On the Impact of MIH Triggering Techniques on the Performance of Video Streaming across Heterogeneous RATs

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Abstract. This paper evaluates the performance of IEEE 802.21 Media Independent Handover (MIH) framework through test-bed experiments conducted on a wireless platform that allows seamless handoff across heterogeneous radio access technology networks of mobile terminals with on-going video sessions. The scope of the study is to evaluate how MIH performs under different handover triggering techniques and to monitor the impact at both packet loss and perceived video quality due to vertical handover. We propose a handover decision policy as part of the MIH framework, which is based on parameters from the physical, network and application layers, gathered from MIH capable mobile terminals and MIH controlled radio access networks. Real testbed experiments demonstrate that triggering from application layer can maintain and optimize QoS better than the network layer triggering.

Keywords: media independent handover, video streaming, heterogeneous radio access networks.

1 Introduction

Recent trends in the mobile communications industry include the connected everywhere, anytime and anyhow concept. This concept is also denominated Always Best Connected (ABC). ABC considers that several "competing" Radio Access Technologies (RATs) can co-exist and overalp in order to improve capacity and coverage [1]. For an advanced scenario these RATs can range from existing technologies (e.g. UMTS, WiMAX) to future networks (e.g. 3GPP LTE) [1], [2]. It is then necessary to have a mechanism that for a particular instant in time it can select the "best" network and perform the inter-working between different technologies. The Radio Access Network (RAN) architecture should evolve in order to provide a common transport for different access networks. Several authors have studied seamless mobility and vertical handoff schemes across heterogeneous RATs. The authors in [3] have described the IEEE 802.21 Media Independent Handover (MIH) framework that could be used in a heterogeneous wireless environment to perform seamless handover. The authors in [4], [5] have studied vertical handover schemes between 3G and WLAN using 802.21 and

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Mobile IP. Handover decisions are taken using signal level thresholds and user's preferences in terms of wireless technologies. The authors have used a simulation environment in order to study the performance of Mobile IP with 802.21. Furthermore, they have observed a trade-off between service continuity and service coverage. In [6], the authors present an implementation model of IEEE 802.21 by introducing three types of MIH services: MIH Event Services (MIES), MIH Command Services (MICS) and MIH Information Services (MIIS). MIH services have been optimized using a new entity, called Connection Manager in order to handle IP mobility and perform discovery services. The performance of the IEEE 802.21 scheme has been evaluated via testbed implementation by examining handover between 802.11 and 802.16e networks. In [7], [8], [9] consider different handover decisions that aim to improve and maintain the quality of service (QoS), optimize wireless network capacity and maintain lifetime battery. Unlike the previous research approaches, this paper considers an MIH framework where statistics are collected also from the physical, network and application layer so that a better handover decision can be considered in order to optimize and maintain the QoS of real-time application with strict characteristics such as video streaming. The main motivation stems from the fact that handover is triggered in order to maintain QoS. This work considers two type of triggering techniques: network layer and application layer. This paper is organized as follows: Section 2 describes the seamless handover concept in heterogeneous RATs and the MIH concept in order to optimize handover decision, presents the proposed MIH implementation along with the MIH triggering events, the handover Decision algorithm, the link selection module and the MIH-Mobile IP signaling interactions. Section 3 describes the real test-bed environment, Section 4 describes the performance results in terms of packet loss and Perceived PSNR for the two triggering schemes. Finally, Section 5 concludes the paper.

2 Seamless Handover in Heterogeneous RATs

2.1 MIH Framework

IEEE created the 802.21 standard [10] in order to challenge one of the main issues in wireless mobility, seamless handovers across inter-technology RATs. In particularly, mobility protocols such as Mobile IP are suffering from sensible latency and they have not knowledge about the application layer parameters and candidate network conditions. IEEE 802.21 proposes the MIH framework where mobile nodes and the network exchange information and commands for an optimal handover. Entities that are responsible for the handover procedure receive information and events from the MIH services and execute the handover with the available standardized commands. Moreover, for hiding the heterogeneity of the MAC and physical layers, MIH inserts an intermediate layer between layer 3 (and above) and the divert Layer 2 technology specifics. This new abstract layer is referred as Media Independent Function (MIHF) and provides a media independent interface to the MIH users (i.e. mobility protocols, applications, handover policies) for controlling and getting information from the lower layers (i.e. WLAN, 3GGP). The MIH framework describes three different types of communication that act as services: Event Service, Command Service and Information Service, as illustrated in Fig. 1.

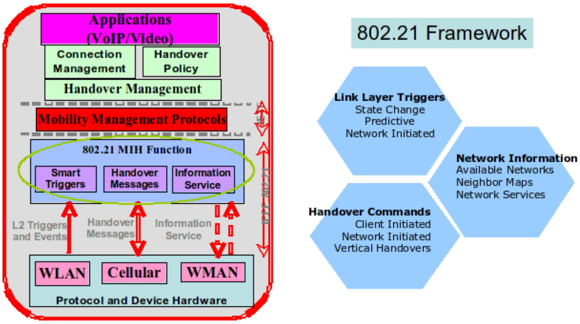

Fig. 1. Media Independent Handover framework

- The Media Independent Event Service (MIES) is a communication procedure where indications for handoff (Events) are passed to the MIH users for further handling. There are two types of Events: Link events and MIH events. The Link events are originating from the Link or Physical layer and can be a change in the state of the parameters of these layers or statistical information. MIH events are Link layer events that are received from the MIH functionality and are either propagated to the MIH users or to a remote MIH entity.
- The Media Independent Command Service (MICS) provides a set of handover commands in order for the MIH users to be able to implement their handover decisions. The local link commands are received from the MIH functionality and are being mapped to Link layer commands. Also remote MIH commands are sent through the MIHF to remote MIH entities to enable network or client originated handovers.
- The Media Independent Information Service (MIIS) is one of the most important services in the MIH framework. MIIS is a database that contains all the available information about the network ranging from channel parameters to presence of application layer services. It is used by mobility protocols in order to find appropriate networks that can facilitate a handover.

Moreover, in order to study the impact of MIH to the perceived QoS of video streaming over heterogeneous wireless access networks, we defined the following MIH entities that reside in the MT, the access networks and the video server.

1. **MIH entities at the MT:** It consists of the following services: MIES, MICS and MIIS. MIES service send reports associated with the dynamic changes of the wireless interfaces of the MT. MIIS collects the following statistics from the MT: SNR(PHY), instantaneous packet loss (using a common probing technique such as iperf [14]), application layer statistics (in case of real-time services RTCP SR could be used to determine the RTP packet loss). All these statistics are sent via the MIH_Client_Parameter_Event (MIIS) message towards the MIH server. In case of sudden change in L2/L3 parameter (SNR, PER), a MIH-Client_Alarm_Event (MIES) must be sent towards the MIH server. The time inter-arrival between two MIIS events can be configured.

2. **MIH Entities at the RATs:** Each RAT is also responsible to implement MIES, MICS, MIIS Services. MIIS services are responsible to measure available bandwidth and throughput using a probe method such as iperf. All this information is collected and is sent via the MIH_Network_Event (MIIS) towards the MIH server. The time inter-arrival between two MIIS events can be configured.
3. **MIH Entities at the Application server:** These events are associated with specific from the application layer. In the case of video, perceived video quality can be estimated by taking into account parameter such as video encoding distortion and loss per video frame. These data are sent via MIH_Application_Event (MIIS) to the MIH Server.

2.2 MIH Triggering Schemes

A handover scheme, as part of the MIH framework is responsible for deciding whether a handover is needed based on physical, network and application layer statistics, collected from both the MT and the RATs. Briefly, the handover algorithm includes three phases: the decision, the initiation and the execution phase. During the handover decision phase all the handover related information (e.g. SNR, delay, jitter, PSNR, packet loss, etc), from the MT, the current RAT and the already discovered neighboring RATs are collected and sent to the MIH entity via the MIIS. These collected parameters are evaluated and compared against a set of predetermined threshold values, during the handover initiation phase. These thresholds are either determined by the network provider or are specified in the user profile. The MIES service is responsible for comparing the collected statistics with the threshold values and for informing the command service when one or more thresholds are violated and the handover criteria are matched. At this state, a link selection scheme indicates the best candidate neighboring network for handoff according to specified target QoS parameters. The target QoS parameters are specified by the service provider according to the Quality of Service classification of the user (gold, silver, bronze). Finally, during the handover execution phase the MIH triggers the Mobile IP module which is responsible for performing the actual handover and bidding with the new point of attachment, ensuring seamless service continuity.

In this context two handover triggering scenarios are examined. In the first scenario the handover triggering is initiated by analyzing network layer events (i.e. packet loss), collected from all the wireless networks monitored by the MIH entity. In the second scenario triggering is initiated by analyzing statistics from application layer (i.e. estimated PSNR). In contrast to other studies that only consider physical and network layer statistics, we are proposing a handover scheme that can be triggered by the estimated perceived quality of service, which is calculated in real time by a distortion estimation model in the application server. The MIH entity will collect from the application server any application layer events, like the drop of current PSNR below a threshold value, in order to trigger the handover procedure. Thus, both the actual estimation of the PSNR (ePSNR) in real time during video streaming and the update of the MIIS from the application server with the new estimated value of PSNR are two key procedure that need to be accurate and simple to implement.

Hence, a mechanism of calculating the perceived QoS, which is also relative simple to implement for large scale deployments, is proposed. This scheme is based on the RTP Control Protocol Extended Report (RTCP-XR) as defined in [15] and is illustrated in Fig.2. In particularly, XR packets convey information beyond that already contained in the reception report blocks of RTCP's sender report (SR) or Receiver Report (RR) packets. The RTCP-XR is a new VoIP and video streaming management protocol which defines a set of metrics that contains information for assessing the multimedia application quality. The RTCP-XR can be implemented as software integrated into IP mobile terminals and gateways inexpensively and then, messages containing key call-quality-related metrics are exchanged periodically between the mobile terminal and the application server.

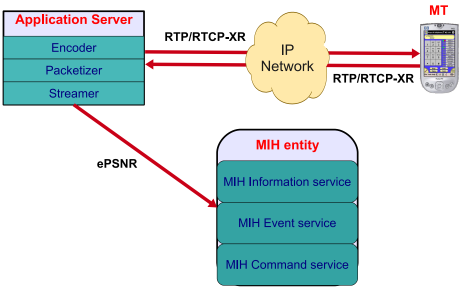

Fig. 2. RTCP-XR exchange between MT and Application Server for the estimation of current PSNR (ePSNR) and update of MIIS

The process of estimating the PSNR of real time video streaming requires the video client of the MT to send a report to the application server through specific RTCP-XR messages with the ID numbers of the lost RTP packets, per frame. Then, the application server estimates the current value of PSNR, based on the RTCP-XR reports, by a video distortion prediction model that calculates the distortion of the received video due to packet losses in real time.

Specifically, the proposed distortion prediction model is a recursive formula that takes into account the correlation among video frames during the intra-frame period. Furthermore, the proposed distortion model incorporates the random behavior of losses in the wireless medium. The random nature of the wireless channel, will result into losses of the transmitted video data. It has been reported in [11] that these losses can be characterized as single or isolated losses, burst of losses and losses separated with a small lag. Apparently, the effect that each of these three types of losses has on the received video sequence is very different because of the inter-frame and intra-frame dependences in the encoded video. Therefore, the proposed model can accurately predict the resulted video distortion due to any error pattern that may include one or more of isolated, burst or errors with lag. In order to analytically express the distortion model, each video frame is coded into a number of RTP packets according to each frame size. The proposed model includes analytical expressions for a single frame loss, a burst of losses with variable burst length B (where $B \geq 2$) and frame losses separated by a lag.

$$D_n = D_{n-1} - \sum_{\substack{k=F_{n-1}\\ \imath=0}}^{\substack{k=F_{n-1}+\imath\\ \imath=N-1+k}} \Lambda_{(i)} \cdot \sigma^2(F_{n-1}) + \sigma^2(F_{n-1}) + \\ + \begin{cases} \sum_{\substack{k=F_n\\ \imath=0}}^{\substack{k=F_n+\imath\\ \imath=N-1+k}} \Lambda_{(i)} \cdot \sigma_s^2(F_n), & uncorrelated \\ \sum_{\substack{k=F_n\\ \imath=0}}^{\substack{k=F_n+\imath\\ \imath=N-1+k}} \Lambda_{(i)} \cdot \sigma^2(F_n), & burst \\ \sum_{\substack{k=F_{n-1}\\ \imath=0}}^{\substack{k=F_n-1\\ \imath=F_n-1-F_{n-1}}} \Lambda_{(i)} \cdot \sigma^2(F_n) + \sum_{\substack{k=F_n\\ \imath=0}}^{\substack{k=F_n+\imath\\ \imath=N-1+k}} \Lambda_{(i)} \cdot \sigma^2(F_n), & lag \end{cases} \quad (1)$$

In 1, $D_1, D_2, \ldots, D_n$ are the total video distortions due to $1, 2, \ldots, n$ error frames. The frame number of the n^{th} erroneous frame is denoted by F_n. This recursive formula calculates the total distortion for the first error frame and depending on whether the next error frame is correlated or not with the previous error frame, it estimates the total distortion of the resulted error pattern. Moreover, $\Lambda_{(i)}$ represents the distortion propagation effect until the end of the intra period *N* due to an error occurred at frame *k*. Additionally, the error power introduced in a single frame F_n is denoted by $\sigma_s^2(k)$ and the total video distortion due to error frame *k* and its error power propagation to the following frames is denoted by $D_s(k)$. Correspondingly, $\sigma^2(k)$ and *D* are the Mean Square Error (MSE) and the sum of the MSE values over all frames in the intra frame period, of more general loss patterns, respectively. Detailed analysis of all the parameters and extensive simulation results that prove the accuracy of the distortion prediction model, for different video sequences, is presented in [12] and [13].

2.3 MIH and Mobile IP Interworking

For the sake of simplicity, we illustrate the MIH and Fast Mobile IP signaling Interworking in case where handover decision is triggered by analyzing the MIIS statistics that are collected by the MT, the RATs and the Application Server (streaming Server). This MSC signaling flow is illustrated at the following figure. In the case of MT, application, network and physical parameters are collected and are sent towards the IIS Server using the MIH_Client_Parameter_Event message. The same applies for the current RAT (802.11 AP) which collects parameters from the network layer and they are sent towards the IIS Server using the MIH_Network_Event message. Similar statistics are collected from other co-located RATs. Furthermore, IIS collects statistics from application server using the MIH_Application_Event message. The MIH IIS

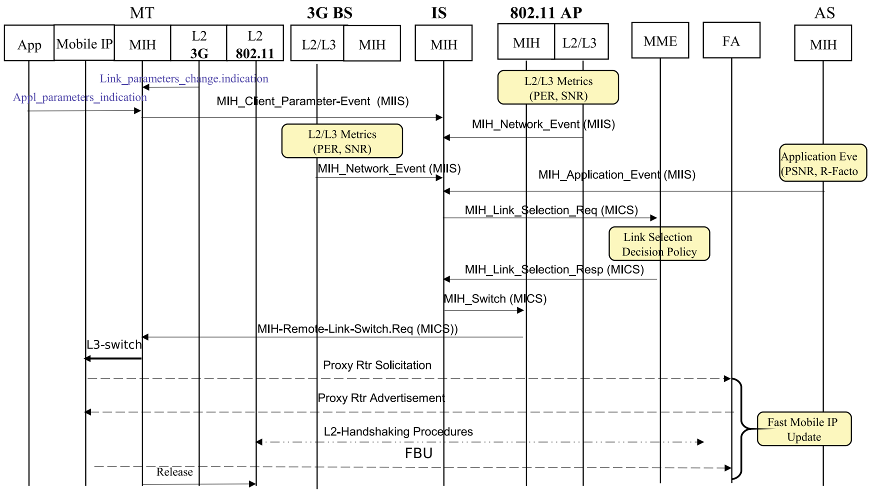

Fig. 3. MIH-FMIP signalling exchange during a WiFi–3G handoff

Server sends continuously the collected information towards the Mobility Management Entity (MME) using the MIH_Link_Selection_Req (MICS). MME implements the handover decision policy, as described in the previous section, regarding the best candidate network where the MT should be handed over. Subsequently, it informs about this selection the MIH IIS Server using the MIH_Link_Selection_Resp (MICS). The MIH ISS Server informs the selected RAT about this decision using the MIH_Switch (MICS) message. The MIH of the selected RAT sends towards the MIH of the MT the MIH_Remote_Link_Switch_Req (MICS) Message. Upon the reception of this message, MIH sends towards the Mobile IP element a L3_switch message to change the link interface to the selected RAT. The following messages contain Fast Mobile IP signaling to perform binding update (Proxy_Rtr_Solicitation, Proxy_Rtr_Advertisement, Fast Binding Update).

The Fig.3 illustrates the signaling interactions between the different entities of MIH and Fast Mobile IP so that seamless mobility is accomplished. MIH entities are located at both the MT and the heterogeneous RATs.

3 Test-Bed Environment

In order to study the performance of MIH triggering scenarios on Fast MIP and its impact on perceived video quality, an experimental testbed has been implemented that is illustrated in Fig. 4 and comprises of the followings modules:

- Two fully configurable 802.11e access points that allow the monitoring and collection of physical and network layer statistics.
- One 3G access network
- A MIH capable mobile terminal that can connect to any access network through two corresponding adapters. The MT monitors the status of the current connection

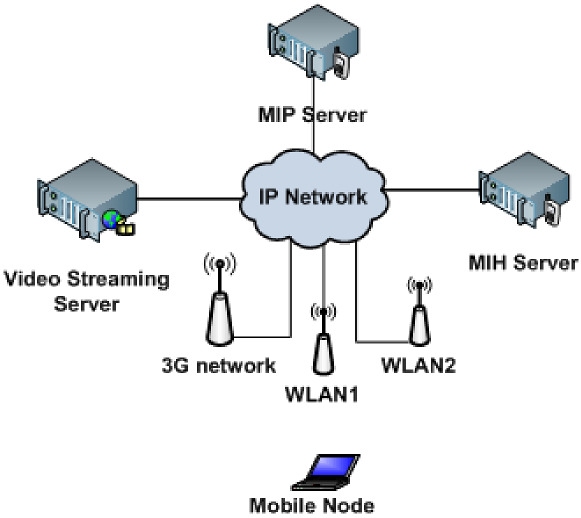

Fig. 4. Implemented testbed setup

and the availability of any other candidate RATs in each vicinity. This information is reported to the MIH (MIIS) through a client-server application, and based on the decision from the vertical handover functions it will be instructed by the MIP core to vertically handover to the new technology. Moreover, the mobile terminal includes a H.264/Advance Video Coding [16] decoder, specifically modified to identify lost RTP packets and video frames and report them to the application server.

– A MIH server that hosts all MIH services MIIS, MIES, MICS as well as, the handover decision functionality. This module is responsible firstly, for collecting the network and application layer statistics from the wireless access networks and the mobile client, secondly, for deciding upon a handover and thirdly, send command messages to the Mobile IP for the completion of the handoff.
– A video server that consists of a fully configurable H.264/Advance Video Coding encoder and streamer, capable of exchanging RTCP-XR messages through a client-server application with the mobile terminal. The video streamer has been specifically modified to estimate in real time the PSNR of the ongoing session, based on the distortion prediction model and the RTCP-XR reports of the mobile terminal.

Furthermore, the wireless access networks are stressed with background traffic based on a statistical video traffic model that assumes a number of multiplexed homogeneous and mutually independent video sources that transmit simultaneously. This background traffic model has been selected because can accurately simulate the effect of aggregate video traffic from multiple video sources [17]. Dummynet [18] has been used in order to emulate the packet loss and delay in each radio access network. Table 1 summarizes the network and application parameters used in the experiments.

Table 1. Simulation Parameters

Parameter name	Parameter value
Video codec	H.264/Advance Video Coding
Video sequence	YUV QCIF (176 × 144 pixels)
Number of frames	2565 frames
Encoder quantazation step	20
Intra-frame period	36 frames
Frame rate	30fps
RTP packet size	1024 bytes

4 Performance Evaluation Results

The experiments conducted over the Test-Bed platform provided new insights to the performance of MIH framework under different triggering techniques and its impact to the perceived video quality in terms of PSNR. During testing, the MT was switched on and could discover both access networks in its vicinity. The handoffs have been monitored during a specified time period and the MT was allowed to handoff from the 3G to WiFi and back, during that time period. Two threshold values have been selected for the two handover scenarios. In the case of network triggering handoff a 5% RTP packet loss is defined as threshold in MIIS and for the case of application triggering handoff a drop in the value of PSNR by 3 dB is selected as handoff threshold. The first significant result is the accuracy of the estimated PSNR, compared to the actual value of PSNR as it is measured at the decoder. Fig. 5 illustrates the PSNR estimation (ePSNR) based to the distortion prediction model of 1, which is performed for every Group of Pictures (GOP). The ePSNR is compared against the actual PSNR measured at the decoder and it is clear that ePSNR can accurately capture the drop in PSNR whenever packet losses occur.

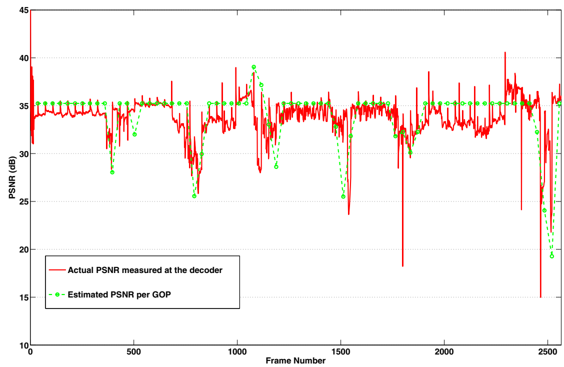

Fig. 5. PSNR per frame measured at the decoder (actual PSNR) and estimated by the distortion prediction model (ePSNR)

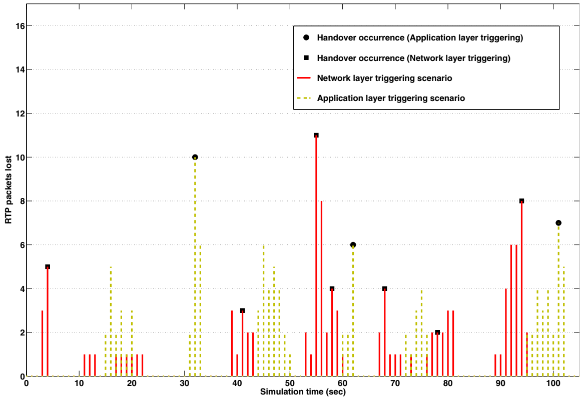

Fig. 6. RTP packet losses measured under both studied handover triggering scenarios

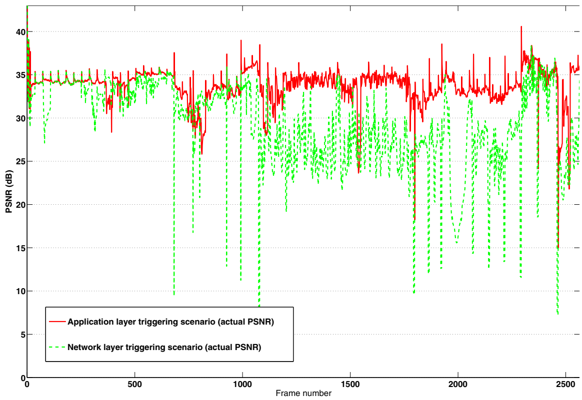

Fig. 7. Actual measured PSNR per frame comparison between the studied application layer and network layer triggering scenarios

Furthermore, Fig. 6 compares the RTP loss measured during the simulation under the two triggering techniques. It is obvious that the MIH under the application layer triggering scenario initiates less handovers compared to the network layer triggering scenario. This is due to the fact that the application layer statistics are collected at the end of every video frame, hence every 33 ms. Whether, during the network layer triggering, the handover statistics are collected with larger granularity (in our test-bed network statistics are collected every 1ms). As a result, applications layer triggering will result in less handovers over the same period of time and at the same time better perceived video QoS and higher achieved video throughput. The latter are illustrated in Fig. 7 and Fig. 8, respectively. In particular, Fig. 7 shows that the

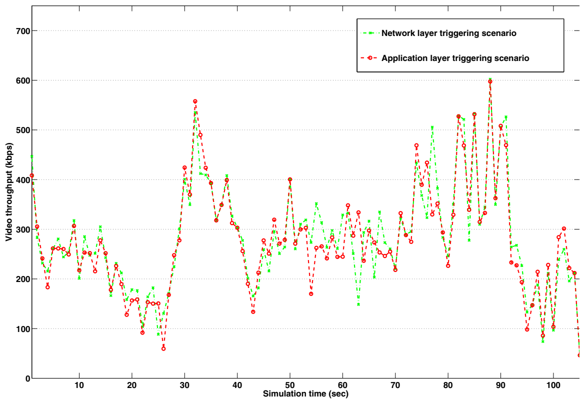

Fig. 8. Video throughput achieved under both studied handover triggering scenarios

application layer triggering results to an average video PSNR of 33 dB as opposed to the much lower 27 dB PSNR on average, resulted by the network layer triggering. Therefore, application layer triggering can capture the impact of physical and network layer parameters on the QoS of applications such as video streaming. As an effect, it can be efficiently used to initiate handover. Moreover, the application layer triggering scenario allows video streaming with a higher average throughput of 283.33 kbps, compared to the 279,1 kbps achieved during network layer triggering. The small difference in achieved throughput among the studied triggering scenarios, is compensated by the far fewer handovers needed (3 against 8 handoffs) over the same simulation time Fig. 6 and the significantly better perceived PSNR, under the application triggering.

5 Conclusions

In conclusion, this paper presented Test-Bed experiments conducted on an wireless platform that allows seamless handoff of mobile terminals with on-going video sessions across heterogeneous radio access technology networks. The experiments prove that the performance of IEEE 802.21 Media Independent Handover framework can significantly improve when handover are triggered due to application layer statistics. In particular, when a handover decision is based on accurate estimated PSNR calculated every GOP time periods instead of only network layer statistics (packet loss), the number of handovers needed is significantly reduced, hence the throughput is increased and ultimately the quality of video user's experience is greatly improved.

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