaluation conditions (cell site deployment, coverage areas, resource distribution, etc.) under which the results presented in this section have been obtained, differ from those of the simulation-based analysis performed in [15]. Therefore, numerical results cannot be compared in a quantitative manner. Thus, the aim of this section is to provide a qualitative comparison between the results obtained with the AROMA real-time testbed, and those obtained by off-line simulations in WP3, which allow us to validate the behaviour and performance of the considered RAT selection algorithms.

3.1 Demonstration 1: Initial RAT selection only using NCCB strategy

3.1.1 Description

The aim of this demonstration is to analyse the performance of the Network-Controlled Cell-Breathing (NCCB) RAT selection algorithm at session initiation. According to the NCCB algorithm, the RAT selection decision is taken based on the path loss measurements in the best UTRAN cell, provided by the terminal in the establishment phase. The path loss PL_{UTRAN} is computed by measuring the received downlink power from a common control channel (pilot signal) whose transmitted power is broadcasted by the network. Path loss measurements are averaged in periods of several seconds to eliminate fluctuations. Upon the reception of a session activation request, the NCCB algorithm selects UTRAN if PL_{UTRAN} is lower than a given threshold PL_{th}. Otherwise, GERAN is selected.

The considered scenario in this trial is composed of GERAN and UTRAN (WLAN is not an eligible candidate RAT). Base stations for both technologies are co-located. A cell site deployment with 3 km between consecutive base stations has been considered. Following [16], a value of 120 dB has been selected for the path loss threshold PL_{th}. All users, including the UUT, are moving within the service area at 50 km/h. While emulated users move randomly, the UUT periodically moves in straight line between two base stations, thus experiencing different path loss values. The QoS client module has been configured in such a way that it periodically performs a session activation/deactivation request (voice or interactive service) every 5 seconds. As a result, every 10 seconds a session activation request is received, and consequently an initial RAT selection decision is taken by the NCCB algorithm. As the UUT is moving between two base stations, different path loss values are experienced by the time the initial RAT selection decisions are performed by the NCCB algorithm, which allow us to analyse the result of such decisions as a function of the measured path loss. Table 7 summarises some of the main configuration parameters.

Table 7 - Main configuration parameters

Parameter	Value
Distance between consecutive BSs	3 km
UTRAN BS pilot power	30 dBm
Mobile terminal sensitivity	-110 dBm
Path loss threshold (PL_{th})	120 dB
Averaging period for PL_{UTRAN} measurements	1 sec
User speed (emulated and UUT)	50 km/h
Voice users	300
Interactive users	300

3.1.2 Results – Analysis and Validation

Figure 21 to Figure 26 show some fragments extracted from the log file generated by the CRRM module, in which the NCCB algorithm is executed. These fragments illustrate the initial RAT selection decisions taken by the NCCB algorithm under different conditions.

```
00:00:05:0407 LOG CRRM "PROCESS ADMISSION TRANSACTION 1"
00:00:05:0407 LOG CRRM "Admission Control for User=0, Service=0, QoS=0#0.000000#12200#12200"
00:00:05:0407 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:00:05:0408 LOG CRRM "      X=4220.000000, Y=2121.000000"
00:00:05:0408 LOG CRRM "      Active Set (0 Cells): "
00:00:05:0408 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:00:05:0408 LOG CRRM "      Lp=149.731406 EcIo=-130.870839 (BS=0),"
00:00:05:0408 LOG CRRM "      Lp=138.870765 EcIo=-120.010199 (BS=1),"
00:00:05:0408 LOG CRRM "      Lp=88.227003 EcIo=-69.366436 (BS=2),"
00:00:05:0408 LOG CRRM "      Lp=137.238233 EcIo=-118.377667 (BS=3),"
00:00:05:0408 LOG CRRM "      Lp=148.957900 EcIo=-130.097334 (BS=4),"
00:00:05:0408 LOG CRRM "      Lp=147.384026 EcIo=-128.523459 (BS=5),"
00:00:05:0408 LOG CRRM "      Lp=138.421575 EcIo=-119.561009 (BS=6),"
00:00:05:0408 LOG CRRM "      Lp=137.648512 EcIo=-118.787945 (BS=7),"
00:00:05:0408 LOG CRRM "      Lp=146.610519 EcIo=-127.749952 (BS=8),"
00:00:05:0408 LOG CRRM "      Lp=147.388921 EcIo=-128.528355 (BS=9),"
00:00:05:0408 LOG CRRM "      Lp=138.436239 EcIo=-119.575673 (BS=10),"
00:00:05:0408 LOG CRRM "      Lp=137.664631 EcIo=-118.804065 (BS=11),"
00:00:05:0408 LOG CRRM "      Lp=146.615901 EcIo=-127.755334 (BS=12),"

00:00:05:0410 LOG CRRM "Admission for User 0, Service=0, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:00:05:0410 LOG CRRM "Admission control UTRAN: SF_adm_UL=64, SF_adm_DL=128"
00:00:05:0410 LOG CRRM "Admission control UTRAN: capac_user_UL=0.018351,
capac_user_DL=0.019481"
00:00:05:0410 LOG CRRM "Admission control UTRAN: Granted Resources Check=1 (Current granted
capacity=0.000000 kbps, requested_capacity=12.200000 kbps)"
00:00:05:0410 LOG CRRM "Admission control UTRAN: Code Check=1"
00:00:05:0410 LOG CRRM "Admission control UTRAN: Capacity Check=1"
00:00:05:0410 LOG CRRM "Admission control UTRAN: UL_power_check=1"
00:00:05:0411 LOG CRRM "Admission control UTRAN: DL_power_check=1"

00:00:05:0411 LOG CRRM "User 0 pre-admitted in BS2 GERAN"

00:00:05:0411 LOG CRRM "Candidate Networks: UTRAN(1), GERAN(1), WLAN(0)"
00:00:05:0412 LOG CRRM "NCCB result: ratSel->availability[GERAN]=0"

00:00:05:0412 LOG CRRM "PRIORITISATION RESULT: UTRAN(5000), GERAN(0), WLAN(0)"
```

Figure 21 - NCCB initial RAT selection when UTRAN and GERAN have free resources ($PL_{UTRAN} < PL_{th}$)

```
00:00:55:2406 LOG CRRM "PROCESS ADMISSION TRANSACTION 16"
00:00:55:2406 LOG CRRM "Admission Control for User=0, Service=0, QoS=0#0.000000#12200#12200,
Policy=aa"
00:00:55:2406 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:00:55:2407 LOG CRRM "      X=4899.000000, Y=2121.000000"
00:00:55:2407 LOG CRRM "      Active Set (0 Cells): "
00:00:55:2407 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:00:55:2407 LOG CRRM "      Lp=152.445277 EcIo=-133.547702 (BS=0),"
00:00:55:2407 LOG CRRM "      Lp=143.790691 EcIo=-124.866962 (BS=1),"
00:00:55:2407 LOG CRRM "      Lp=123.768320 EcIo=-104.686672 (BS=2),"
00:00:55:2407 LOG CRRM "      Lp=129.204837 EcIo=-110.492842 (BS=3),"
00:00:55:2407 LOG CRRM "      Lp=145.525534 EcIo=-126.720587 (BS=4),"
00:00:55:2407 LOG CRRM "      Lp=150.177588 EcIo=-131.278271 (BS=5),"
00:00:55:2407 LOG CRRM "      Lp=141.824575 EcIo=-122.912426 (BS=6),"
00:00:55:2407 LOG CRRM "      Lp=135.746810 EcIo=-116.896587 (BS=7),"
00:00:55:2408 LOG CRRM "      Lp=143.362927 EcIo=-124.552106 (BS=8),"
00:00:55:2408 LOG CRRM "      Lp=150.181066 EcIo=-131.281765 (BS=9),"
00:00:55:2408 LOG CRRM "      Lp=141.834244 EcIo=-122.922157 (BS=10),"
00:00:55:2408 LOG CRRM "      Lp=135.767151 EcIo=-116.916903 (BS=11),"
00:00:55:2408 LOG CRRM "      Lp=143.370936 EcIo=-124.560067 (BS=12),"

00:00:55:2411 LOG CRRM "Admission for User 0, Service=0, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:00:55:2412 LOG CRRM "Admission control UTRAN: SF_adm_UL=64, SF_adm_DL=128"
00:00:55:2412 LOG CRRM "Admission control UTRAN: capac_user_UL=0.018351,
capac_user_DL=0.019481"
00:00:55:2412 LOG CRRM "Admission control UTRAN: Granted Resources Check=1 (Current granted
capacity=768.000000 kbps, requested_capacity=12.200000 kbps)"
00:00:55:2412 LOG CRRM "Admission control UTRAN: Code Check=1"
00:00:55:2412 LOG CRRM "Admission control UTRAN: Capacity Check=1"
00:00:55:2412 LOG CRRM "Admission control UTRAN: UL_power_check=1"
00:00:55:2413 LOG CRRM "Admission control UTRAN: DL_power_check=1"

00:00:55:2413 LOG CRRM "User 0 pre-admitted in BS2 GERAN"

00:00:55:2413 LOG CRRM "Candidate Networks: UTRAN(1), GERAN(1), WLAN(0)"
00:00:55:2413 LOG CRRM "NCCB result: ratSel->availability[UTRAN]=0"

00:00:55:2414 LOG CRRM "PRIORITISATION RESULT: UTRAN(0), GERAN(5000), WLAN(0)"
```

Figure 22 - NCCB initial RAT selection when UTRAN and GERAN have free resources ($PL_{UTRAN} > PL_{th}$)

```
00:02:05:5210 LOG CRRM "PROCESS ADMISSION TRANSACTION 37"
00:02:05:5210 LOG CRRM "Admission Control for User=0, Service=2, QoS=0#0.000000#32000#32000"
00:02:05:5210 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:02:05:5211 LOG CRRM "      X=5844.000000, Y=2121.000000"
00:02:05:5211 LOG CRRM "      Active Set (0 Cells): "
00:02:05:5211 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:02:05:5211 LOG CRRM "      Lp=155.580449 EcIo=-136.719882 (BS=0),"
00:02:05:5211 LOG CRRM "      Lp=148.806976 EcIo=-129.946409 (BS=1),"
00:02:05:5211 LOG CRRM "      Lp=136.831983 EcIo=-117.971417 (BS=2),"
00:02:05:5211 LOG CRRM "      Lp=94.784753 EcIo=-75.924187 (BS=3),"
00:02:05:5211 LOG CRRM "      Lp=139.147046 EcIo=-120.286480 (BS=4),"
00:02:05:5211 LOG CRRM "      Lp=153.501583 EcIo=-134.641017 (BS=5),"
00:02:05:5211 LOG CRRM "      Lp=146.415602 EcIo=-127.555036 (BS=6),"
00:02:05:5211 LOG CRRM "      Lp=137.465760 EcIo=-118.605194 (BS=7),"
00:02:05:5212 LOG CRRM "      Lp=138.622872 EcIo=-119.762306 (BS=8),"
00:02:05:5212 LOG CRRM "      Lp=153.503898 EcIo=-134.643331 (BS=9),"
00:02:05:5212 LOG CRRM "      Lp=146.421114 EcIo=-127.560548 (BS=10),"
00:02:05:5212 LOG CRRM "      Lp=137.482244 EcIo=-118.621677 (BS=11),"
00:02:05:5212 LOG CRRM "      Lp=138.637180 EcIo=-119.776613 (BS=12),"

00:02:05:5214 LOG CRRM "Admission for User 0, Service=2, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:02:05:5215 LOG CRRM "Admission control UTRAN: SF_adm_UL=32, SF_adm_DL=16"
00:02:05:5215 LOG CRRM "Admission control UTRAN: capac_user_UL=0.007009,
capac_user_DL=0.018341"
00:02:05:5215 LOG CRRM "Admission control UTRAN: Granted Resources Check=0 (Current granted
capacity=2176.000000 kbps, requested_capacity=32.000000 kbps)"

00:02:05:5217 LOG CRRM "User 0 pre-admitted in BS3 GERAN"

00:02:05:5217 LOG CRRM "Candidate Networks: UTRAN(0), GERAN(1), WLAN(0)"

00:02:05:5217 LOG CRRM "PRIORITISATION RESULT: UTRAN(0), GERAN(5000), WLAN(0)"
```

Figure 23 - NCCB initial RAT selection when UTRAN has no free resources ($PL_{UTRAN} < PL_{th}$)

```
00:01:15:3211 LOG CRRM "PROCESS ADMISSION TRANSACTION 22"
00:01:15:3211 LOG CRRM "Admission Control for User=0, Service=2, QoS=0#0.000000#32000#32000"
00:01:15:3211 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:01:15:3211 LOG CRRM "      X=5165.000000, Y=2121.000000"
00:01:15:3211 LOG CRRM "      Active Set (0 Cells): "
00:01:15:3211 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:01:15:3211 LOG CRRM "      Lp=153.374354 EcIo=-134.513787 (BS=0),"
00:01:15:3211 LOG CRRM "      Lp=145.339103 EcIo=-126.478537 (BS=1),"
00:01:15:3211 LOG CRRM "      Lp=128.535056 EcIo=-109.674490 (BS=2),"
00:01:15:3211 LOG CRRM "      Lp=124.659049 EcIo=-105.798483 (BS=3),"
00:01:15:3211 LOG CRRM "      Lp=143.995549 EcIo=-125.134983 (BS=4),"
00:01:15:3212 LOG CRRM "      Lp=151.154838 EcIo=-132.294272 (BS=5),"
00:01:15:3212 LOG CRRM "      Lp=143.147040 EcIo=-124.286473 (BS=6),"
00:01:15:3212 LOG CRRM "      Lp=135.710115 EcIo=-116.849549 (BS=7),"
00:01:15:3212 LOG CRRM "      Lp=142.044817 EcIo=-123.184250 (BS=8),"
00:01:15:3212 LOG CRRM "      Lp=151.157923 EcIo=-132.297357 (BS=9),"
00:01:15:3212 LOG CRRM "      Lp=143.155264 EcIo=-124.294697 (BS=10),"
00:01:15:3212 LOG CRRM "      Lp=135.730548 EcIo=-116.869982 (BS=11),"
00:01:15:3212 LOG CRRM "      Lp=142.054229 EcIo=-123.193662 (BS=12),"

00:01:15:3215 LOG CRRM "Admission for User 0, Service=2, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:01:15:3216 LOG CRRM "Admission control UTRAN: SF_adm_UL=32, SF_adm_DL=16"
00:01:15:3216 LOG CRRM "Admission control UTRAN: capac_user_UL=0.007009,
capac_user_DL=0.018341"
00:01:15:3216 LOG CRRM "Admission control UTRAN: Granted Resources Check=0 (Current granted
capacity=2048.000000 kbps, requested_capacity=32.000000 kbps)"

00:01:15:3218 LOG CRRM "User 0 pre-admitted in BS2 GERAN"

00:01:15:3218 LOG CRRM "Candidate Networks: UTRAN(0), GERAN(1), WLAN(0)"

00:01:15:3218 LOG CRRM "PRIORITISATION RESULT: UTRAN(0), GERAN(5000), WLAN(0)"
```

Figure 24 - NCCB initial RAT selection when UTRAN has no free resources ($PL_{UTRAN} > PL_{th}$)

```
00:01:35:3810 LOG CRRM "PROCESS ADMISSION TRANSACTION 28"
00:01:35:3810 LOG CRRM "Admission Control for User=0, Service=2, QoS=0#0.000000#32000#32000"
00:01:35:3810 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:01:35:3810 LOG CRRM "      X=5438.000000, Y=2121.000000"
00:01:35:3810 LOG CRRM "      Active Set (0 Cells): "
00:01:35:3810 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:01:35:3810 LOG CRRM "      Lp=154.319102 EcIo=-135.458536 (BS=0),"
00:01:35:3810 LOG CRRM "      Lp=146.857200 EcIo=-127.996634 (BS=1),"
00:01:35:3810 LOG CRRM "      Lp=132.471967 EcIo=-113.611400 (BS=2),"
00:01:35:3810 LOG CRRM "      Lp=117.732802 EcIo=-98.872235 (BS=3),"
00:01:35:3810 LOG CRRM "      Lp=142.169856 EcIo=-123.309289 (BS=4),"
00:01:35:3811 LOG CRRM "      Lp=152.156053 EcIo=-133.295486 (BS=5),"
00:01:35:3811 LOG CRRM "      Lp=144.532816 EcIo=-125.672250 (BS=6),"
00:01:35:3811 LOG CRRM "      Lp=136.144802 EcIo=-117.284235 (BS=7),"
00:01:35:3811 LOG CRRM "      Lp=140.608867 EcIo=-121.748301 (BS=8),"
00:01:35:3811 LOG CRRM "      Lp=152.158782 EcIo=-133.298215 (BS=9),"
00:01:35:3811 LOG CRRM "      Lp=144.539757 EcIo=-125.679190 (BS=10),"
00:01:35:3811 LOG CRRM "      Lp=136.164177 EcIo=-117.303611 (BS=11),"
00:01:35:3811 LOG CRRM "      Lp=140.620088 EcIo=-121.759521 (BS=12),"

00:01:35:3814 LOG CRRM "Admission for User 0, Service=2, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:01:35:3815 LOG CRRM "Admission control UTRAN: SF_adm_UL=32, SF_adm_DL=16"
00:01:35:3815 LOG CRRM "Admission control UTRAN: capac_user_UL=0.007009,
capac_user_DL=0.018341"
00:01:35:3815 LOG CRRM "Admission control UTRAN: Granted Resources Check=1 (Current granted
capacity=1920.000000 kbps, requested_capacity=32.000000 kbps)"
00:01:35:3815 LOG CRRM "Admission control UTRAN: Code Check=1"
00:01:35:3815 LOG CRRM "Admission control UTRAN: Capacity Check=1"
00:01:35:3815 LOG CRRM "Admission control UTRAN: UL_power_check=1"
00:01:35:3816 LOG CRRM "Admission control UTRAN: DL_power_check=1"

00:01:35:3816 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 3 is
cost=1.000000"
00:01:35:3817 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 2 is
cost=1.000000"
00:01:35:3817 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 7 is
cost=1.000000"
00:01:35:3818 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 11 is
cost=1.000000"
00:01:35:3818 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 8 is
cost=1.000000"
00:01:35:3819 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 12 is
cost=1.000000"
00:01:35:3819 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 4 is
cost=1.000000"
00:01:35:3819 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 0,
cost=1.000000)"
00:01:35:3819 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 1,
cost=1.000000)"
00:01:35:3819 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 5,
cost=1.000000)"
00:01:35:3820 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 6,
cost=1.000000)"
00:01:35:3820 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 9,
cost=1.000000)"
00:01:35:3820 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 10,
cost=1.000000)"

00:01:35:3820 LOG CRRM "Candidate Networks: UTRAN(1), GERAN(0), WLAN(0)"

00:01:35:3820 LOG CRRM "PRIORITISATION RESULT: UTRAN(5000), GERAN(0), WLAN(0)"
```

Figure 25 - NCCB initial RAT selection when GERAN has no free resources ($PL_{UTRAN} < PL_{th}$)

```
00:01:05:2609 LOG CRRM "PROCESS ADMISSION TRANSACTION 19"
00:01:05:2609 LOG CRRM "Admission Control for User=0, Service=2, QoS=0#0.000000#32000#32000"
00:01:05:2609 LOG CRRM "DETAILED MOBILE LOCATION INFORMATION FOR MOBILE 0 (Active.RAT: -1))"
00:01:05:2609 LOG CRRM "      X=5032.000000, Y=2121.000000"
00:01:05:2609 LOG CRRM "      Active Set (0 Cells): "
00:01:05:2609 LOG CRRM "      UTRAN Measurements and Propagation Data:"
00:01:05:2609 LOG CRRM "      Lp=152.952107 EcIo=-134.055670 (BS=0),"
00:01:05:2610 LOG CRRM "      Lp=144.642645 EcIo=-125.722161 (BS=1),"
00:01:05:2610 LOG CRRM "      Lp=126.506044 EcIo=-107.459610 (BS=2),"
00:01:05:2610 LOG CRRM "      Lp=126.914968 EcIo=-108.224652 (BS=3),"
00:01:05:2610 LOG CRRM "      Lp=144.719545 EcIo=-125.917384 (BS=4),"
00:01:05:2610 LOG CRRM "      Lp=150.709684 EcIo=-131.811373 (BS=5),"
00:01:05:2610 LOG CRRM "      Lp=142.539785 EcIo=-123.628020 (BS=6),"
00:01:05:2610 LOG CRRM "      Lp=135.672997 EcIo=-116.813851 (BS=7),"
00:01:05:2610 LOG CRRM "      Lp=142.656665 EcIo=-123.846532 (BS=8),"
00:01:05:2610 LOG CRRM "      Lp=150.712942 EcIo=-131.814646 (BS=9),"
00:01:05:2610 LOG CRRM "      Lp=142.548644 EcIo=-123.636935 (BS=10),"
00:01:05:2611 LOG CRRM "      Lp=135.693523 EcIo=-116.834373 (BS=11),"
00:01:05:2611 LOG CRRM "      Lp=142.665398 EcIo=-123.855211 (BS=12),"

00:01:05:2613 LOG CRRM "Admission for User 0, Service=2, Networks reachable: UTRAN(1),
GERAN(1), WLAN(0)"

00:01:05:2614 LOG CRRM "Admission control UTRAN: SF_adm_UL=32, SF_adm_DL=16"
00:01:05:2614 LOG CRRM "Admission control UTRAN: capac_user_UL=0.007009,
capac_user_DL=0.018341"
00:01:05:2614 LOG CRRM "Admission control UTRAN: Granted Resources Check=1 (Current granted
capacity=1536.000000 kbps, requested_capacity=32.000000 kbps)"
00:01:05:2614 LOG CRRM "Admission control UTRAN: Code Check=1"
00:01:05:2614 LOG CRRM "Admission control UTRAN: Capacity Check=1"
00:01:05:2614 LOG CRRM "Admission control UTRAN: UL_power_check=1"
00:01:05:2615 LOG CRRM "Admission control UTRAN: DL_power_check=1"

00:01:05:2616 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 2 is
cost=1.000000"
00:01:05:2616 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 3 is
cost=1.000000"
00:01:05:2617 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 7 is
cost=1.000000"
00:01:05:2617 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 11 is
cost=1.000000"
00:01:05:2618 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 6 is
cost=1.000000"
00:01:05:2618 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 8 is
cost=1.000000"
00:01:05:2618 LOG CRRM "GERAN: Not a candidate BTS. Evaluate cost for UE_id=0 in BTS 10 is
cost=1.000000"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 0,
cost=1.000000)"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 1,
cost=1.000000)"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 4,
cost=1.000000)"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 5,
cost=1.000000)"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 9,
cost=1.000000)"
00:01:05:2619 LOG CRRM "GERAN: Not a candidate BTS. Pilot below minimum (UE_id=0, BTS 12,
cost=1.000000)"

00:01:05:2619 LOG CRRM "Candidate Networks: UTRAN(1), GERAN(0), WLAN(0)"

00:01:05:2620 LOG CRRM "PRIORITISATION RESULT: UTRAN(5000), GERAN(0), WLAN(0)"
```

Figure 26 - NCCB initial RAT selection when GERAN has no free resources ($PL_{UTRAN} > PL_{th}$)

The fragment shown in Figure 21 corresponds to a case in which the UUT requests a 12.2 kbit/s voice session when it is not attached to any RAT (Active RAT: -1). At the moment of requesting the session, the measured path loss PL_{UTRAN} for the best UTRAN cell (BS=2) is 88.23 dB, which is below the path loss threshold PL_{th} (120 dB). Both RATs are reachable and have free resources to accept the new request, as shown in the UTRAN admission control messages and in the GERAN admission result. As a result, both RATs are eligible candidates. In this case, since PL_{UTRAN} is lower than PL_{th}, the NCCB algorithm discards GERAN and selects UTRAN, as shown in the prioritisation result of Figure 21. This result shows that NCCB selects UTRAN when both RATs have resources and the path loss PL_{UTRAN} measured for the best UTRAN cell is lower than PL_{th}.

In the case shown in Figure 22, the UUT requests again a 12.2 kbit/s voice session without being attached to any RAT (Active RAT: -1). As in the case shown in Figure 21, both RATs are reachable, have free resources for the new request, and are eligible candidates. However, in this case the NCCB algorithm selects GERAN since the path loss PL_{UTRAN} measured for the best UTRAN cell (123.77 dB in BS=2) is above the path loss threshold PL_{th} (120 dB). This result shows that NCCB selects GERAN when both RATs have resources and the path loss PL_{UTRAN} measured for the best UTRAN cell is higher than PL_{th}.

In Figure 23, the UUT requests the activation of a 32 kbit/s interactive session. Both RATs are reachable and the path loss PL_{UTRAN} measured for the best UTRAN cell (94.78 dB in BS=3) is lower than the path loss threshold PL_{th} (120 dB). However, in this case, the NCCB algorithm is obliged to select GERAN since the UTRAN admission control rejects the request due to the lack of free resources (Granted Resouces Check=0). Figure 24 shows the case in which UTRAN has no free resources and PL_{UTRAN} is higher than PL_{th}. Again, GERAN is selected. These results show that NCCB selects GERAN when UTRAN has no free resources, regardless of the path loss PL_{UTRAN} measured for the best UTRAN cell.

Finally, Figure 25 and Figure 26 show two cases in which GERAN has no free resources, and the measured path loss PL_{UTRAN} for the best UTRAN cell is lower and higher, respectively, than the path loss threshold PL_{th} (120 dB). As it can be observed, UTRAN is selected in both cases. These results show that NCCB selects UTRAN when GERAN has no free resources, regardless of the path loss PL_{UTRAN} measured for the best UTRAN cell.

3.2 Demonstration 2: RAT selection including VHO using NCCB strategy

3.2.1 Description

The aim of this demonstration is to analyse the performance of the NCCB algorithm when a VHO is considered, according to the procedure presented in Figure 27.

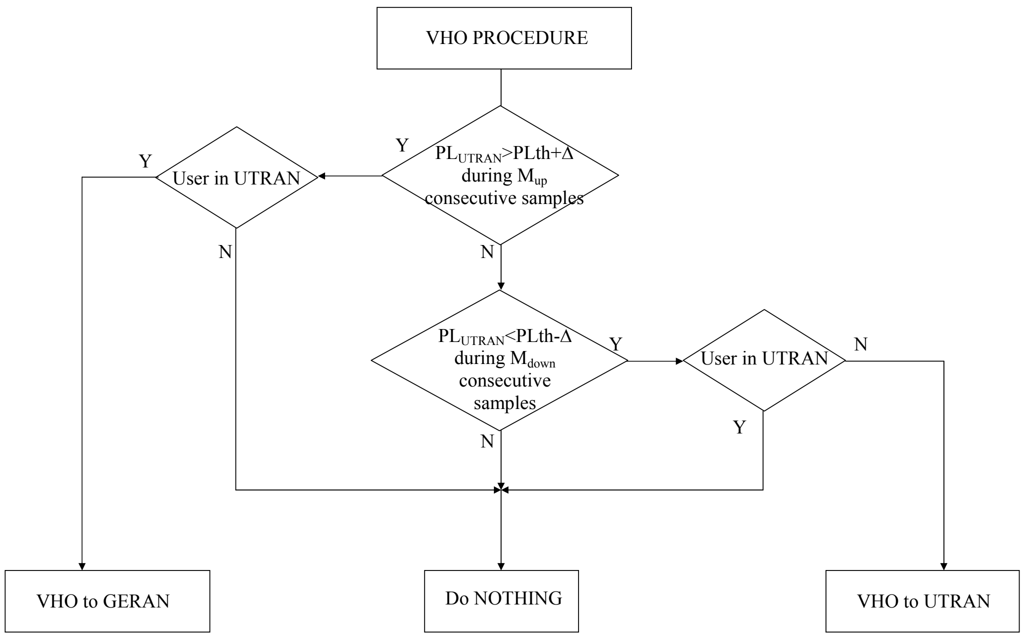


Figure 27 - VHO procedure with NCCB algorithm

The idea is to keep high path loss users connected to GERAN and low path users connected to UTRAN depending on how the propagation conditions change along the session lifetime. VHO is triggered upon the relation of the path loss measurements (PL_{UTRAN}) and the path loss threshold value (PL_{th}) with a certain hysteresis margin (Δ), provided that the inequalities shown in Figure 27 are verified during at least M_{up}/M_{down} consecutive measurements.

As in section 3.1, the scenario considered in this trial is composed of GERAN and UTRAN (WLAN is not an eligible candidate RAT). Base stations for both technologies are co-located. A cell site deployment with 3 km between consecutive base stations has been considered. Following [16], three different values have been selected for the path loss threshold PL_{th} (115, 120 and 125 dB). All users, including the UUT, are moving within the service area at 50 km/h. While emulated users move randomly, the UUT periodically moves in straight line between two base stations, thus experiencing different path loss values. In this trial, the QoS client module has been configured in such a way that it performs a session activation request at time instant 5 seconds and the session remains active during the whole emulation. As the UUT is moving between two base stations, different path loss values are experienced during the session lifetime, which allow us to analyse the behaviour of the NCCB algorithm as a function of the measured path loss. The main configuration parameters are shown in Table 8.

Table 8 - Main configuration parameters

Parameter	Value
Distance between consecutive BSs	3 km
UTRAN BS pilot power	30 dBm
Mobile terminal sensitivity	-110 dBm
Path loss threshold (PL_{th})	115 dB, 120 dB, and 125 dB
Averaging period for PL_{UTRAN} measurements	1 sec
Hysteresis margin (Δ)	1 dB
Number of samples for triggering VHO (M_{up}/M_{down})	3/3
User speed (emulated and UUT)	50 km/h
Interactive users to voice users ratio	4:1

3.2.2 Results – Analysis and Validation

Figure 28, Figure 29 and Figure 30 show the VHO decisions taken by the NCCB RAT selection algorithm for the UUT as it moves between two consecutive base stations, when the system is loaded with 500 emulated users and different path loss threshold values (115, 120 and 125 dB, respectively) are considered. The upper graph of these figures shows the current RAT the UUT is connected to. Values 0 and 1 correspond to UTRAN and GERAN, respectively. When the UUT is not connected to any RAT (during the first 5 seconds) the value –1 is shown. The lower graph of the figures shows the path loss PL_{UTRAN} between the UUT and the two base stations located at the end-points of the trajectory. At time instant 0 seconds the UUT is near base station 2 (dark blue line). Base station 3 (light blue line) is reached at time instant around 130 seconds. Then, the UUT turns back to base station 2, which is reached again at time instant around 260 seconds.

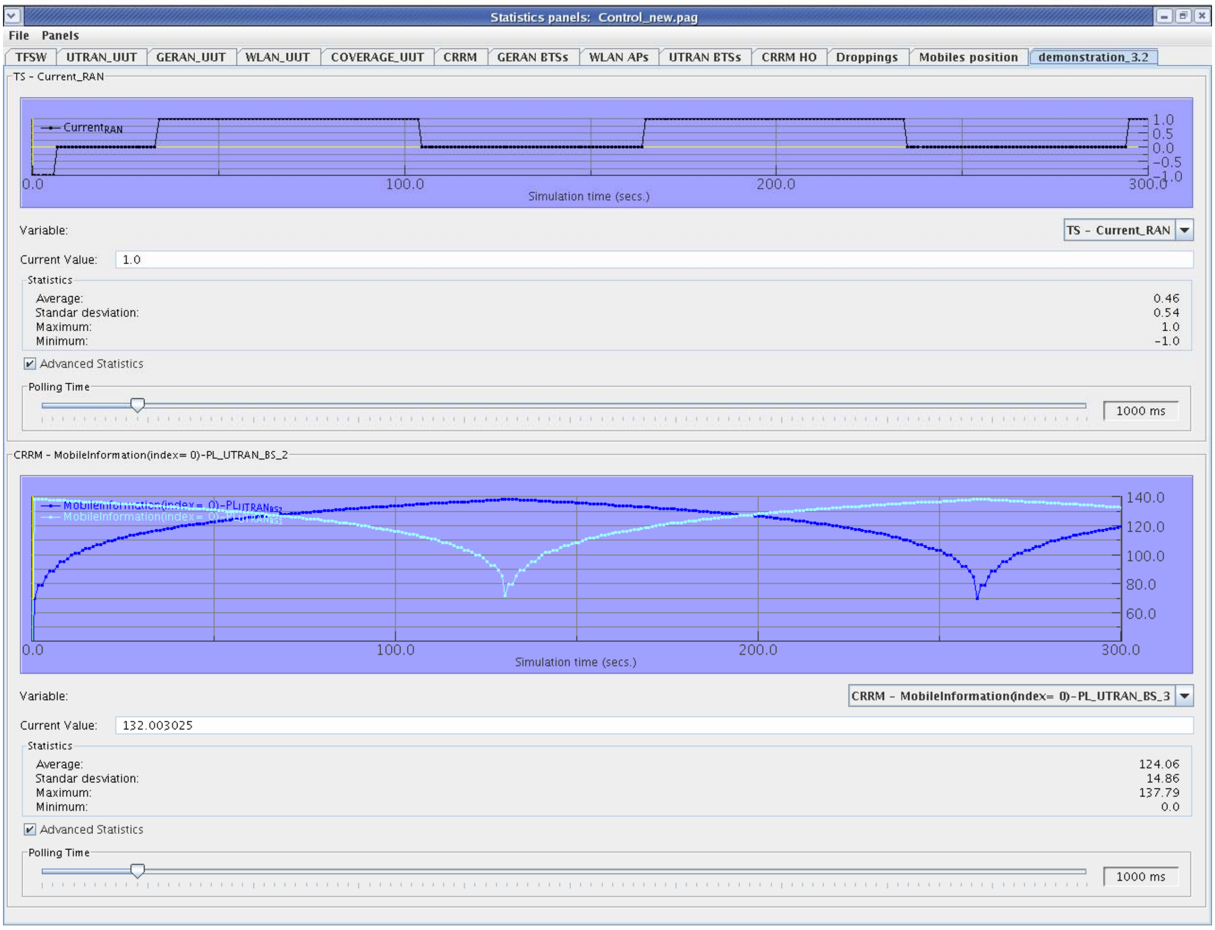


Figure 28 - NCCB VHO RAT selection (PL_{th} = 115 dB, 500 emulated users)

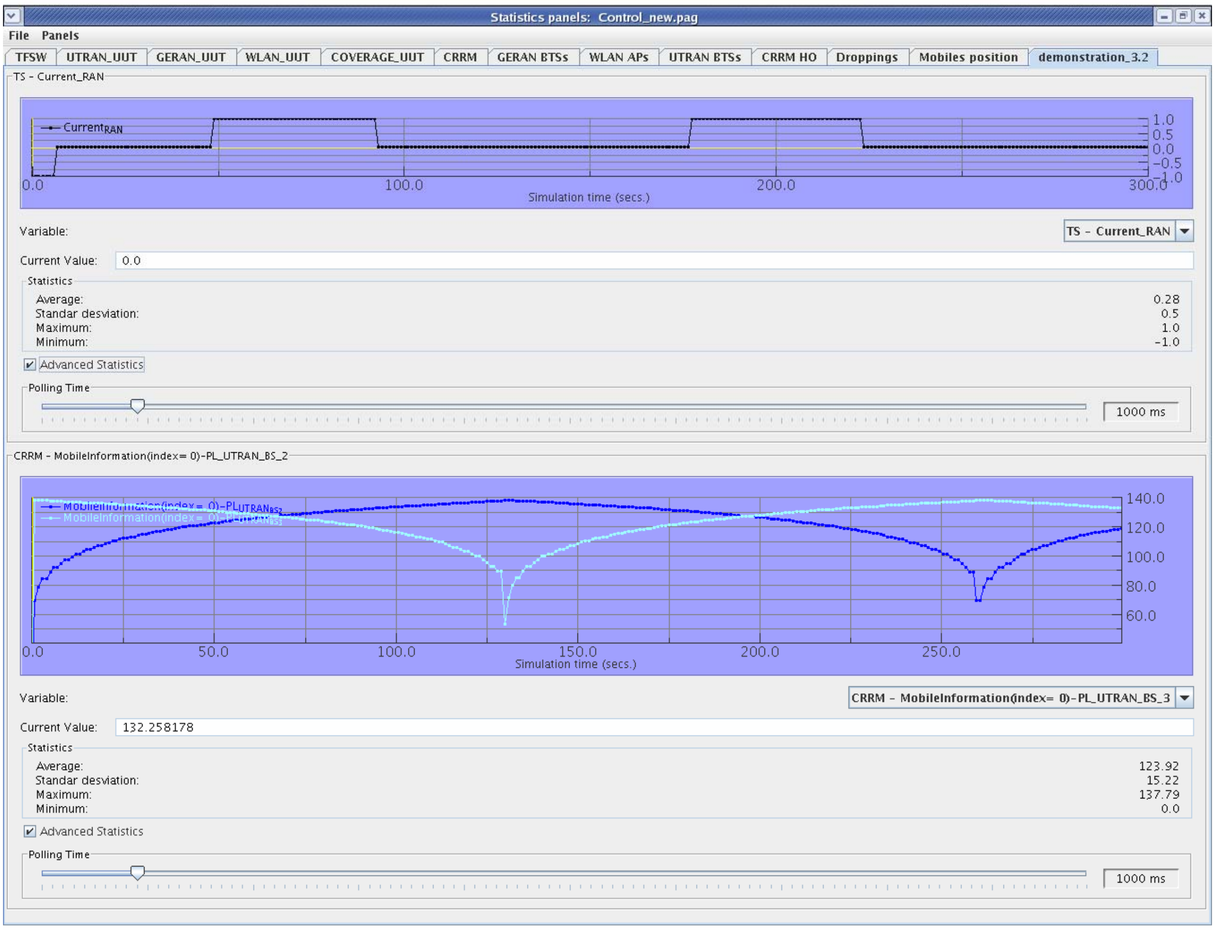


Figure 29 - NCCB VHO RAT selection (PL_{th} = 120 dB, 500 emulated users).

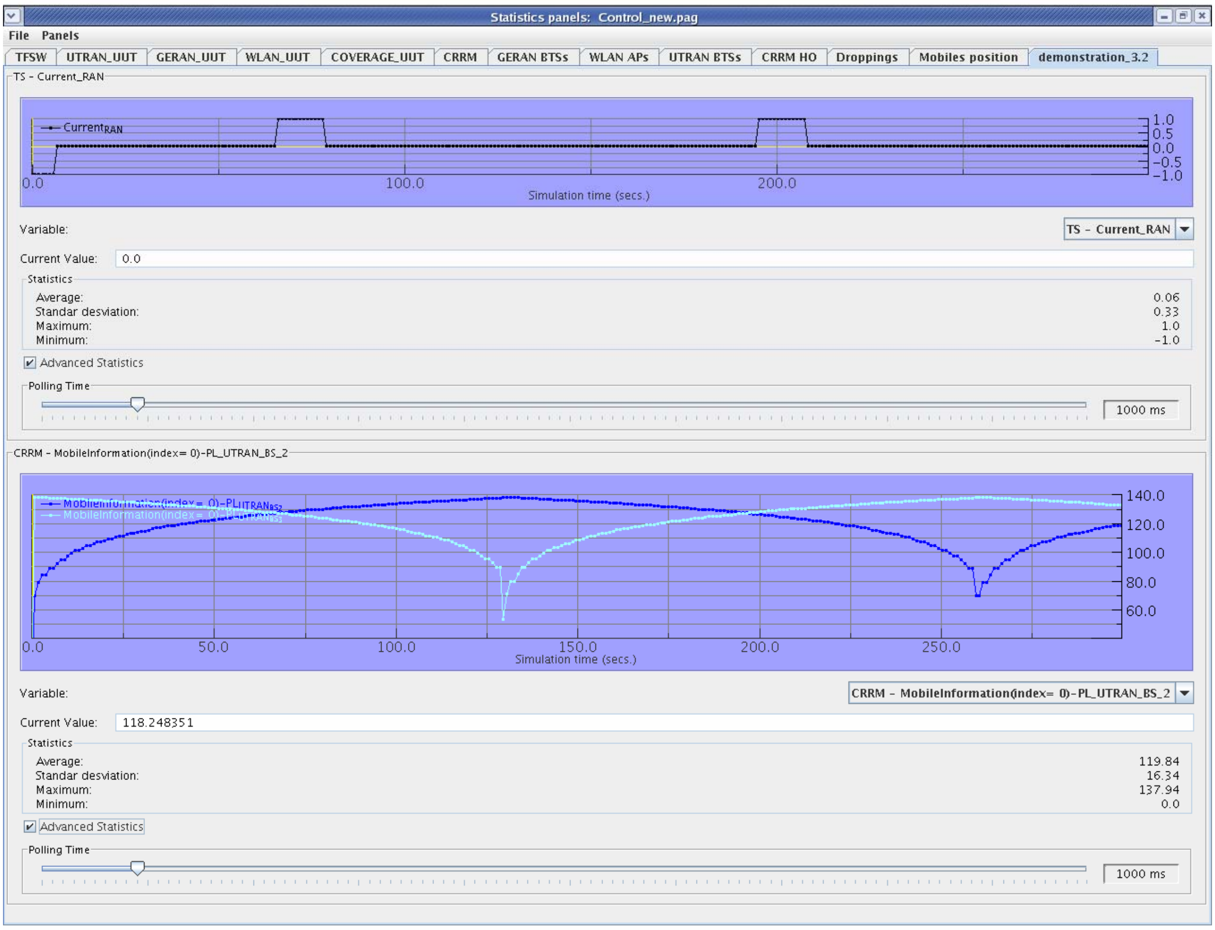


Figure 30 - NCCB VHO RAT selection (PL_{th} = 125 dB, 500 emulated users)

As it can be appreciated in Figure 28, Figure 29 and Figure 30, the UUT is initially connected to UTRAN at base station 2 since it is the best UTRAN cell and the path loss PL_{UTRAN} experienced for that base station is lower than the maximum allowed value determined by the threshold PL_{th}. As the UUT moves towards base station 3, the path loss PL_{UTRAN} for base station 2 increases and the path loss PL_{UTRAN} for base station 3 decreases. There exists a point in time in which the experienced path loss PL_{UTRAN} for base station 2 becomes greater than $PL_{th} + \Delta$, while the decreasing path loss PL_{UTRAN} value for base station 3 is still greater than $PL_{th} - \Delta$. When this situation occurs, a VHO from UTRAN (base station 2) to GERAN (base station 2) is triggered by the NCCB algorithm since no UTRAN base station is able to provide a path loss lower than PL_{th}. As the UUT moves towards base station 3, the path loss PL_{UTRAN} for base station 3 decreases. When a value lower than $PL_{th} - \Delta$ is measured, then a VHO is triggered from GERAN (base station 3) to UTRAN (base station 3). Therefore, when at least one of the two reachable UTRAN base stations provides a path loss value PL_{UTRAN} lower that the threshold $PL_{th} \pm \Delta$, the NCCB algorithm maintains the UUT connected to UTRAN. Otherwise, GERAN is the RAT selected for providing connectivity. As it can be appreciated, this behaviour is observed in the three figures. The only difference among the three figures is the time instants in which the VHOs are triggered by the NCCB algorithm. These time instants depend on the path loss threshold value PL_{th} and on the hysteresis margin Δ. As it can be observed, the NCCB behaves as expected in the three cases considered in Figure 28, Figure 29 and Figure 30.

One interesting consequence observed in Figure 28, Figure 29 and Figure 30 is that the variation of the threshold PL_{th} (for a constant hysteresis margin Δ) determines the duration of the connection to UTRAN/GERAN for the UUT as it moves from one base station to the other. For low values of PL_{th} (Figure 28) the NCCB algorithm becomes more restrictive and the VHO from UTRAN to GERAN is triggered sooner. In this case, the UUT is connected to GERAN during a longer time period. On the other hand, for high values of PL_{th} (Figure 30) the NCCB algorithm is more permissive and the UUT is moved to GERAN only during a short time period in which the UUT is crossing the cell boundaries. This behaviour suggests the possibility of controlling the user distribution between UTRAN and GERAN by simply changing the value of the threshold PL_{th}. To verify this point, Figure 31, Figure 32 and Figure 33 show the number of active users, i.e. with a session activated, connected to each RAT with the NCCB algorithm. The total number of active users in the system is represented by the red line. The number of active users connected to UTRAN and GERAN are represented by the dark blue and orange lines, respectively, while the number of active users in WLAN, represented by the light blue line, is equal to zero since WLAN has not been considered as a candidate RAT in this trial.

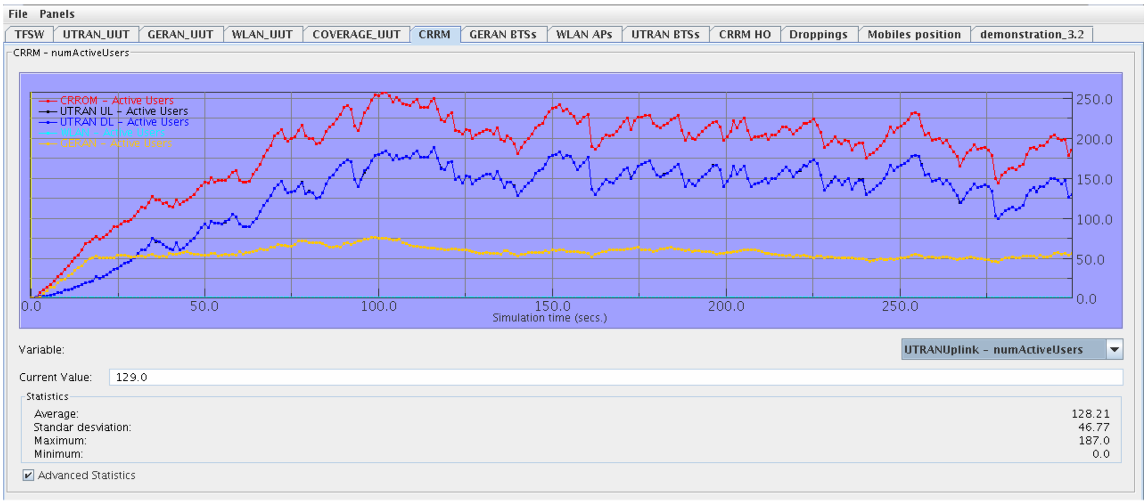


Figure 31 - Number of active users in each RAT with NCCB (PL_{th} = 115 dB, 500 emulated users)

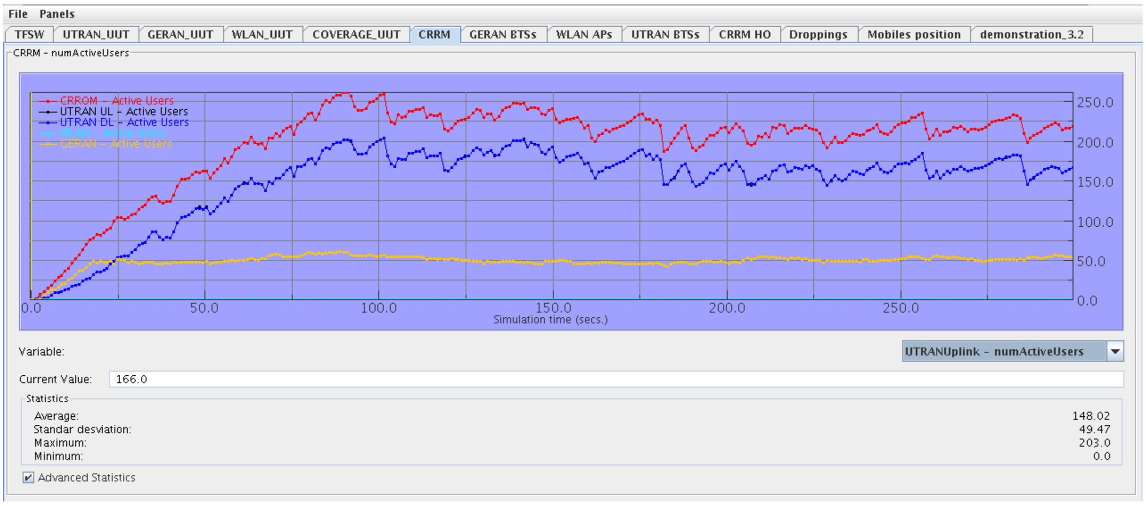


Figure 32 - Number of active users in each RAT with NCCB (PL_{th} = 120 dB, 500 emulated users)

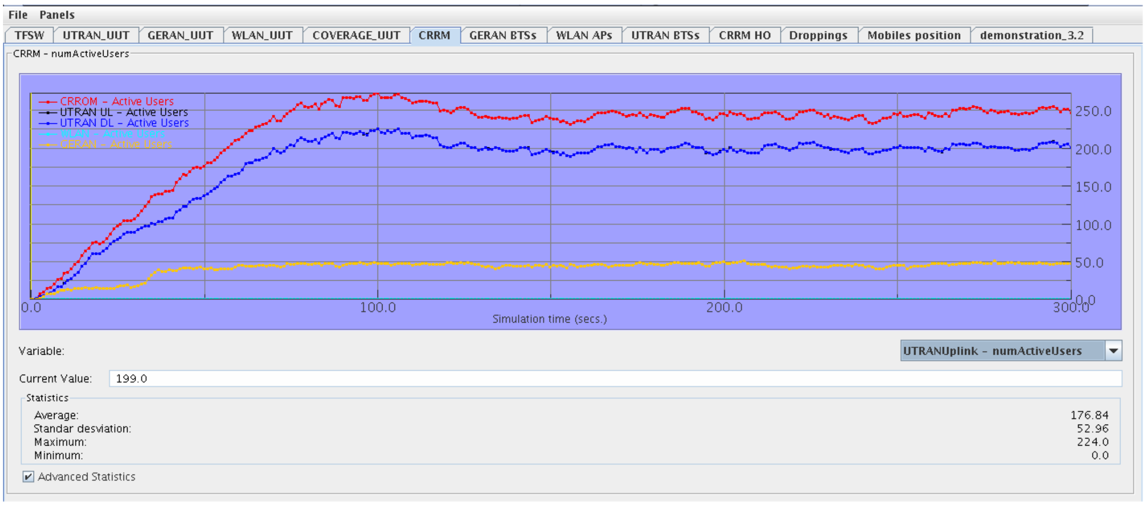


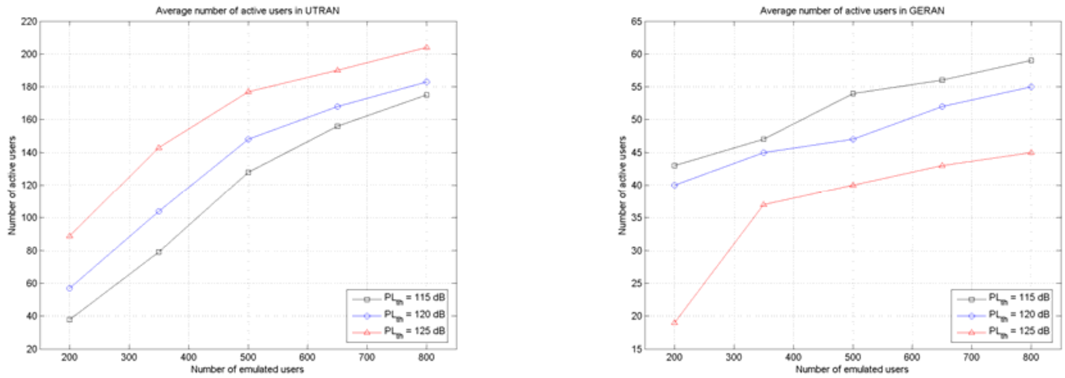
Figure 33 - Number of active users in each RAT with NCCB (PL_{th} = 125 db, 500 emulated users)

The average values of these curves are summarised in Table 9 (in absolute and relative values). The obtained results show that the user distribution between RATs can be controlled by modifying the path loss threshold PL_{th}. An increase in the threshold value PL_{th} results in a higher number of users being assigned to UTRAN and a reduction in the number of users allocated to GERAN, while a decrease in the threshold PL_{th} leads to a lower amount of users in UTRAN and an increase in the number of users assigned to GERAN. Therefore, the threshold PL_{th} can be configured so that the desired load distribution is obtained.

Table 9 - Number of active users connected to each RAT with NCCB for different path loss threshold values PL_{th} (500 emulated users)

	Absolute values		Relative values	
	UTRAN	GERAN	UTRAN	GERAN
PL_{th} = 115 dB	128	54	70.33 %	29.67 %
PL_{th} = 120 dB	148	47	75.90 %	24.10 %
PL_{th} = 125 dB	177	40	81.57 %	18.43 %

The experiments performed to obtain Figure 28 to Figure 33 were repeated with a different number of emulated users in the system (200, 350, 650 and 800 emulated users) with the aim to compare the user distribution performed by the NCCB algorithm under different load levels. Although all the figures are not shown for the sake of brevity, the obtained results are summarised in Figure 34. As it can be appreciated, the trends observed in Table 9 are also verified for other traffic loads. Moreover, the curves shown in Figure 34 follow the same trend than the results shown in figures 4 and 5 in [16], which confirms that these results are aligned with those obtained in WP3.



(a) **(b)**

Figure 34 - Average number of active users in UTRAN (a) and GERAN (b) with NCCB (PL_{th} = 115/120/125 db, 200/350/500/650/800 emulated users)

3.3 Demonstration 3: RAT selection including VHO using Fittingness factor based strategy

3.3.1 Description

The aim of this demonstration is to analyse the performance of the fittingness factor-based RAT selection algorithm when the two-step VHO procedure described in [18] is considered. As in sections 3.1 and 3.2, the scenario considered in this trial is composed of GERAN and UTRAN (WLAN is not an eligible candidate RAT). Base stations for both technologies are co-located. A cell site deployment with 3 km between consecutive base stations has been considered. All users, including the UUT, are moving within the service area at 50 km/h. While emulated users move randomly, the UUT periodically moves in straight line between two base stations, thus experiencing different path loss values. In this trial, the QoS client module has been configured in such a way that it performs a session activation request at time instant 5 seconds and the session remains active during the whole emulation. The main configuration parameters are shown in Table 10. It is worth noting that the sensitivity of the receiver has been adjusted in order to obtain the desired values of maximum path loss for GERAN voice users (L_{max}). The counterpart of L_{max} for UTRAN cannot be configured since it varies depending on the instantaneous load conditions (see definition in [18]).

Table 10 - Main configuration parameters

Parameter	Value
Distance between consecutive BSs	3 km
Weight factor ($\alpha_{p,s}$)	0.5
Averaging period for measurements (T)	1 sec
Hysteresis margin (Δ_{VHO})	0.1
Time interval for triggering VHO (T_{VHO})	1 sec
Maximum path loss for GERAN voice users (L_{max})	110 to 130 dB (5 dB increments)
User speed (emulated and UUT)	50 km/h
Interactive users to voice users ratio	4:1
Maximum bit-rate for interactive in GERAN	118.4 kbit/s (2 slots) in uplink 236.8 kbit/s (4 slots) in downlink
Maximum bit-rate for interactive in UTRAN	64 kbit/s in uplink 128 kbit/s in downlink

3.3.2 Results – Analysis and Validation

Figure 35, Figure 36 and Figure 37 show the behaviour of the fittingness factor based algorithm for a voice service as the UUT moves between two consecutive base stations, when the system is loaded with 500 emulated users and different path loss threshold values L_{max} (110, 120 and 130 dB, respectively) are considered for computing the GERAN fittingness factor value. For the two first columns of graphs, upper graphs correspond to UTRAN while lower graphs are related to GERAN. The left graphs of the figures show the measured path loss between the UUT and the two base stations located at the end-points of the trajectory. At time instant 0 seconds the UUT is near base station 2 (white line). Base station 3 (dark blue line) is reached at time instant around 130 seconds. Then, the UUT turns back to base station 2, which is reached again at time instant around 260 seconds. The dark line represents the value of the threshold L_{max}. The middle graphs of the figures show the value of the suitability parameter $Q_{i,p,s,j}$ defined in [15][18] for both directions in each RAT (uplink in orange and downlink in blue). The values of these parameters for both directions are weighted by $\alpha_{p,s}$ = 0.5 to obtain the final value of the fittingness factor $\Psi_{i,p,s,j}$ for each RAT, which is shown in the top right graph (UTRAN in yellow and GERAN in red). The RAT offering the highest fittingness factor is selected. When both RATs offer the same value for the voice service, GERAN is preferred. The bottom right graph shows the current RAT the UUT is connected to. Values 0 and 1 correspond to UTRAN and GERAN, respectively. When the UUT is not connected to any RAT (during the first 5 seconds) the value –1 is shown.

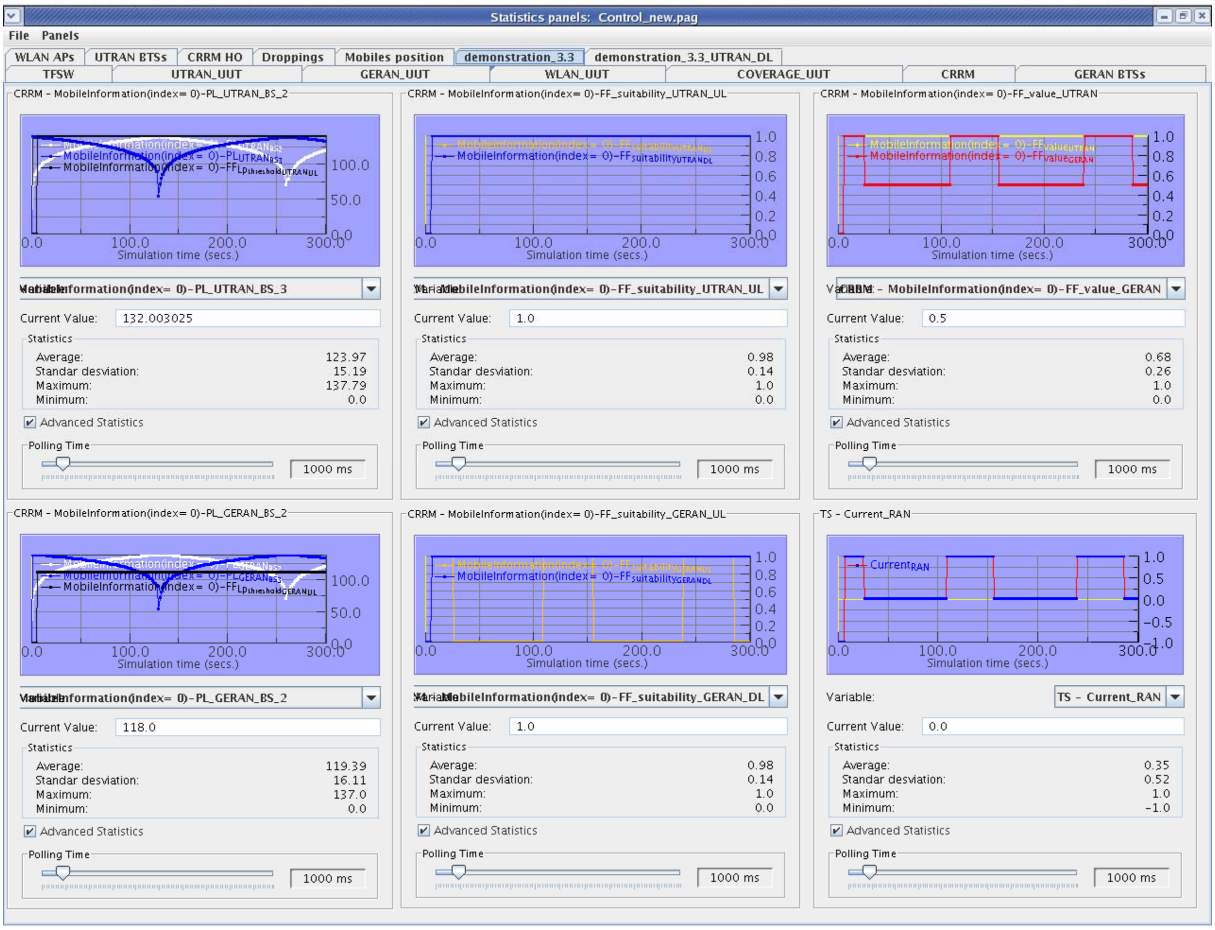


Figure 35 - Fittingness Factor VHO RAT selection for voice service (L_{max} = 110 dB, 500 emulated users)

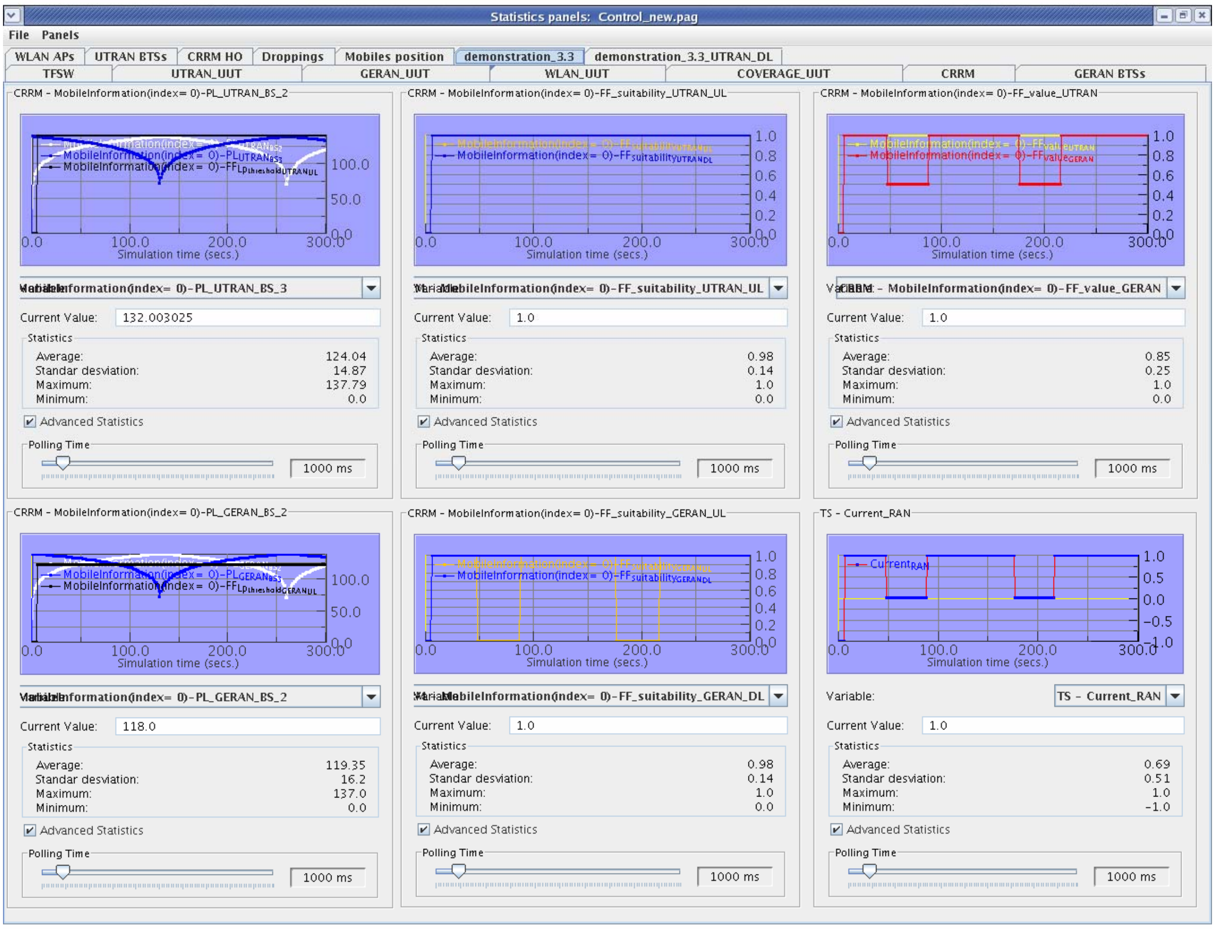


Figure 36 - Fittingness Factor VHO RAT selection for voice service (L_{max} = 120 dB, 500 emulated users)

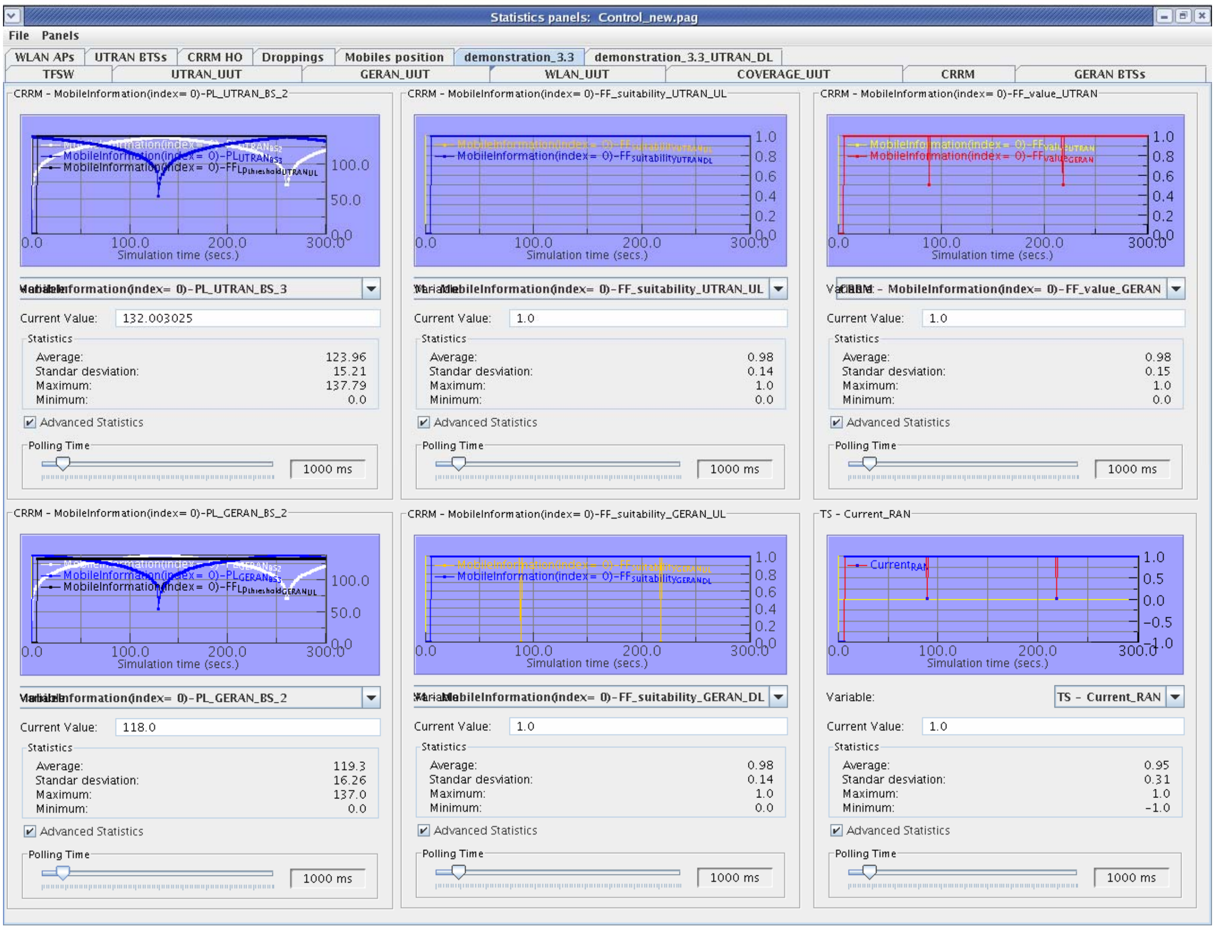


Figure 37 - Fittingness Factor VHO RAT selection for voice service (L_{max} = 130 dB, 500 emulated users)

The suitability parameter for voice services can take the values 0 or 1 depending on the relation between the measured path loss and the threshold L_{max} (see definition in [15][18]). As it can be observed in Figure 35, Figure 36 and Figure 37, the threshold L_{max} for UTRAN (around 140 dB) is never exceeded, and therefore the suitability of UTRAN for voice is always equal to one. In GERAN, however, the selected values of sensitivity and maximum transmitted power lead to different values of L_{max} that are exceeded during some time intervals. When this situation occurs for the two available base stations, the suitability of GERAN decreases from one to zero, as it can be appreciated in the middle graphs of Figure 35, Figure 36 and Figure 37. This behaviour is only observed for the uplink direction in GERAN since the maximum transmission power in uplink is more limited than in downlink. As a result, the value of the fittingness factor for GERAN during these time intervals decreases from 1 to 0.5 (due to the weighting factor $\alpha_{p,s}$ = 0.5), and UTRAN is selected. Therefore, when the maximum allowable path loss L_{max} is exceeded in one of the candidate RATs (in one or in both directions), the resulting fittingness factor for that RAT decreases and, as result, the alternative RAT is selected for providing the voice service.

Analysing Figure 35, Figure 36 and Figure 37 in detail, it is possible to infer how the variation of the threshold L_{max} impacts on the RAT selection decisions. As it can be observed, for low values of L_{max} (Figure 35), the probability of exceeding the limit is high and the fittingness factor value for GERAN is low during a longer interval. As a result, the UUT is connected to UTRAN. As the value of L_{max} increases, the probability of exceeding the limit decreases and the time period during which the UUT is connected to UTRAN becomes shorter. For sufficiently high values of L_{max} (Figure 37), the fittingness factor value for GERAN is in general equal to the value for UTRAN and the UUT is connected to GERAN almost all the time. This behaviour suggests the existence of a relation between the value of L_{max} and the user distribution among RATs. To verify this point, Figure 38 depicts the average fittingness factor for both GERAN and UTRAN as a function of L_{max}. The resulting distribution of users among the RATs is shown in Figure 39. As the value of L_{max} increases, the average fittingness factor for GERAN also increases since a higher number of users experience a path loss in GERAN lower than L_{max}. As a result, a higher number of users are allocated to GERAN when the value of L_{max}, and the fittingness factor for GERAN, increase.

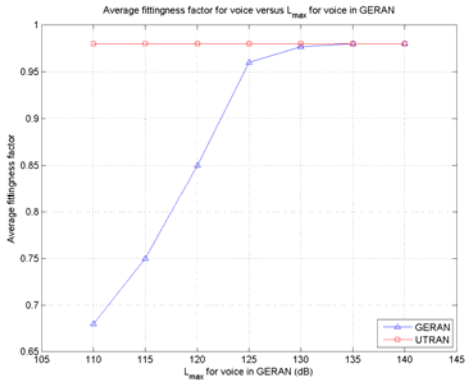


Figure 38 - Average fittingness factor for voice versus L_{max} for voice in GERAN (500 emulated users)

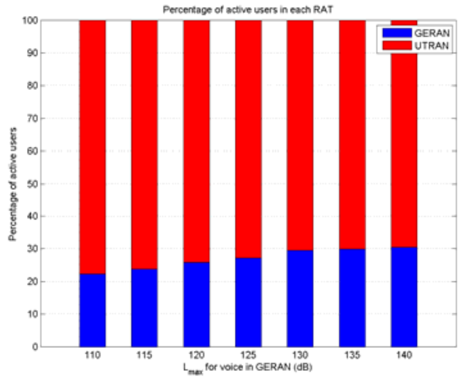


Figure 39 - Percentage of active users in each RAT with fittingness factor algorithm (500 emulated users)

Concerning the behaviour of the fittingness factor algorithm for interactive users, Figure 40 shows the evolution of some interesting parameters when an interactive service is considered instead of voice. Figure 40 is completely analogous to Figure 35, Figure 36 and Figure 37. As it can be appreciated, the algorithm always allocates the user to the RAT offering the highest fittingness factor, triggering VHOs whenever they are required.

Figure 40 - Fittingness Factor VHO RAT selection for interactive service (L_{max} = 120 dB, 500 emulated users)

The main difference between Figure 40, and Figure 35 to Figure 37 is that in this case the values of the suitability parameter $Q_{i,p,s,j}$ and the fittingness factor $\Psi_{i,p,s,j}$ are not limited to 0 or 1; they can take any real value within the interval [0,1] for both RATs. The rigorous definition of these parameters can be found in [15][18]. In this section, however, it will be sufficient to consider the following qualitative definition of the suitability for interactive services:

$$Suitability\ for\ RAT\ i = \frac{Expected\ bitrate\ in\ RAT\ i}{Maximum\ achievable\ bitrate\ in\ any\ available\ RAT} \times Multiplexing\ factor$$

The expected bit-rate for a given RAT is estimated based on the experienced channel quality. The multiplexing factor provides an estimation of the average amount of resources that the user may obtain based on the number of active users, multi-slot capabilities, and so on. The denominator of the above expression is a constant value. Concretely, for the configuration parameters shown in Table 10, it is 118.4 kbit/s in uplink and 236.8 kbit/s in downlink.

To analyse the behaviour of the fittingness factor algorithm, Figure 41 shows the average fittingness factor for interactive services in GERAN and UTRAN, while Figure 42 shows the distribution of users among the available RATs. The presented results correspond to two different cases. The first case (depicted with black lines) considers the availability of 3 carrier frequencies in each GERAN cell. Since one time-slot must be reserved for signalling, 23 time-slots are available for Traffic Channels (TCHs). The second case (depicted with pink lines) considers 2 carrier frequencies in each GERAN cell (15 TCHs). For the first case, Figure 41 shows that GERAN, in general, offers a higher average fittingness factor than UTRAN. This is due to the fact that the bit-rates obtained in GERAN with 2 slots in uplink (up to 118.4 kbit/s) and 4 slots in downlink (up to 236.8 kbit/s) are considerably higher than those of

UTRAN interactive bearers with 64 kbit/s in uplink and 128 kbit/s in downlink (see Table 10). As a result, the fittingness factor is considerably higher for GERAN. One interesting point in Figure 41 is the higher sensitivity of the UTRAN fittingness factor to an increment in the number of users. While the value for UTRAN rapidly decreases as the number of users increases in the first case, the value for GERAN experiences a small variation. This is due to the low number of users admitted in GERAN (see Figure 42), which forces UTRAN to absorb the increment of users. If the number of admitted users in a given RAT increases, or alternatively the amount of available resources decreases, the value of the multiplexing factor will decrease, and therefore a reduction of the fittingness factor is expected. This behaviour is observed for GERAN in Figure 41 when the number of carrier frequencies per GERAN cell is reduced from 3 to 2. In this second case, the fittingness factor for GERAN exhibits a higher sensitivity to the number of users than in the first case due to the smaller amount of available resources. As a result, the number of users admitted to GERAN decreases with respect to the first case, and some users are moved to UTRAN as it can be appreciated in Figure 42. The higher load level supported by UTRAN in this second case is at the origin of the reduction in the UTRAN fittingness factor shown in Figure 41 (the amount of UTRAN resources is the same in both cases).

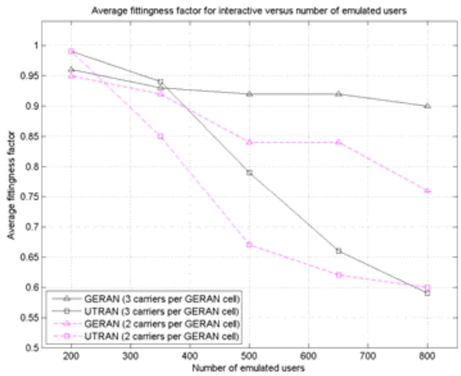


Figure 41 - Average fittingness factor for interactive in each RAT (L_{max} = 120 dB).

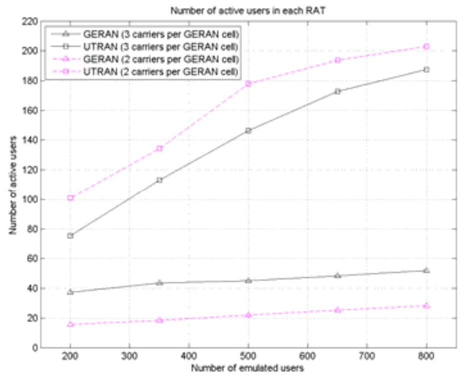


Figure 42 - Number of active users in each RAT with fittingness factor algorithm (L_{max} = 120 dB).

To conclude this section, it is worth noting that the curves shown in Figure 41 follow the same trend than the results shown in figure 5 in [18], which confirms that these results are aligned with those obtained in WP3.

4 AREA 3: STRATEGIES FOR E2E QOS

The objective of this set of trials is to demonstrate the performance of some of the strategies that are being proposed within WP3 for providing e2e QoS management over the network, taking into account the new concepts and functionalities introduced in the AROMA project in both the access and core network parts.

Demonstrations in this section should corespond to trials from section 3.3 in [1]. However, slight modifications to those trials will be presented. In the same section in [1], demonstration 1 and 2 were given as cases where QoS negotiation is done when only the best RAT or all the RATs are taken into account. In the final WQB realization all the RATs are considered in QoS negotiation, so exclusion of all but the best one of them may indirectly be done by choosing different CRRM algorithms. For example, NCCB [16] algorithm will give 0 as a weight to all but the best RAT in negotiation, and by that mask all but the best RAT. As this woud not change the behaviour of the WQB algorithm, in this document, only one QoS negotiation will be demonstrated.

Additionaly, apart of the previsioned demonstration of two re-negotiation mechanisms (triggered by RANs and CN), in this document another demonstration of QoS re-negotiation triggered by the UUT, as a consequence of changes in its preferences, will be added. This demonstration, usually refered to as *session modification*, will be detailed in 4.2 and is not given in [1].

4.1 Demonstration 1: QoS negotiation – Session Inicialization

4.1.1 Description

In this demonstration the objective is to show the interaction of the modules that provide e2e QoS for the application run by the user. The procedure scheme is shown in the Figure 43. As part of the results, all the messages will be seen as written in *log* files in the following subsection.

The implementation of the testbed supposes connection to one IR as the default one (IR1 in the example) in session initialization. However, the WQB decision may decide that the session should be connected to the other IR (both because of the RAN or CN preferences). In that case the additional set of communication appears due to IR change from predefined to elected one. As occurring at the beginning of the session establishment (the QoS Client negotiates before the application is run) this does not influence the application of the UUT. Therefore, this case is not drawn in the figure, and the procedures that follow VHO may be seen in later sections 4.3 and 4.4.

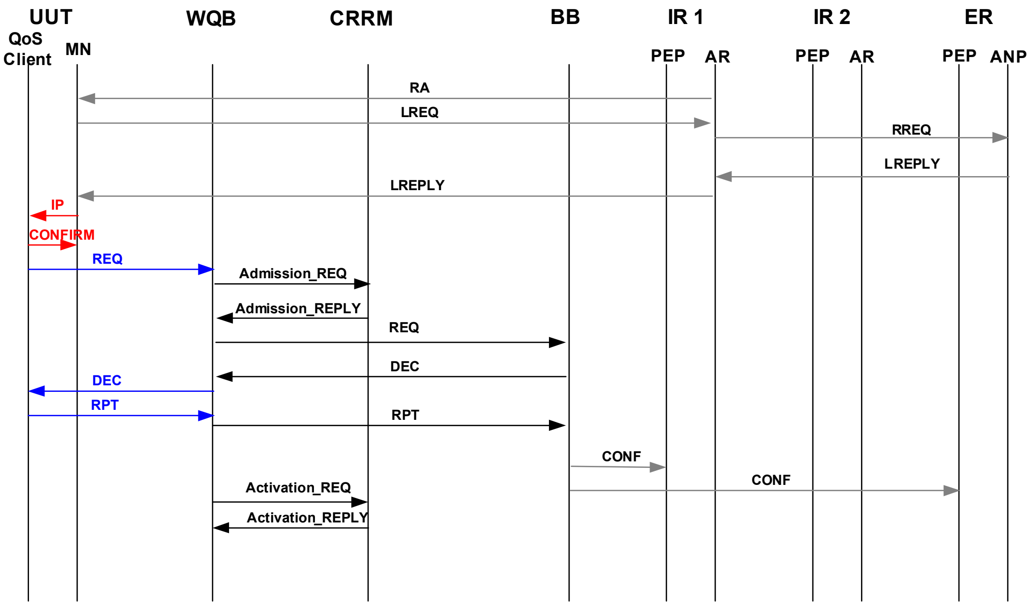


Figure 43 - QoS negotiation for session initialization

4.1.2 Results - Analysis and Validation

The results in this demonstration consist in two parts. First the trace of the *log* files will show the message exchange among QoS responsible entities. After that, the statistics will show the RAN selection differentiation when different network conditions appear under the same QoS policies.

4.1.2.1 Messaging in QoS negotiation for session initialization

In this test a simple UUT session establishment has been started from the user's console (QoS Client). The user has been approved connection, so the *log* files have recorded the message exchange. In AGMT the mixed *log* files option enables insight into the occurrences in selected entities in chronological order.

In the Figure 44 the message exchange for WQB, BB, QoS Client, Mobile Node and CRRM entities is given in mixed log files. Due to the excessive content of the CRRM configuration messages, the negotiation between WQB and CRRM relies on WQB's *log* file. The messages correspond to ones given in Figure 43. Each new line in all the log files begins with time instance and the module to which the logged line belongs. In some of the cases due to the buffering and the load of the certain processes in execution, some messages may be written in *log* file after the subsequent messages, while within the same execution time frame (10 or 20 ms usually).

```
00:00:00:0006 LOG QoSClient "Waiting for IP from MN"
. . .
00:00:01:2262 LOG MN "Passing the IP information to QoS client"
00:00:01:2406 LOG QoSClient "Making GUI visible"
00:00:01:2406 LOG QoSClient "Received ip from MN: 192.168.70.129"
00:00:01:2406 MSG QoSClient>MN "Received IP" "Confirmation sent to MN"
00:00:01:2407 LOG QoSClient "VISIBLE#"

00:00:07:1620 MSG QoSClient>WQB "REQ" "Sent REQuest-> Header_ID:0, Header_Type:0,
Header_Len:56 #### REQ_Type:0, srcIP:192.168.70.129, srcport:10203, dstIP:192.168.70.3,
dstport:10000, protocol_UL:0, protocol_DL:0, service:0, thrp_UL:12200, thrp_DL:12200"
00:00:07:1805 LOG WQB "Recv REQuest-> Header_ID:0, Header_Type:0, Header_Len:56 ####
REQ_Type:0, srcIP:192.168.70.129, srcport:10203, dstIP:192.168.70.3, dstport:10000,
protocol_UL:0, protocol_DL:0, service:0, thrp_UL:12200, thrp_DL:12200"
00:00:07:1805 LOG WQB "Request received from QoS Client"

00:00:07:2010 LOG WQB "QoS Client requested Session Activation"
00:00:07:2010 LOG WQB "Sending Admission request to CRRM"
00:00:07:2010 MSG WQB>CRRM "ADMISSION REQ" ""

00:00:07:2204 LOG BB "WQBBConnection receiving data"
00:00:07:2204 LOG WQB "Received Message from CRRM"

00:00:07:2204 LOG WQB "Sending Admission request to BB"
00:00:07:2205 LOG BB "Aroma received a QoS Request message, sending to process..."
00:00:07:2205 MSG WQB>BB "REQ" "Sent REQuest-> Header_ID:0, Header_Type:0, Header_Len:80 ####
REQ_Type:0, srcIP:192.168.70.129, srcport:0, dstIP:192.168.70.3, dstport:0, ir_id:0,
protocol_UL:0, protocol_DL:0, oneway:0, jitter:0, loss:0, thrp_UL:12200, thrp_DL:12200,
DSCP:1, rate:0, burstREQ"

00:00:07:2206 LOG BB "Destination = 192.168.70.3 (0)"
00:00:07:2206 LOG BB "IR ID = 0"
00:00:07:2206 LOG BB "Protocol_dl = 0"
00:00:07:2206 LOG BB "Protocol_ul = 0"
00:00:07:2206 LOG BB "Source = 192.168.70.129 (0)"
00:00:07:2206 LOG BB "Throughput_ul = 12200"
00:00:07:2206 LOG BB "Type = 0"
00:00:07:2206 LOG BB " Performance att: "
00:00:07:2206 LOG BB " QoSMessageRequest"
00:00:07:2207 LOG BB "DSCP = 1"
00:00:07:2207 LOG BB "Throughput_dl = 12200"
00:00:07:2208 LOG BB "        Packet Loss Rate = 0"
00:00:07:2208 LOG BB "        Packet Loss Rate = 0"
00:00:07:2208 LOG BB "        Through dl = 12200"
00:00:07:2208 LOG BB "        Through ul = 12200"
00:00:07:2208 LOG BB "  Option1:"
00:00:07:2208 LOG BB "  Option2:"
00:00:07:2208 LOG BB "Type of message (Answer): 3"
00:00:07:2208 LOG BB " QoS Decision"
00:00:07:2209 LOG BB "        Through dl = 12200"
```

```
00:00:07:2209 LOG BB "        Through ul = 12200"
00:00:07:2209 LOG BB " Sent Decision48bytes!------------------------------------------------"
00:00:07:2209 LOG BB "Sending QoS Decision message"

00:00:07:2405 LOG WQB "Received DEC message from BB"
00:00:07:2405 LOG WQB "Recv DECision-> Header_ID:0, Header_Type:1, Header_Len:36 ####
DEC_Answer:3 OpID1:1, packetloss1:0, throughput1_UL:12200, throughput1_DL:12200, OpID2:2,
packetloss2:0, throughput2_UL:12200, throughput2_DL:12200"

00:00:07:2405 LOG WQB "Sending DEC message to QoS Client"
00:00:07:2405 MSG WQB>QoSClient "DEC" "Sent DECision-> Header_ID:0, Header_Type:1,
Header_Len:4 #### DEC_Answer:1"
00:00:07:2605 LOG QoSClient "Recv DECision-> Header_ID:0, Header_Type:1, Header_Len:4 ####
DEC_Answer:1"

00:00:07:2660 LOG QoSClient "1 ACCEPTED ACTIVATION REQUEST"
00:00:07:2661 MSG QoSClient>WQB "RPT" "Sent RePorT-> Header_ID:0, Header_Type:2, Header_Len:4
#### RPT_Report:1"

00:00:07:2804 LOG BB "WQBBConnection receiving data"

00:00:07:2805 LOG WQB "Received RPT message from QoS"
00:00:07:2805 LOG WQB "Recv RePorT-> Header_ID:0, Header_Type:2, Header_Len:4 ####
RPT_Report:1"

00:00:07:2805 LOG WQB "Requesting Activation from CRRM"

00:00:07:2805 LOG WQB "Sending RPT message to BB"
00:00:07:2805 MSG WQB>BB "RPT" "Sent RePorT-> Header_ID:0, Header_Type:2, Header_Len:8 ####
RPT_Report:0 Option_ID:1"

00:00:07:2805 MSG WQB>CRRM "ACTIVATION REQ" ""

00:00:07:3005 LOG WQB "Received Message from CRRM: Action executed well in radio part"

00:00:07:3201 LOG BB "Aroma received a QoS Report message"
00:00:07:3203 LOG BB " Option ID: 1"
00:00:07:3203 LOG BB " Type of message: 0"
00:00:07:3203 LOG BB "QoSReport"
00:00:07:3203 LOG BB "Request processed in 0.099599 seconds"
```

Figure 44 - Log File: Showing Session Activation

4.1.2.2 QoS mechanism – WQB decisions under different conditions

In the second group of results, the resulting decision that QoS negotiation has produced is presented. For this test, a QoS Client Dummy has been used. That Dummy is connected and disconnecting user from the system periodically, where ON and OFF time of the connection are constant and predefined. The UUT is set up to be static (speed =0) in this test, so the position does not influence the final decision. The testing has been done with Fittingness Factor [18] as a CRRM policy. The UUT is registering as a conversational user. The scenario has been repeated varying the number of users in system.

Four scenarios have been considered in the test:
Scenario_1: There are only conversational users in system, low number (30).
Scenario_2: There are only conversational users in system, high number (600).
Scenario_3: There are conversational and streaming users in system (conversational 600, streaming 300).
Scenario_4: There are conversational and streaming users in system (conversational 600, streaming 300). The BB has blocked the IR2 for the UUT – closing GERAN access point by CN for UUT.

In Figure 45 the results for the tests can be seen, both ON and OFF session times were 1s. As it may be noticed, all the sessions from *Scenario_1* are connected to UTRAN (preferred RAN by Fittingness Factor algorithm setup) due to more than sufficient network resources. In the case of *Scenario_2* the increased number of conversational users will make UUT connect to GERAN in 27% of the cases. In *Scenario_3* even more of the sessions of the UUT are connecting to GERAN due to the higher occupancy of the UTRAN when streaming users are included. In all the previous scenarios the CN was giving sufficient resources for the user to connect (on both IRs). Therefore, in them CRRM algorithms dominated the QoS negotiation. In *Scenario_4*, although the UTRAN resources are more occupied, the final decision on connecting UUT is on WQB, and as the CN's decision does not let connection of the UUT to IR2, the WQB is forcing UUT to connect to IR1, that is UTRAN.

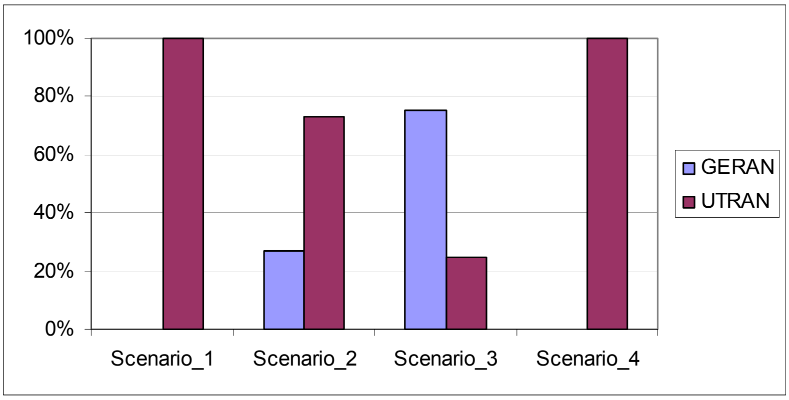


Figure 45 - Admission results in different scenarios

4.2 Demonstration 2: QoS re-negotiation procedure triggered by the UUT

4.2.1 Description

In this demonstration the objective is to show the interaction of the modules that provide e2e QoS for the application run by the user when user is expressing a change in its preferences. The procedure scheme is shown in the Figure 46. As part of the results, all the messages will be seen as written in *log* files in the following subsection. Here, as in the previous subsection, the negotiation may lead to HO, so the additional set of messages may be included. As the HOs are topic of next subsections it is not part of this example.

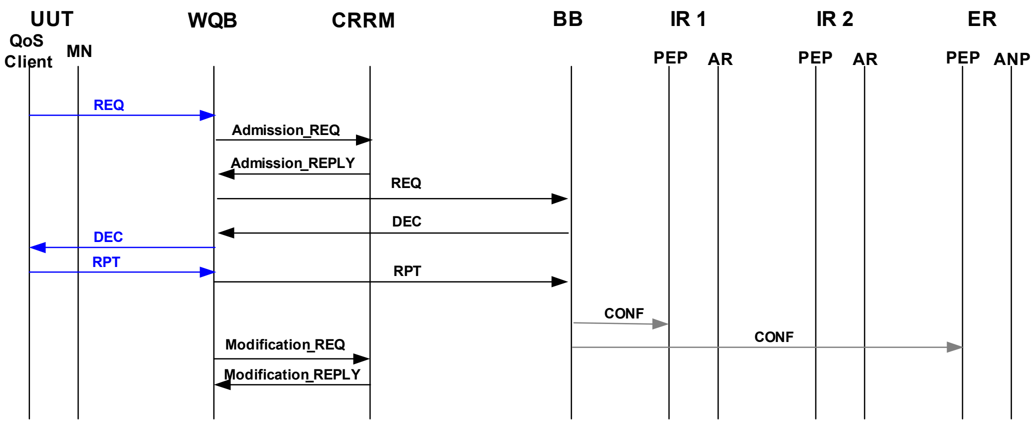


Figure 46 - QoS re-negotiation: UUT triggered

4.2.2 Results - Analysis and Validation

In this test the UUT has session already started. Supposed service is web browsing. During the session the user, as supposing not to be satisfied, is re-negotiating more bandwidth from the system. The QoS Client starts the re-negotiation with WQB, and is approved for the requested modification.

In the test the UUT will start the session with 64kbps in downlink, and will start web browsing application. After a while a user decides to download a file from FTP server (FileZilla Server [19]). As not being satisfied with downloading speed, the user will ask for 96kbps in downlink.

In this example, user is connected to UTRAN all the time, due to the designed scenario and chosen policies. In another conditions, and with other type of service, session modification initiated by the user may include VHO. In this example it is unnecessary and will not happen. Another point not presented here is the possibility of the user to change the class of service and not only the connection speed.

The *log* files have recorded the message exchange. In AGMT the mixed *log* files option enables insight into the occurrences in selected entities in chronological order. In the Figure 47 the message exchanging among entities involved in QoS re-negotiation is presented. Those are WQB, QoS Client, BB and CRRM. The correspondence to messages given in Figure 46 may be seen. Due to the excessive content of the CRRM configuration messages, the negotiation between WQB and CRRM relies on WQB's *log* file. Each new line in all the log files begins with time instance and the module to which the logged line belongs. In some of the cases due to the buffering and the load of the certain processes in execution, some messages may be written in *log* file after the subsequent messages, while within the same execution time frame (10 or 20 ms usually).

```
00:02:18:8018 MSG QoSClient>WQB "REQ" "Sent REQuest-> Header_ID:0, Header_Type:0,
Header_Len:56 #### REQ_Type:2, srcIP:192.168.70.129, srcport:10203, dstIP:192.168.70.3,
dstport:10000, protocol_UL:0, protocol_DL:0, service:2, thrp_UL:32000, thrp_DL:96000"
00:02:18:8207 LOG WQB "Recv REQuest-> Header_ID:0, Header_Type:0, Header_Len:56 ####
REQ_Type:2, srcIP:192.168.70.129, srcport:10203, dstIP:192.168.70.3, dstport:10000,
protocol_UL:0, protocol_DL:0, service:2, thrp_UL:32000, thrp_DL:96000"
00:02:18:8207 LOG WQB "Request received from QoS Client"

00:02:18:8407 LOG WQB "QoS Client requested Session Modification"
00:02:18:8407 LOG WQB "Sending Admission request to CRRM"
00:02:18:8407 MSG WQB>CRRM "ADMISSION REQ" ""

00:02:18:8606 LOG BB "WQBBConnection receiving data"
00:02:18:8607 LOG BB "Aroma received a QoS Request message, sending to process..."

00:02:18:8607 LOG WQB "Received Message from CRRM"

00:02:18:8607 LOG WQB "Sending Admission request to BB"
00:02:18:8607 MSG WQB>BB "REQ" "Sent REQuest-> Header_ID:0, Header_Type:0, Header_Len:80 ####
REQ_Type:2, srcIP:192.168.70.129, srcport:0, dstIP:192.168.70.3, dstport:0, ir_id:1,
protocol_UL:0, protocol_DL:0, oneway:0, jitter:0, loss:0, thrp_UL:32000, thrp_DL:96000,
DSCP:3, rate:0, burstREQ"

00:02:18:8608 LOG BB "DSCP = 3"
00:02:18:8608 LOG BB "Destination = 192.168.70.3 (0)"
00:02:18:8608 LOG BB "IR ID = 1"
00:02:18:8608 LOG BB "Protocol_dl = 0"
00:02:18:8608 LOG BB "Protocol_ul = 0"
00:02:18:8608 LOG BB "Source = 192.168.70.129 (0)"
00:02:18:8608 LOG BB "Throughput_dl = 96000"
00:02:18:8608 LOG BB "Throughput_ul = 32000"
00:02:18:8608 LOG BB "Type = 2"
00:02:18:8608 LOG BB " Performance att: "
00:02:18:8608 LOG BB " QoSMessageRequest"
00:02:18:8610 LOG BB "        Packet Loss Rate = 0"
00:02:18:8610 LOG BB "        Packet Loss Rate = 0"
00:02:18:8610 LOG BB "        Through dl = 96000"
00:02:18:8610 LOG BB "        Through ul = 32000"
00:02:18:8610 LOG BB "  Option1:"
00:02:18:8610 LOG BB "  Option2:"
00:02:18:8610 LOG BB "Type of message (Answer): 3"
00:02:18:8610 LOG BB " QoS Decision"
00:02:18:8611 LOG BB "        Through dl = 96000"
00:02:18:8611 LOG BB "        Through ul = 32000"
00:02:18:8611 LOG BB " Sent Decision48bytes!-------------------------------------------------"
00:02:18:8611 LOG BB "Sending QoS Decision message"
00:02:18:8807 LOG WQB "Received DEC message from BB"
00:02:18:8807 LOG WQB "Recv DECision-> Header_ID:0, Header_Type:1, Header_Len:36 ####
DEC_Answer:3 OpID1:1, packetloss1:0, throughput1_UL:32000, throughput1_DL:96000, OpID2:2,
packetloss2:0, throughput2_UL:32000, throughput2_DL:96000"

00:02:18:8807 LOG WQB "Sending DEC message to QoS Client"
00:02:18:8808 MSG WQB>QoSClient "DEC" "Sent DECision-> Header_ID:0, Header_Type:1,
Header_Len:4 #### DEC_Answer:1"
00:02:18:9204 LOG QoSClient "Recv DECision-> Header_ID:0, Header_Type:1, Header_Len:4 ####
DEC_Answer:1"

00:02:18:9258 LOG QoSClient "4 ACCEPTED MODIFICATION REQUEST"
00:02:18:9258 MSG QoSClient>WQB "RPT" "Sent RePorT-> Header_ID:0, Header_Type:2, Header_Len:4
#### RPT_Report:1"
```

```
00:02:18:9406 LOG BB "WQBBConnection receiving data"

00:02:18:9408 LOG WQB "Received RPT message from QoS"
00:02:18:9408 LOG WQB "Recv RePorT-> Header_ID:0, Header_Type:2, Header_Len:4 ####
RPT_Report:1"

00:02:18:9408 LOG WQB "Requesting Acctivation from CRRM"

00:02:18:9408 LOG WQB "Sending RPT message to BB"
00:02:18:9408 MSG WQB>BB "RPT" "Sent RePorT-> Header_ID:0, Header_Type:2, Header_Len:8 ####
RPT_Report:0 Option_ID:1"

00:02:18:9408 MSG WQB>CRRM "MODIFICATION REQ" ""

00:02:18:9608 LOG WQB "Received Message from CRRM: Acction executed well in radio part"

00:02:18:9806 LOG BB "Aroma received a QoS Report message"
```

Figure 47 - Log File: Demonstrating QoS Modification

In addition to the *log* file confirmation, the Figure 48 is a snapshot of AGMT's online statistics, and in this example it shows the traffic passing through the network for UUT. The recorded traffic is in TFSW – node responsible for UUT's traffic management, and in the corresponding RAN – UTRAN in this example. From the figure it may be noticed how the traffic amount (bitrate) changes after a modification request has successfully been accepted by the network.

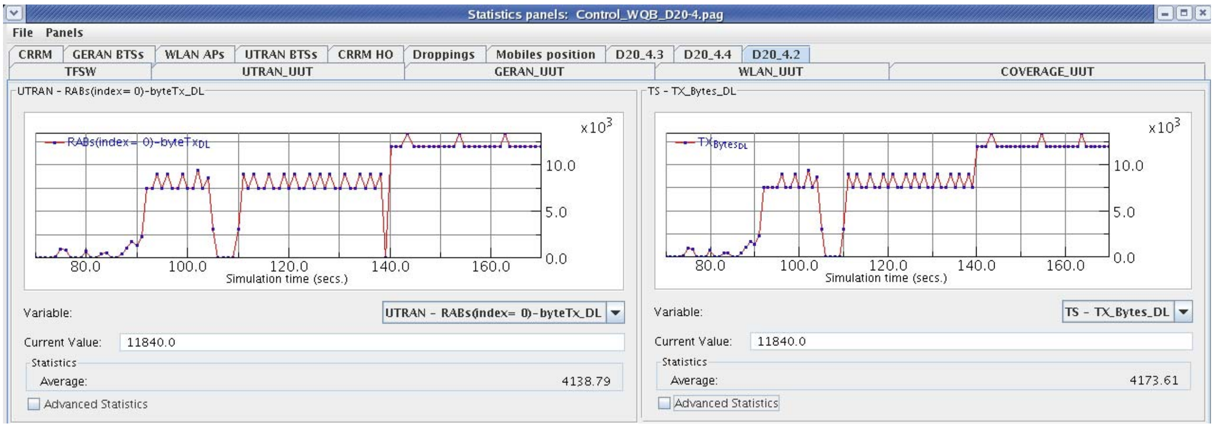


Figure 48 - Change in the amount of traffic UUT is receiving due to the session modification

4.3 Demonstration 3: QoS re-negotiation procedure triggered by a RAT

4.3.1 Description

In this demonstration the objective is to show the interaction of the modules that provide e2e QoS when the RAN (CRRM) decides to re-negotiate with WQB due to the lack of chance to continue supporting the QoS. The procedure scheme is shown in the Figure 49. As part of the results, all the messages will be seen as written in *log* files in the following subsection. The final decision may influence the QoS degradation as well – in case the WQB could not transfer the session to another RAN that is able to provide QoS. In that case, WQB should inform QoS Client and include it in negotiation. This case would include messaging drawn with dashed arrows in Figure 49. However, in the example considered here, successful negotiation is presented, with the accent on the VHO as a result of QoS re-negotiation.

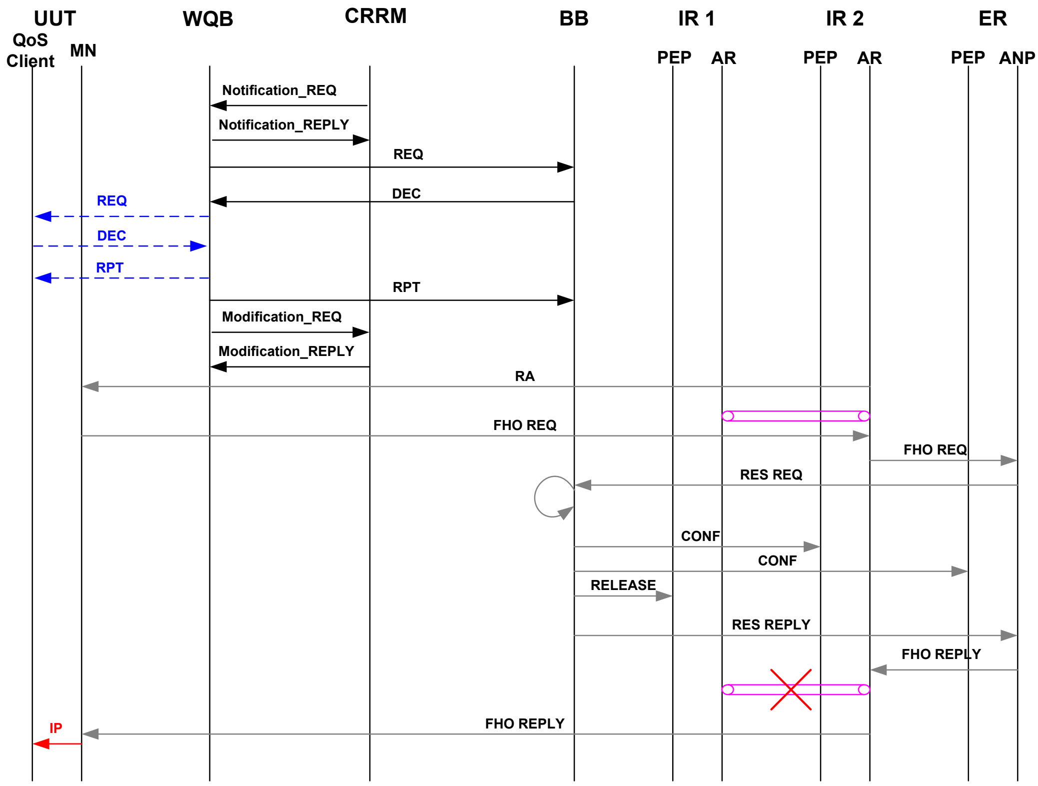


Figure 49 - QoS re-negotiation, RAN triggered

4.3.2 Results - Analysis and Validation

In this test the UUT has session already started. The tested service is video streaming. User is connecting to the system and is watching a movie using Quick Time player [11]. The movie is QCIF with 64kbps video rate and 24kbps audio rate. The UUT is connected to system with speed of 96kbps.

To have the VHO initialization in RAN the UUT is set to have appropriate path in the emulated terrain. That path will make the user enter and leave WLAN hotspot, so CRRM polices will enable connecting and disconnecting to it. When not connected to WLAN user will stream through UTRAN.

The *log* files have recorded the message exchange. In AGMT the mixed *log* files option enables insight into the occurrences in selected entities in chronological order. In the Figure 50 the message exchange between entities involved in this re-negotiation shows their correspondence to ones given in Figure 49. Those are BB, WQB, CRRM and optionally QoS Client. Due to the excessive content of the CRRM configuration messages, the negotiation between WQB and CRRM relies on WQB's *log* file. Each new line in all the log files begins with time instance and the module to which the logged line belongs. In some of the cases due to the buffering and the load of the certain processes in execution, some messages may be written in *log* file after the subsequent messages, while within the same execution time frame (10 or 20 ms usually). Note that the tunnel creation between IRs in Figure 49 is optional and is completely under the responsibility of mobility manager. Therefore, messaging for it has been omitted in this area.

```
00:03:45:1805 LOG WQB "RECEIVED Notification Request FROM CRRM"

00:03:45:2007 LOG BB "WQBBConnection receiving data"
00:03:45:2008 LOG BB "Aroma received a QoS Request message, sending to process..."
00:03:45:2009 LOG BB "Destination = 192.168.70.3 (0)"
00:03:45:2009 LOG BB "IR ID = 2"
00:03:45:2009 LOG BB "Protocol_dl = 0"
00:03:45:2009 LOG BB "Protocol_ul = 0"
00:03:45:2009 LOG BB "Source = 192.168.70.129 (0)"
00:03:45:2009 LOG BB "Type = 2"
00:03:45:2009 LOG BB " Performance att: "
00:03:45:2009 LOG BB " QoSMessageRequest"
00:03:45:2010 LOG BB "DSCP = 2"
```

```
00:03:45:2010 LOG BB " Throughput_dl = 96000"
00:03:45:2010 LOG BB " Throughput_ul = 32000"

00:03:45:2010 LOG WQB "Confirming reception of NOTIFICATION to CRRM"

00:03:45:2010 LOG WQB "VHO includes IR change. Sending REQ to BB"
00:03:45:2010 MSG WQB>BB "REQ" "Sent REQuest-> Header_ID:0, Header_Type:0, Header_Len:80 ####
REQ_Type:2, srcIP:192.168.70.129, srcport:0, dstIP:192.168.70.3, dstport:0, ir_id:2,
protocol_UL:0, protocol_DL:0, oneway:0, jitter:0, loss:0, thrp_UL:32000, thrp_DL:96000,
DSCP:2, rate:0, burstREQ"

00:03:45:2010 MSG WQB>CRRM "NOTIFICATION REPLY" ""

00:03:45:2011 LOG BB "        Packet Loss Rate = 0"
00:03:45:2011 LOG BB "        Packet Loss Rate = 0"
00:03:45:2011 LOG BB "        Through dl = 96000"
00:03:45:2011 LOG BB "        Through dl = 96000"
00:03:45:2011 LOG BB "        Through ul = 32000"
00:03:45:2011 LOG BB "        Through ul = 32000"
00:03:45:2011 LOG BB "  Option1:"
00:03:45:2011 LOG BB "  Option2:"
00:03:45:2011 LOG BB " Type of message (Answer): 3"
00:03:45:2011 LOG BB " QoS Decision"
00:03:45:2011 LOG BB "Sending QoS Decision message"
00:03:45:2012 LOG BB " Sent Decision48bytes!------------------------------------------------"
00:03:45:2202 LOG BB "WQBBConnection receiving data"

00:03:45:2205 LOG WQB "Received DEC from BB"
00:03:45:2205 LOG WQB "Recv DECision-> Header_ID:0, Header_Type:1, Header_Len:36 ####
DEC_Answer:3 OpID1:1, packetloss1:0, throughput1_UL:32000, throughput1_DL:96000, OpID2:2,
packetloss2:0, throughput2_UL:32000, throughput2_DL:96000"

00:03:45:2205 LOG WQB "Sending MODIFICATION-REQ to CRRM"

00:03:45:2205 LOG WQB "Sending RPT (ACK) to BB"
00:03:45:2205 MSG WQB>BB "RPT" "Sent RePorT-> Header_ID:0, Header_Type:2, Header_Len:8 ####
RPT_Report:0 Option_ID:2"

00:03:45:2205 MSG WQB>CRRM "MODIFICATION REQ" ""
00:03:45:2405 LOG WQB "Received Message from CRRM: Acction executed well in radio part"

00:03:45:2605 LOG BB "Aroma received a QoS Report message"

00:03:45:9907 LOG MN " HO preparation triggered  "
00:03:45:9907 LOG MN "Auto message: "HANDOVER EXECUTION 192.168.40.1""
00:03:45:9907 LOG MN "Auto message: "HANDOVER PREPARATION 192.168.40.1""
00:03:45:9908 MSG MN>TS "HOFF" "Handover Execution to BAR 192.168.40.1 (Old BAR is
192.168.30.1)"
00:03:46:0044 LOG ANP "HOFF message received from 192.168.40.1"
00:03:46:0058 MSG ANP>AR1 "HOFF ACK" "Handoff Acknowledge to Old BAR 192.168.30.1"
00:03:46:0059 LOG ANP "Anchor: Connection established between the Mobility Anchor Point and
the BB"
00:03:46:0059 MSG ANP>AR2 "HOFF ACK" "Handoff Acknowledge to New BAR 192.168.40.1"
00:03:46:0061 LOG ANP "Anchor: Msg to BB containing the information about the MN and AR sent"
00:03:46:0062 LOG BB "Waiting for data on MM socket"
00:03:46:0062 LOG BB "Warning: Received an HOFF QoS Request message from MM"
00:03:46:0065 LOG BB "Modification processed in 0.805546 seconds"
00:03:46:0065 LOG BB "QoSReport"
00:03:46:0066 LOG BB " Option ID: 2"
00:03:46:0066 LOG BB " Type of message: 0"
00:03:46:0066 LOG BB "Closing MM connection thread "
00:03:46:0066 LOG BB "MN ID: 5"
00:03:46:0066 LOG BB "New AR: 192.168.40.1"
00:03:46:0066 LOG BB "New IP: 192.168.70.129"
00:03:46:0066 LOG BB "Old AR: 192.168.30.1"
00:03:46:0066 LOG BB "Old IP: 192.168.70.129"
00:03:46:0066 LOG BB "ProcessRequest ---- Begin "
00:03:46:0066 LOG BB "ProcessRequest ---- End "
00:03:46:0066 LOG BB "Sending Decision message to MM... sent 148 bytes....-------------------"
```

Figure 50 - Log File: Demonstrating messaging due to VHO initiated by a RAT

In addition to the *log* file confirmation, the Figure 51 is a snapshot of AGMT's online statistics, showing in this example traffic passing through the network for the UUT. The recorded traffic in UTRAN and WLAN show the traffic through the corresponding RAN before and after the VHO execution. Two HO may be seen in the graphs – showing that the user was connected to WLAN between ~225s and ~240s. The rest of the time, the user is streaming through UTRAN. In Figure 50, the presented HO is actually the first of the two HOs that are shown in Figure 51 (~225s).

Figure 51 - Change in the RAT that will deliver the traffic to UUT

While two upper graphs in Figure 51 show the traffic passing through corresponding RAN, the lower left graph shows continuity in traffic received by the user (captured in TS) – including gaps in transmission that present loss due to HOs. The lower right graph shows connectivity of the UUT to IRs in each moment.

4.4 Demonstration 4: QoS re-negotiation procedure triggered by the core network

4.4.1 Description

In this demonstration the objective is to show the interaction of the modules that provide e2e QoS when the CN (BB) decides to re-negotiate with WQB due to the lack of possibility to continue supporting the QoS in current configuration. The procedure scheme is shown in the Figure 52. As part of the results, all the messages will be seen as written in *log* files in the following subsection. The final decision may influence the QoS degradation as well – in case the WQB could not transfer the session to another IR that is capable of providing QoS for the session. This case would include UUT on re-negotiation, and additional messaging for it is presented with dashed arrows in Figure 52. However, in the example presented here, successful negotiation is presented, with the accent on the VHO as a result of the QoS re-negotiation.

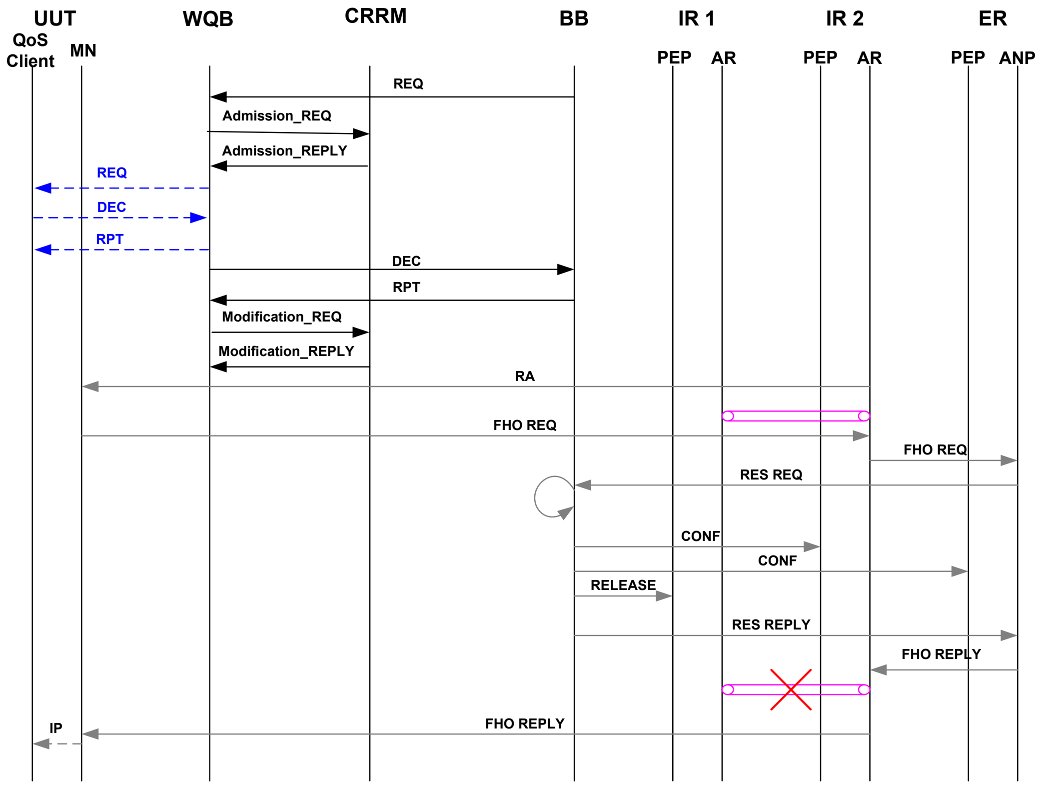


Figure 52 - QoS re-negotiation, CN triggered

4.4.2 Results - Analysis and Validation

In this test the UUT has session already started. The service under test is conversational. The user application is Robust Audio Tool (RAT) [8]. In order not to influence the renegotiation, the UUT may be set as static (speed=0). To force the HO initialization in CN, the core network is set to sense the bandwidth occupancy in the CN and will inform the UUT in cases when uses a path in which bottlenecks occur, suggesting a VHO to an alternative IR if any.

The *log* files have recorded the message exchange. In AGMT the mixed *log* files option enables insight into the occurrences in selected entities in chronological order. In the Figure 53 the message exchange between entities involved in this re-negotiation shows their correspondence to ones given in Figure 52. Those are BB, WQB, CRRM and optionally QoS Client. Due to the excessive content of the CRRM configuration messages, the negotiation between WQB and CRRM relies on WQB's *log* file. Each new line in all the log files begins with time instance and the module to which the logged line belongs. The lines less relevant to QoS negotiation have been written in italic in the trace. In some of the cases due to the buffering and the load of the certain processes in execution, some messages may be written in *log* file after the subsequent messages, while within the same execution time frame (10 or 20 ms usually). Note that, as in the previous section, the tunnel creation between IRs in Figure 52 is optional and is completely under the responsibility of mobility manager. Therefore, messaging for it has been omitted in this section.

```
00:00:39:5398 LOG BB "Check links occupation"
00:00:39:5398 LOG BB "Link values: 297.662 > 5.24288e+07"
00:00:39:5399 LOG BB "Link values: 0 > 5.24288e+07"
00:00:39:5399 LOG BB "Link values: 0 > 5.24288e+07"
00:00:39:5399 LOG BB "Link values: 59.0542 > 5.24288e+07"
00:01:39:5407 LOG BB "Check links occupation"
00:01:39:5407 LOG BB "Link values: 5.10163e+07 > 5.24288e+07"
00:01:39:5407 LOG BB "Link values: 59.0542 > 5.24288e+07"
00:01:39:5408 LOG BB "Link values: 0 > 5.24288e+07"
00:01:39:5408 LOG BB "Link values: 0 > 5.24288e+07"
00:02:39:5416 LOG BB "Check links occupation"
00:02:39:5416 LOG BB "Conditions to trigger an handover"
00:02:39:5416 LOG BB "Link values: 8.97602e+07 > 5.24288e+07"
00:02:39:5416 LOG BB "Preparing to send a QoS Request message to force a handover......"
```

```
00:02:39:5417 LOG BB " Destination = 0.0.0.0 (0)"
00:02:39:5417 LOG BB " IR ID = 2"
00:02:39:5417 LOG BB " Protocol_dl = 0"
00:02:39:5417 LOG BB " Protocol_ul = 0"
00:02:39:5417 LOG BB " Source = 0.0.0.0 (0)"
00:02:39:5417 LOG BB " Type = 0"
00:02:39:5417 LOG BB "  Performance att: "
00:02:39:5417 LOG BB "  QoSMessageRequest"
00:02:39:5418 LOG BB " DSCP = 0"
00:02:39:5418 LOG BB " Destination = 0.0.0.0 (0)"
00:02:39:5418 LOG BB " Protocol_ul = 0"
00:02:39:5418 LOG BB " Source = 0.0.0.0 (0)"
00:02:39:5418 LOG BB " Throughput_dl = 0"
00:02:39:5418 LOG BB " Throughput_ul = 0"
00:02:39:5418 LOG BB " Type = 0"
00:02:39:5418 LOG BB "  QoSMessageRequest"
00:02:39:5419 LOG BB " DSCP = 0"
00:02:39:5419 LOG BB " IR ID = 33554432"
00:02:39:5419 LOG BB " Protocol_dl = 0"
00:02:39:5419 LOG BB " Throughput_dl = 0"
00:02:39:5419 LOG BB " Throughput_ul = 0"
00:02:39:5419 LOG BB "  Performance att: "
00:02:39:5419 LOG BB "Handover request sent to WQB - Sent 92 bytes -------"
00:02:39:5419 LOG BB "Link values: 0 > 5.24288e+07"
00:02:39:5419 LOG BB "Link values: 0 > 5.24288e+07"
00:02:39:5419 LOG BB "Link values: 59.0542 > 5.24288e+07"

00:02:39:5608 LOG WQB "Recv REQuest-> Header_ID:0, Header_Type:0, Header_Len:80 ####
REQ_Type:0, srcIP:0.0.0.0, srcport:0, dstIP:0.0.0.0, dstport:0, ir_id:2, protocol_UL:0,
protocol_DL:0, oneway:0, jitter:0, loss:0, thrp_UL:0, thrp_DL:0, DSCP:0, rate:0, burst:0"
00:02:39:5608 LOG WQB "Request received from BB"

00:02:39:5808 LOG WQB "BB Requires VHO, Sending Admission (evaluation) Message to CRRM"
00:02:39:5808 MSG WQB>CRRM "ADMISSION REQ" ""

00:02:39:6007 LOG BB "WQBBConnection receiving data"

00:02:39:6008 LOG BB "        Packet Loss Rate = 0"
00:02:39:6008 LOG BB "  Option1:"
00:02:39:6008 LOG BB " Type of message (Answer): 2"
00:02:39:6008 LOG BB " QoS Decision"

00:02:39:6008 LOG BB "Aroma received a QoS Decision message"
00:02:39:6008 LOG BB "Received a QoSDecision from WQB... with type = 2"

00:02:39:6008 LOG WQB "CRRM Approved IR Change, Sending DEC to BB"
00:02:39:6008 MSG WQB>BB "DEC" "Sent DECision-> Header_ID:0, Header_Type:1, Header_Len:36 ####
DEC_Answer:2 OpID1:0, packetloss1:0, throughput1_UL:0, throughput1_DL:0, OpID2:0,
packetloss2:0, throughput2_UL:0, throughput2_DL:0"

00:02:39:6009 LOG BB "        Packet Loss Rate = 0"
00:02:39:6009 LOG BB "        Through dl = 0"
00:02:39:6009 LOG BB "        Through dl = 0"
00:02:39:6009 LOG BB "        Through ul = 0"
00:02:39:6009 LOG BB "        Through ul = 0"
00:02:39:6009 LOG BB "  Option2:"
00:02:39:6012 LOG BB "Handover processed in 0.059567 seconds"
00:02:39:6012 LOG BB "Report sent to the WQB (finishing the HO started by the core process) -
Sent 20 bytes"

00:02:39:6208 LOG WQB "Received RPT from BB"
00:02:39:6208 LOG WQB "Recv RePorT-> Header_ID:0, Header_Type:2, Header_Len:8 ####
RPT_Report:0 Option_ID:402653184"

00:02:39:6208 LOG WQB "Sending a Modification REQ to CRRM"
00:02:39:6208 MSG WQB>CRRM "MODIFICATION REQ" ""

00:02:39:6408 LOG WQB "Received Message from CRRM: Acction executed well in radio part"

00:02:39:7105 LOG MN " HO preparation triggered  "
00:02:39:7105 LOG MN "Auto message: "HANDOVER EXECUTION 192.168.40.1""
00:02:39:7105 LOG MN "Auto message: "HANDOVER PREPARATION 192.168.40.1""
00:02:39:7106 MSG MN>TS "HOFF" "Handover Execution to BAR 192.168.40.1 (Old BAR is
192.168.30.1)"
```

Figure 53 - Log File: Demonstrating messaging due to VHO initiated by BB

In addition to the *log* file confirmation, the Figure 54 shows the traffic passing through the network for the UUT. In the left two graphs, the recorded traffic in UTRAN and GERAN show the passing of the traffic through the corresponding RAN before and after the VHO execution.

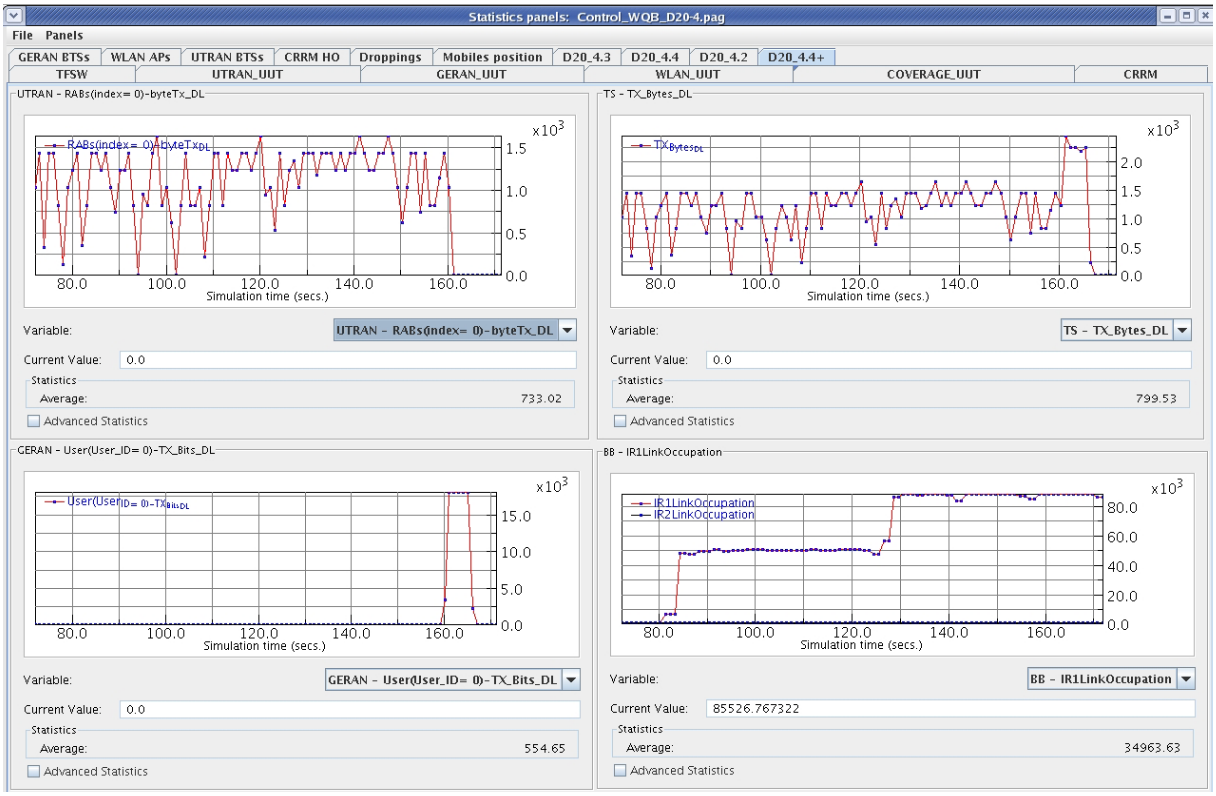


Figure 54 - Change in the RAT that will deliver the traffic to UUT

The right upper graph of the Figure 54 shows traffic captured by TS, and occupancy of the IRs is given in right lower graph. It may be seen that soon after the increment in traffic using IR1, the BB realizes the congestion ad informs UUT suggesting an IR switching, which later results in a VHO execution by the system.

5 AREA 4: ADMISSION CONTROL ALGORITHMS IN THE BB

This section presents the performance evaluation for different CAC algorithms used by the BB during the session setup and handover processes.
The tests presented are limited to AROMA's characteristics, being the more important the existence of only a user session. The particularities of the AROMA testbed doesn't give us the possibility to test all the types of algorithms presented in D15 Trials Description [1]. The presence of only a user session makes trivial the use of a parameter-based algorithm, which should be used in the presence of several users' sessions.

The process of requesting a new session is summarized as:

1) WQB **Requests** a 12200 kb session

2) BB performs the CAC and answers with a **Decision** message which presents the availability of the IRs – the final decision is made by the WQB, which acts as a MPDF (Master Policy Decision Function);

3) WQB decides which IR should use and sends a **Report**. The report message contains the final choice.

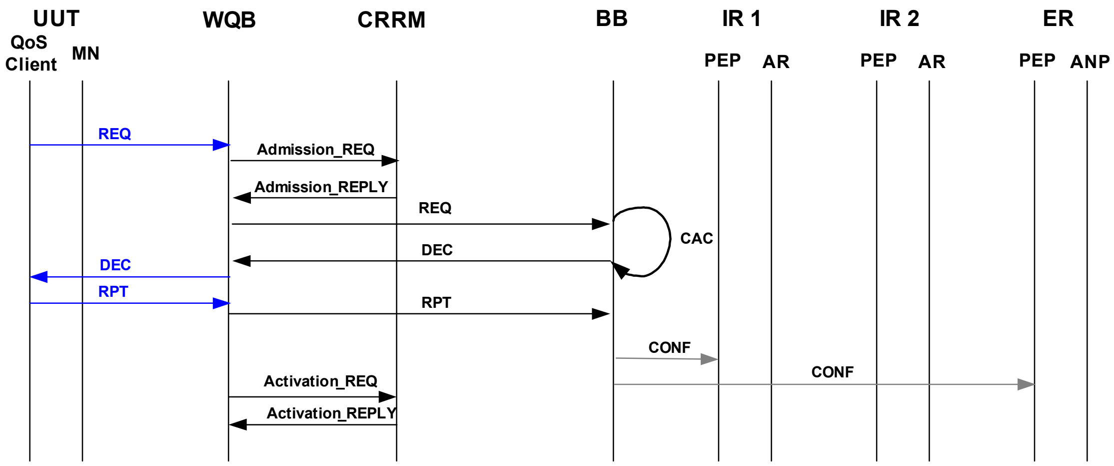


Figure 55 - Session QoS Request and routers' configuration

The implemented algorithm has a characteristic in terms of router's occupation requests periodicity. When the background traffic increases the SNMP gets also increase. With this approach we take more attention to the CN traffic and are able to react quickly (for example force a handover request to the radio part of the network). This characteristic has an obvious drawback, in a scenario of congestion BB uses more control messages, per time slot, what can contribute to more congestion; however from other point of view the user may experience better quality if when the network is congested a handover is immediately request to the WQB.

5.1 Demonstration 1: Test CAC algorithm with light load

5.1.1 Description

This demonstration is proposed to test the CAC algorithm implemented in the CN in the presence of a light load scenario. The CAC algorithm implemented of measurement-based type, which means his answers are based in the information maintained in the DB and the one collect via SNMP from the ingress routers MIBs. The algorithm, as explained in the introductory text of section 5, increases and decreases the periodicity of requests made to the routers, based in the values collected previously. If more traffic is perceived, more times the BB collects information.
Figure 56 illustrates, graphically, as an example, the SNMP data collected from both IRs's MIBs.
In this scenario a session is initialised 10 times with a measurement based CAC algorithm. The time it takes to accept the session is an important result and is presented in next section.

5.1.2 Results

This section presents the BB's behaviour in respect with the admission control process. Partial log files are shown next, to demonstrate the correctness of the process.

Table 11 - BB's log snapshot for a session request

```
…
00:05:33:7575 LOG BB "Check links occupation"
00:05:33:7575 LOG BB "Link values: 781028 > 5.24288e+07"
00:05:33:7575 LOG BB "Link values: 0 > 5.24288e+07"
00:05:33:7575 LOG BB "Link values: 0 > 5.24288e+07"
00:05:33:7575 LOG BB "Link values: 0 > 5.24288e+07"
….
00:05:41:0806 LOG BB " QoSMessageRequest"
00:05:41:0807 LOG BB "  Type = 1"
00:05:41:0807 LOG BB "  Source = 192.168.70.129 (0)"
00:05:41:0807 LOG BB "  Destination = 192.168.70.3 (0)"
00:05:41:0807 LOG BB "  Protocol_ul = 0"
00:05:41:0807 LOG BB "  Protocol_dl = 0"
00:05:41:0807 LOG BB "  IR ID = 1"
00:05:41:0807 LOG BB " Performance att: "
00:05:41:0807 LOG BB "  Throughput_ul = 32000"
00:05:41:0807 LOG BB "  Throughput_dl = 64000"
….
00:05:48:1860 LOG BB "Request processed in 0,121121 seconds"
```

The time of response for the CAC algorithm is presented next.

Table 12 - CAC execution time

# Requests	Time (s)
1	0,121121
2	0,099845
3	0,10093
4	0,120303
5	0,099562
6	0,130633
7	0,098436
8	0,103601
9	0,100148
10	0,096695

Table 13 - Statistical analysis

Average	Std
0,1071274	0,0120928

The values are presented in seconds, and represent a session setup in 10 different testbed running instances.

5.1.3 Analysis and Validation

The average time needed to execute the CAC algorithm is the 0,107s, which has a little influence in the overall process. A deeper analysis is presented in section 5.2.3, where this value is compared with the one collected in a heavy load traffic scenario.

5.2 Demonstration 2: Test CAC algorithm with heavy load

5.2.1 Description

This demonstration is proposed to test the CAC algorithm implemented in the CN in the presence of a heavy load scenario.
To achieve this, a background traffic generator is initiated between two end points outside the CN. The generated traffic is only perceived by the BB, periodically, when it measures the network. Figure 56 illustrates, graphically, as an example, the SNMP data collected from both IRs's MIBs. BB collects all the bytes passing in the IR interface, which means it gets data as an aggregate of i) UUT traffic, ii) Emulated traffic and iii) Background traffic.
In this scenario a session is initialized 10 times with a measurement based CAC algorithm. The time it takes to accept the session is an important result and is presented in next section.

5.2.2 Results

This section presents the BB's behaviour in respect with the admission control process. Partial log files are shown next, to demonstrate the correctness of the process.

Table 14 - BB's log snapshot for a session request

```
…
00:00:33:7541 LOG BB "Check links occupation"
00:00:33:7541 LOG BB "Link values: 1.1435e+06 > 5.24288e+07"
00:00:33:7541 LOG BB "Link values: 0 > 5.24288e+07"
00:00:33:7541 LOG BB "Link values: 0 > 5.24288e+07"
00:00:33:7541 LOG BB "Link values: 0 > 5.24288e+07"
….
00:01:09:2010 LOG BB " QoSMessageRequest"
00:01:09:2011 LOG BB "  Type = 1"
00:01:09:2011 LOG BB "  Source = 192.168.70.129 (0)"
00:01:09:2011 LOG BB "  Destination = 192.168.70.3 (0)"
00:01:09:2011 LOG BB "  Protocol_ul = 0"
00:01:09:2011 LOG BB "  Protocol_dl = 0"
00:01:09:2011 LOG BB "  IR ID = 1"
00:01:09:2011 LOG BB " Performance att: "
00:01:09:2011 LOG BB "  Throughput_ul = 32000"
00:01:09:2011 LOG BB "  Throughput_dl = 64000"
….

00:01:10:1860 LOG BB "Request processed in 0.199342 seconds"
```

The time of response for the CAC algorithm is presented next.

Table 15 - CAC execution time

# Requests	Time (s)
1	0,199342
2	0,249845
3	0,213451
4	0,199353
5	0,221027
6	0,213635
7	0,19941
8	0,224611
9	0,210249
10	0,296695

Table 16 - Statistical analysis

Average	Std
0,2227618	0,0301374

The values are presented in seconds, and represent a session setup in 10 different testbed running instances.

5.2.3 Analysis and Validation

A measurement algorithm, as the one presented in previous section, only accepts sessions if the requested bandwidth is lower than the IR interface occupation plus a certain threshold. With the limitations presented in the beginning of section 5 the analysis should be done comparing these values with the ones presented in section 5.1.2.
In the presence of background traffic – not pre-reserved by BB - the CAC algorithm collects data from the routers in a higher periodicity, which gives it a more realistic vision of the network occupation, but introduces more control traffic, and of course increases the CAC's respond time. As natural the time taken by the CAC in the presence of high traffic in the network is higher. Next table wrap up the results.

Table 17 - Time Response for CAC in light and Heavy Load scenarios

	Average time response	**Std**
Light Load	0,1071274	0,0120928
Heavy Load	0,2227618	0,0301374

5.3 Demonstration 3: CAC algorithm performance during a handover process

5.3.1 Description

This demonstration is proposed to test the CAC algorithm in the presence of a handover initiated by the terminal. The process is summarized in next:

1) WQB triggers a modification request to the BB. This step is a modification because the ingress router is changed and because the session bandwidth can be downgraded, due to radio characteristics.

2) BB executes the CAC procedure and answers to the WQB

3) MM informs the BB that a handover is being executed and the BB changes the MPLS tunnels from the old AR to the new one.

In the presence of a measurement-based CAC algorithm the basis of the CAC is the data collected from the IRs via SNMP. Figure 56 illustrates an example of the data collected from the ingress routers MIBs presented graphically in the AGMT.

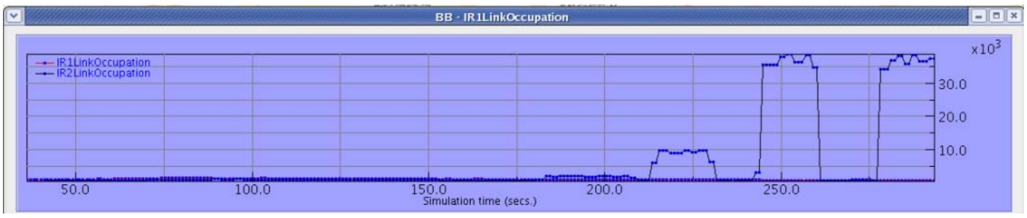


Figure 56 - SNMP data collect from IR1 and IR2

5.3.2 Results

This sub-section presents the BB's behaviour in respect with the modification process, imposed by the handover process. Partial log files are shown next, to demonstrate the correctness of the process.

Table 18 - BB's log snapshot for a session modification (Handover process)

```
…
00:02:17:8407 LOG BB "WQBBConnection receiving data"
00:02:17:8409 LOG BB "Aroma received a QoS Request message, sending to process..."
00:02:17:8410 LOG BB " QoSMessageRequest"
00:02:17:8411 LOG BB "          Type = 2"
00:02:17:8411 LOG BB "          Source = 192.168.70.129 (0)"
00:02:17:8411 LOG BB "          Destination = 192.168.70.3 (0)"
00:02:17:8411 LOG BB "          Protocol_ul = 0"
00:02:17:8411 LOG BB "          Protocol_dl = 0"
00:02:17:8411 LOG BB "          IR ID = 1"
00:02:17:8411 LOG BB " Performance att: "
00:02:17:8411 LOG BB "          Throughput_ul = 12200"
00:02:17:8411 LOG BB "          Throughput_dl = 12200"
00:02:17:8411 LOG BB "          DSCP = 1
…
00:02:17:9112 LOG BB "Modification processed in 0.832303 seconds"
…
00:02:18:6735 LOG BB "MN ID: 5"
00:02:18:6736 LOG BB "Old IP: 192.168.70.129"
00:02:18:6736 LOG BB "New IP: 192.168.70.129"
00:02:18:6736 LOG BB "Old AR: 192.168.40.1"
00:02:18:6736 LOG BB "New AR: 192.168.30.1"
00:02:18:6736 LOG BB "ProcessRequest ---- End "
…
```

The time of response for the CAC algorithm, in the presence of a handover, is presented next.

Table 19 - CAC execution time

# Modifies	Time (s)
1	0,180088
2	0,729184
3	0,446143
4	0,425544
5	0,388357
6	0,34783
7	0,740465
8	0,585021
9	0,396285
10	0,448218

Table 20 - Statistical analysis

Avg	Std
0,4687135	**0,172444789**

The values are presented in seconds, and represent a session setup in 10 different testbed running instances.

5.3.3 Analysis and Validation

The time taken for a handover decision, when compared with the one taken when a new session is requested is slightly higher. Next table shows that.

Table 21 - Time response (New Session Request vs Handover)

	Average time response	Std
New Session Req - Light Load	0,1071274	0,0120928
New Session Req - Heavy Load	0,2227618	0,0301374
Handover	0,4687135	0,17244479

A higher value for the handover process happens mainly because the handover is taken as a modification to an existing session, which means a set of actions need to be executed in the BB. A search needs to be performed to take the correct session, take the stored values for that session, execute CAC and, finally, perform a session modification for session's data (mainly the ingress router identification and the used bandwidth in the case of bandwidth downgrade).

5.4 Demonstration 4: flows pre-empts a lower priority flow

The tests presented in this sub-section are slightly different from the ones specified in D15 [1], section 3.4.3, and should be seen as a tentative to show pre-emptive behaviour of the DiffServ queues, even in the presence of different priority queues. The obtained results need to be attested with the results presented in section 2 of this Deliverable, where an analysis of the perceived QoS by the user is done. The present is a tentative to show that no perceived QoS degradation exists, by getting/looking into the values of the Linux Kernel's Traffic Condition (TC).
The difficulty of getting those values was higher due the use of MPLS extensions [20], which creates a new abstraction layer into the Linux Kernel. The results gathering and the control of the triggers are different even in a controlled testbed as the AROMAs' one. The presented is a demonstration that the technique is working and exists in the overall testbed.

5.4.1 Description

When a class requests less than the amount assigned (per default), the remaining (excess) bandwidth can be used by other classes each time they need it (we can say the class *borrows* to another class).
We should, however, mention that there is obligation to repay the resource that was "borrowed" if the priority class needs it.

The following diagram shows the relationship between routing decisions and Netfilter [21].

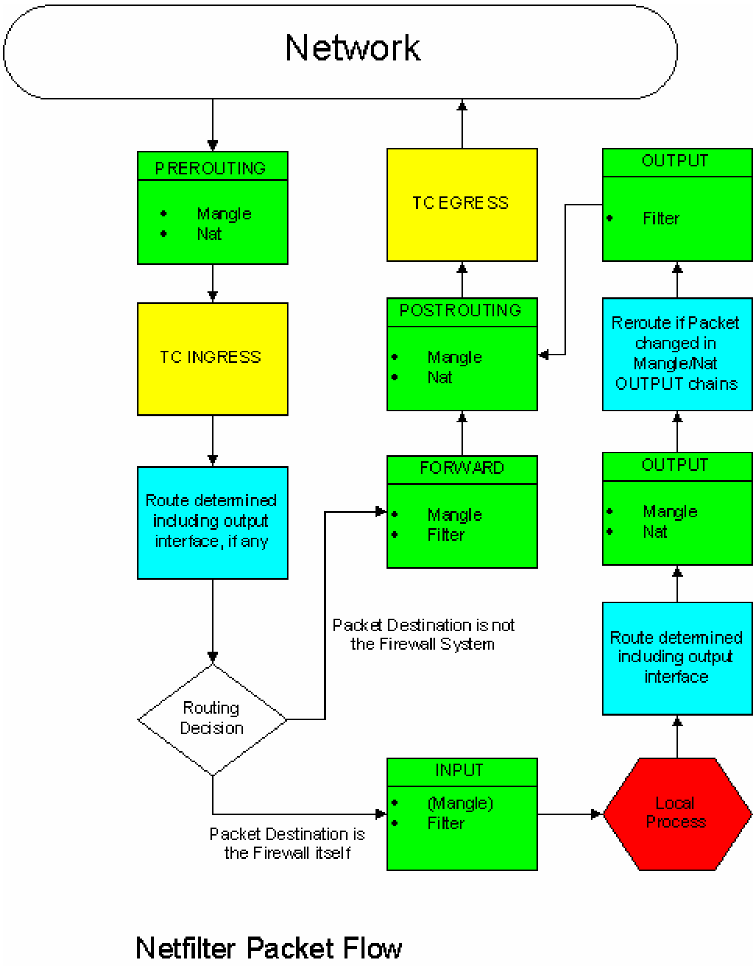


Figure 57 - Netfilter Packet Flow

The blue boxes indicate where routing decisions are made. Upon exit from one of these boxes, if the packet is being sent to another system then the interface and the next hop have been uniquely determined.

The green boxes show where Netfilter processing takes place.
The values retrieved and presented in the next section are from the “TC Egress” function, which means are taken before packets are insert into the network.
Each time a new session is requested, or in the presence of a handover, after the admission control process the BB creates (or changes) the firewall filters (IPTables), in the involved core routers. These rules are not only for packets filtering, but also for marking, or labeling, internally to the router(s). The mark is used after to put them in the correct queues.

The proposed scenario is composed by three traffic flows marked with different DSCP (ToS field in IPv4) originated from emulated users and corresponding to Video Stream, Voice and Data/Interactive. Packets are labeled in the POSTROUTING area and based in the label, they are forwarded to the correct TC queue. Finally they are inserted in the network.

The explained behavior occurs in all the situations, even during a handover. This pre-emption policy dissociates handover flows and new incoming flows.

5.4.2 Results

To demonstrate the pre-emptive characteristics of the queues we first present the IPtables description, to show that packets with certain characteristics should be labelled with a certain value, in order to be inserted in the correct TC queue.

```
[root@IR1 tc]# iptables -t mangle -L -nvvv
Chain PREROUTING (policy ACCEPT 37M packets, 5855M bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain INPUT (policy ACCEPT 2330K packets, 269M bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain FORWARD (policy ACCEPT 35M packets, 5585M bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain OUTPUT (policy ACCEPT 2336K packets, 277M bytes)
 pkts bytes target     prot opt in     out     source               destination

Chain POSTROUTING (policy ACCEPT 37M packets, 5863M bytes)
 pkts bytes target     prot opt in     out     source               destination
11520  668K MARK       all  --  *      *       192.168.30.2         192.168.70.2/0       DSCP match
0x01 MARK set 0x1
 3637 1539K MARK       all  --  *      *       192.168.30.2/0       192.168.70.2/0       DSCP match
0x02 MARK set 0x2
   17  1496 MARK       all  --  *      *       192.168.30.2/0       192.168.70.2/0       DSCP match
0x03 MARK set 0x3
```

Figure 58 - Iptables output

Note that packets received by the router with DSCP equals 1 are “marked” with an internal label with the value 1. It is important to state that the internal label is not present in the packets when they are travelling in the network. It is only an internal router marks.

```
class cbq 1: root rate 100000Kbit cell 4b (bounded,isolated) prio no-transmit/8 weight 100000Kbit allot
1514b
level 1 ewma 5 avpkt 500b maxidle 0us
 Sent 5430449944 bytes 31800001 pkt (dropped 0, overlimits 0 requeues 0)
 rate 0bit 0pps backlog 0b 0p requeues 0
  borrowed 11281051 overactions 0 avgidle 40 undertime 0
class cbq 1:1 parent 1: rate 1000Kbit cell 8b prio 5/5 weight 1000Kbit allot 1520b
level 0 ewma 5 avpkt 500b maxidle 0us
 Sent 30151936 bytes 396736 pkt (dropped 0, overlimits 0 requeues 0)
 rate 0bit 0pps backlog 0b 0p requeues 0
  borrowed 285808 overactions 0 avgidle 40 undertime 0
class cbq 1:2 parent 1: rate 20000Kbit cell 8b prio 4/4 weight 20000Kbit allot 1520b
level 0 ewma 5 avpkt 500b maxidle 0us
 Sent 1936562205 bytes 11112296 pkt (dropped 23, overlimits 0 requeues 0)
 rate 0bit 0pps backlog 0b 0p requeues 0
  borrowed 10983695 overactions 0 avgidle 40 undertime 0
class cbq 1:3 parent 1: rate 30000Kbit cell 8b prio 3/3 weight 30000Kbit allot 1520b
level 0 ewma 5 avpkt 500b maxidle 0us
 Sent 2444126 bytes 28039 pkt (dropped 0, overlimits 0 requeues 0)
 rate 0bit 0pps backlog 0b 0p requeues 0
  borrowed 11548 overactions 0 avgidle 40 undertime 0
```

Figure 59 - TC queues output

Figure 59 illustrates the TC statistics for the output queues of one router. A CBQ discipline is used for all the queues. We have three different queues 1:1, 1:2 and 1:3 above a parent class named 1:. Priority is higher for class 1:1 and decreases until 1:3, which means 1:1 is the most priority discipline, being used for EF traffic.

In bold are the “borrowed” information for all the queues. As we are in the presence of high traffic the remaining (excess) bandwidth of a class can be used by other classes each time they need it. The “borrowed” field gives us that statistics and shows that flows pre-empt exist.

5.4.3 Analysis and Validation

Last section provides a small demonstration of the flows pre-empt into different classes with different priorities. During a critical process, as a handover, the use of such technique could provide higher session completion. Section 2 of this document presents an analysis of the perceived QoS by the user. The use of “borrowed” classes is a contribution for the optimal results presented in the referred section.

6 AREA 5: QOS AND MOBILITY

The objective of this set of trials is to use the implementation of QoS-aware mobility management in order to measure the IP handover delay with and without fast handover mechanism.

6.1 Demonstration 1: IP handover with MPLS

6.1.1 Description

In this demonstration, we plan to show the interaction between the mobility management protocol, BB and MPLS during handover. MN is configured to move from one AR to another thereby performing an IP handover. During the IP handover, the ANP sends a signaling message to the BB containing the MN's IP address and the AR to which the MN is currently attached. The BB processes this message and setup up MPLS path in the CN. The process in the BB is very simple, upon the reception of the FHO message; BB simply created the tunnel to/from the new IR and deletes the old one.

6.1.2 Results

The below log file shows the handover process message executed by the ANP and the connection establishment between the ANP and the BB entity. Once the connection is established the information about the MN and the handover is sent to the BB from the ANP.

```
00:03:45:9907 LOG MN "Auto message: "HANDOVER EXECUTION
192.168.40.1""
00:03:45:9907 LOG MN "Auto message: "HANDOVER PREPARATION
192.168.40.1""
00:03:45:9908 MSG MN>TS "HOFF" "Handover Execution to BAR
192.168.40.1 (Old BAR is 192.168.30.1)"
00:03:46:0044 LOG ANP "HOFF message received from 192.168.40.1"
00:03:46:0058 MSG ANP>AR1 "HOFF ACK" "Handoff Acknowledge to Old
BAR 192.168.30.1"
Opening listening socket on port 12347
00:03:46:0059 LOG ANP "Anchor: Connection established between the
Mobility Anchor Point and the BB"
Received a new connection from 147.83.105.70
00:03:46:0059 MSG ANP>AR2 "HOFF ACK" "Handoff Acknowledge to New
BAR 192.168.40.1"
00:03:46:0061 LOG ANP "Anchor: Msg to BB containing the information
about the MN and AR sent"

Commiting command iptables -F FORWARD
Commiting command iptables -t nat -F PREROUTING
Commiting command echo 1 > /proc/sys/net/ipv4/ip_forward
Data waiting
Received 4 bytes
Req type is 2
4 Received a LSP request... processing
Processing LSP request:       Incomming LSP: 0
      Incomming Interface: eth1
      Outgoing LSP: 1110
      Outgoing Interface: << eth0
      Next Hop: 192.168.10.2
Create LSP
Creating an outgoing LSP
Command to issue is : /usr/sbin/mpls nhlfe add key 0 instructions
push gen 1110 nexthop eth0 ipv4 192.168.10.2

Establishing a new LSP starting on IR1 comming from interface eth1
to lsp 1110
 to next router CR1 in ip 192.168.10.2
---->Router IR1 is activating LSP 0 incomming from interface eth1,
outgoing to lsp 1110 exiting on interface eth0 directed to ip
192.168.10.2 (router name CR1)
```

Figure 60 - Interactions between the ANP, BB and MPLS

6.1.3 Analysis and Validation

The log files show the interaction between the MPLS, mobility management and BB during the handover phase. The log file shows that, during Handover, connection is established between the ANP and the BB and the MN information is sent from the ANP to the BB.

```
00:03:45:9907 LOG MN "Auto message: "HANDOVER EXECUTION
192.168.40.1""
00:03:45:9907 LOG MN "Auto message: "HANDOVER PREPARATION
192.168.40.1""
00:03:45:9908 MSG MN>TS "HOFF" "Handover Execution to BAR
192.168.40.1 (Old BAR is 192.168.30.1)"
00:03:46:0044 LOG ANP "HOFF message received from 192.168.40.1"
00:03:46:0058 MSG ANP>AR1 "HOFF ACK" "Handoff Acknowledge to Old
BAR 192.168.30.1"
Opening listening socket on port 12347
00:03:46:0059 LOG ANP "Anchor: Connection established between the
Mobility Anchor Point and the BB"
Received a new connection from 147.83.105.70
00:03:46:0059 MSG ANP>AR2 "HOFF ACK" "Handoff Acknowledge to New
BAR 192.168.40.1"
00:03:46:0061 LOG ANP "Anchor: Msg to BB containing the information
about the MN and AR sent"
```

Figure 61 - Mobility Management Handover Messages

The message received by IR1 to configure a new LSP is shown next.

```
Opening listening socket on port 12347
Received a new connection from 147.83.105.70
Commiting command iptables -F FORWARD
Commiting command iptables -t nat -F PREROUTING
Commiting command echo 1 > /proc/sys/net/ipv4/ip_forward
Data waiting
Received 4 bytes
Req type is 2
4 Received a LSP request... processing
Processing LSP request:       Incomming LSP: 0
      Incomming Interface: eth1
      Outgoing LSP: 1110
      Outgoing Interface: << eth0
      Next Hop: 192.168.10.2
Create LSP
Creating an outgoing LSP
Command to issue is : /usr/sbin/mpls nhlfe add key 0 instructions
push gen 1110 nexthop eth0 ipv4 192.168.10.2
```

Figure 62 - LSP Creation commands in IR1

Information to create a new LSP and change the Diffserv filters are issued by the BB with the following command (log's snapshot).

```
Establishing a new LSP starting on IR1 comming from interface eth1
to lsp 1110
 to next router CR1 in ip 192.168.10.2
---->Router IR1 is activating LSP 0 incomming from interface eth1,
outgoing to lsp 1110 exiting on interface eth0 directed to ip
192.168.10.2 (router name CR1)
```

Figure 63 - BB sending a command to IR1

By analyzing the log file, we validate that during handover, a communication is established between the above mentioned entities and a MPLS tunnel is established.

6.2 Demonstration 2: fast IP handover

6.2.1 Description

Fast IP handover is used to improve the performance of the IP handover by reducing the packet loss. In this case, when the mobile node senses the L2 vertical handover; it sends a HPREP message to its current AR in order to set up a tunnel to the new AR. The new AR processes the received HPREP and sends a HPREP_ACK message, which enables the IP-in-IP tunnel between both ARs. During handover, the packets in transit that reach the old AR are tunnelled to the new AR using the tunnel thereby reducing the packet loss. In addition to the procedures mentioned above, all the signalling procedures for IP handover mentioned in section 6.3 takes place.

In this demonstration, Iperf is used to generate the traffic of various data rates namely 40, 80 and 130 Kbps. As the MN moves along the path, VHO triggers the fast IP handover procedures. The period of the router advertisement is changed for each experiment to study its impact on the handover.

6.2.2 Results

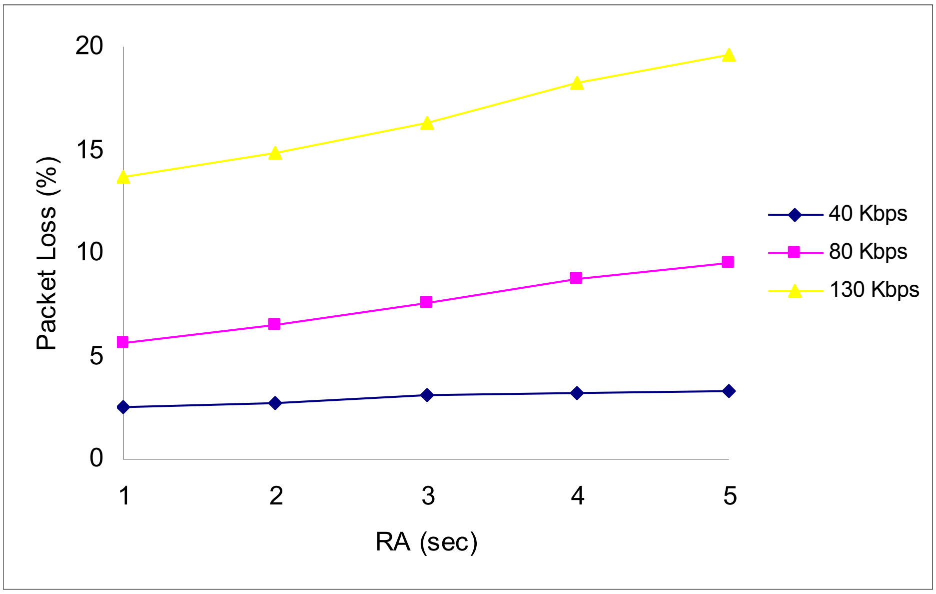


Figure 64 - Packet loss of UDP traffic with Fast mobility

The above graph shows the percentage loss of packets during handover for different router advertisement intervals and data rate. Based on the captured packets, packet loss percentage was calculated. When the router advertisement interval is 1 sec and data rate is 40 Kbps, the packet loss percentage is almost constant. As the data rate and advertisement interval increases, the loss percentage also increases. For 130 Kbps, the ratio of the packet loss is high compared to 40 and 80 Kbps.

6.2.3 Analysis and Validation

During the Fast handover, a tunnel is established between the current point of attachment and the new point of attachment. Packets in transit during the handover are tunnelled from the old access router to the new access router and then forwarded to the MN.
One of the pre-requisite for the fast mobility is that the MN should be able hears from the new access router before the handover. In other words, the MN should be able to receive the router advertisement from its current point of attachment as well as from the new access router its planning to handover. The reachability of the new point of attachment is based on the received advertisement which in turn triggers the neighbour discovery and address resolution. One of constraints in testing the fast mobility comes from the inability of the traffic switch / CRRM modules to allow simulations router advertisements and the ability of the MN to communicate with new router during the process of vertical

handover. This increases the handover time and packet loss as the neighbour discovery and address resolution are postponed till the communication with the new point of attachment is established. Enhancements can be made by configuring the traffic switch to allow simultaneous advertisements from the routers and also by introducing buffers to hold the packets during handover and forward them to the new point of attachment once the handover is over. Based on the reachability of the new point of the attachment and the reception of the advertisement from the new router, the MN performs the ARP and neighbour discovery before

6.3 Demonstration 3: evaluation of the IP handover disruption

6.3.1 Description

In this demonstration, IP handover procedure is initiated only after the MN has moved from AR to another. After a successful layer 2 handover, the MN receives the router advertisement from the AR it is currently attached to. The MN processes the router advertisement and sends a HOFF message to the new AR. The AR forwards the HOFF message to the ANP. ANP processes this message and notifies BB about the change in the network parameters. Then the ANP replies the MN with the HOFF_ACK message.

In this demonstration, we illustrate a break and make scenario. Iperf is used to generate user traffic and the MN moves between the ARs. The objective of this demonstration is to show the impact of the handover on the performance namely the packet loss. As the MN moves, packets generated by the Iperf and the packets in transit during handover are lost.

6.3.2 Results

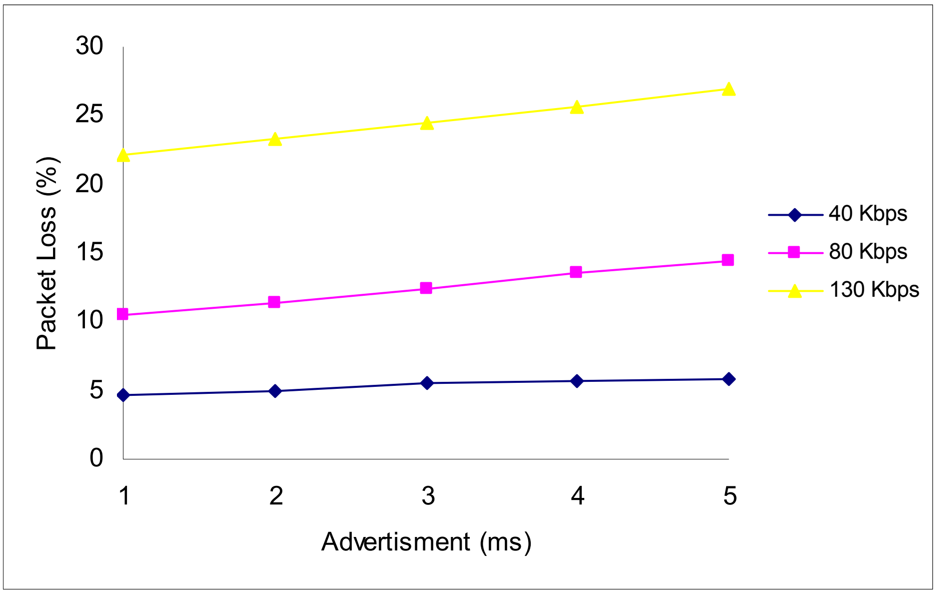


Figure 65 - Packet loss of UDP traffic

The above graph shows the packet loss percentage caused by the IP handover when the MN moves from one IR to another. The experiment is repeated by varying the traffic load of 40, 80 and 130 Kbps and their packet loss is analysed. Iperf is used to generate traffic between the server and the client with varying data rate as mentioned above. Based on the captured packets, packet loss percentage figures have been calculated.

6.3.3 Analysis and Validation

From Figure 65, we find a direct correlation between the advertisement interval, data rate and the packet loss percentage. As the advertisement interval increases, the ability of the MN to discover its point of attachment increases, leading to increase in the packet loss. On the other hand, if the data rate is high, more packets are lost during the handover leading to the increase in packet loss percentage. Comparing Figure 64 and Figure 65, we find that there is a considerable reduction in the packet loss with fast handover enabled.

CONCLUSIONS

This deliverable includes the results of the demonstrations defined in the different trials described in D15 to test and validate the behaviour of the implemented real time system, where some of the CRRM algorithms and QoS techniques, studied during the project, have been evaluated. Several procedures have been tested based on the scenarios described in Deliverable D15 to evaluate RAT Selection algorithms, E2E QoS renegotiation, CN Mobility Management, Impact of the Applications on the perceived QoS, and Admission Control Algorithms in BB.

For each demonstration its description, the obtained results, and the analysis and validation of them are included.These demonstrations are organized in five main areas.

Area 1 is devoted to evaluate the variation in perceived QoS experienced by a user running multimedia applications when changing QoS management policies or algorithms. Both quantitative and qualitative results are given for two streaming applications in order to stress that not only the network conditions impact the QoS experienced by the user but also the application in use.

Area 2 provide a qualitative comparison between the results obtained with the AROMA real-time testbed, and those obtained by off-line simulations in WP3 for two proposed RAT selection algorithms.

Area 3 includes results about the performance of some of the strategies that are being proposed within AROMA for providing e2e QoS management over the network.

Area 4 presents the performance evaluation for different CAC algorithms used by the BB during the session setup and handover process. Expected results have been obtained.

And finally area 5 measures the IP handover delay with and without fast handover mechanism. Results show that the fast IP handover reduces the packet loss, which has a direct correlation with the advertisement interval and data rate.

In summary, results in this deliverable show that the AROMA real-time testbed can be used to evaluate the e2e QoS experienced by a user that is immersed in a heterogeneous mobile environment with IP connectivity as well as to test and validate the specific algorithms and mechanisms within them.

WORK DISTRIBUTION

The five areas in this deliverable have been developed by the three partners involved in WP4 with the following distribution:

AREA 1: Quality measurements with applications	UPC
AREA 2: Radio Access Technology (RAT) selection / Common Radio Resources Management (CRRM) Algorithms	UPC
AREA 3: Strategies for e2e QoS	UPC
AREA 4: Admission Control Algorithms in the BB	PTIN
AREA 5: QoS and Mobility	KCL

LIST OF ACRONYMS

3G	3rd Generation
AF	Assured Forwarding
AGMT	Advanced Graphical Management Tool
AN	Access Network
ANP	Anchor Point
AR	Access Router
BB	Bandwidth Broker
BE	Best Effort
CAC	Call Admission Control
CBQ	Class-Based Queueing
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CN	Core Network
CR	Core Router
CRRM	Common Radio Resource Management
DB	Data Base
DL	Downlink
DSCP	DIffserv Code Point
E2E	End-to-End
EDGE	Enhanced Data Rates for GSM Evolution
EF	Expedited Forwarding
ER	Egress Router
GERAN	GSM/EDGE Radio Access Network
GSM	Global System for Mobile Communications
HO	Handover
HHO	Horizontal Handover
HOFF	Handoff or Handover Message
HOFF_ACK	Handoff Acknoweldgement Message
IR	Ingress Router
IP	Internet Protocol
L2	Layer 2
L3	Layer 3
LAN	Local Area Network
LSP	Label Switch Protocol
MIB	Management Information Base
MPDP	Master PDP
MPLS	Multiprotocol Label Switching
MM	Mobility Management
MN	Mobile Node
MOS	Mean Opinion Score
MPDP	Master PDP
MPLS	Multiprotocol Label Switching
NCCB	Network-Controlled Cell-Breathing
PC	Personal Computer
PDP	Policy Decision Point
PL	Path Loss
QoS	Quality of Service
QT	QuickTime
RA	Route Advertisement
RAN	Radio Access Network
RAT	Robust Audio Tool
RAT	Radio Access Technology
RRM	Radio Resource Management
RTP	Real Time Protocol
SLA	Service Layer Agreement
SLS	Service Level Specification

SNMP	Simple Network Management Protocol
TC	Traffic Condition
TCH	Traffic Channel
TCP	Transport Control Protocol
TG	Traffic Generator
ToS	Type of Service
TS	Traffic Switch
UE	User Equipment
UDP	User Datagram Protocol
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
UUT	User Under Test
VHO	Vertical Handover
VIC	Video Conference Tool
VLC	Video LAN Client
VUT	Video Under Test
WLAN	Wireless LAN
WQB	Wireless QoS Broker

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