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MEASUREMENTS OF QoS/QoE PARAMETERS FOR MEDIA STREAMING IN A PMIPv6 TESTBED WITH 802.11 b/g/n WLANs

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Abstract

The growing number of mobile devices and the increasing popularity of multimedia services result in a new challenge of providing mobility in access networks. The paper describes experimental research on media (audio and video) streaming in a mobile IEEE 802.11 b/g/n environment realizing network-based mobility. It is an approach to mobility that requires little or no modification of the mobile terminal. Assessment of relevant parameters has been conducted in an IPv6 testbed. During the tests, both Quality of Service (QoS) and Quality of Experience (QoE) parameters have been considered. Against the background of standard L3 and L2 handovers, an emerging mobility solution named Proxy Mobile IPv6 (PMIPv6) has been examined. Its advantages (L3 connectivity maintenance) and disadvantages (packet loss during handover) are emphasized based on the obtained results. Moreover, a new solution for handover optimization has been proposed. A handoff influence upon audio/video generation and transfer imperfections has been studied and found to be an interesting direction of future work.

Keywords: media streaming, mobility, Proxy Mobile IPv6, IEEE 801.11, QoS/QoE.

1. Introduction

Owing to easy access to reliable high-speed Internet connectivity, numerous real-time multimedia services, including high quality video streaming, are gaining popularity. Such services are currently perceived as a standard, obligatory feature, and their absence, poor reliability or low quality will be perceived by the majority of Internet users as a significant disadvantage.

At the same time, advances in the mobile communication technology allow smart devices such as mobile phones or palmtops to provide functionality comparable to desktop computer systems, in particular to exhibit multimedia capabilities. It is natural, therefore, that the users expect real-time multimedia services to be of comparable quality both under stationary and mobile access to the Internet. As the current stack of IPv6 protocols is poorly suited for mobile users, this requirement creates multiple challenges, of which provision of necessary bandwidth over wireless connections is the easiest to meet.

In this paper we concentrate on various aspects of ensuring high-quality undisturbed IPv6 network connectivity for mobile users. The paper contains a theoretical analysis of the most popular IPv6 mobility solutions, as well as a description of testbed measurement methods and results concerning the new Proxy Mobile IPv6 (PMIPv6) mechanisms. PMIPv6 aims to provide both effective mobility support and high mobile client compatibility by placing all necessary mechanisms within the access network.

For easy comparison, we include network oriented Quality of Service (QoS) measurement results and user-centric Quality of Experience (QoE) assessments for a number of

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representative mobility scenarios often encountered by mobile users in modern IP networks. The results confirm both the necessity of inclusion of mobility support mechanisms as an integral part of modern IP systems and the advantages of network-side mobility support solutions.

A performance analysis of multimedia transmissions in fixed wireless IEEE 802.11 b/g/n networks was presented in [1] along with a description and evaluation of several experiments with audio and video streaming and the related QoS/QoE. The paper [2] presents the impact of the 802.11b handover procedures on Voice over IP (VoIP) traffic, based on experiments conducted in a real-world environment using different devices and scenarios. Moreover, QoS statistics (delay, packet loss) for voice-like data traffic are presented as well; however, the paper lacks a QoE analysis. In [3], assessment of classical Mobile IPv6 performance is presented by means of simulation. The authors analyze several parameters like packet loss, delay and jitter of a constant bit rate (CBR) stream and voice-like traffic. An alternative to the classical mobility solutions is proposed in [4] in the form of a distributed mobility management architecture called Asymmetric Double-Agents. Using quantitative analysis and ns2 based simulations, the proposed solution is compared, in terms of handoff latency, single interaction delay and total time cost, to other mobility protocols – MIPv6, HMIPv6 and CNLP, excluding, however, Proxy Mobile IPv6. In [5], PMIPv6 is compared to Mobile IPv6 and its enhancements – Hierarchical Mobile IPv6, and the optimistic versions of Duplicate Address Detection (DAD). The authors use quantitative analysis to present their results for different scenarios. Handover optimization mechanisms are discussed in several publications [6-9]. The paper [6] introduces an integrated architecture supporting network-based mobility (Proxy Mobile IPv6) and network-controlled handover (MIH – Media Independent Handover). In this approach, a Mobile Host (MH) reports current radio link conditions to a centralized Handover Controller that triggers handovers. It contrasts with other approaches in that the decision about handover is taken by an MH based on radio measurements [7] or on a specific algorithm [8]. The paper [9] presents an analysis of the operations affecting the handoff delay and introduces MIH services to optimize it.

This paper is organized as follows. In Section 2, factors affecting mobile handover delay are described along with a detailed description of the IEEE 802.11 handoff mechanism. In Section 3, Mobile IPv6 and Proxy Mobile IPv6 are compared and their impact upon handoff delay is discussed. Section 4 presents standard-defined and best-practice requirements for streaming transfers as well as methods of QoS/QoE evaluation. In Section 5, experimental testbed and PMIPv6 implementation with a proposed optimization are presented in detail. Section 6 discusses the results obtained in the course of our experiments. The papers is concluded in Section 7.

2. Mobility and quality: requirements and limitations

In future networks mobile users should be able to communicate in the same way as fixed ones. Moving across different access networks, which necessitates changes of the network attachment point (handover) and of Network Layer settings (such as IP addressing or routing), should cause as few interruptions as possible. Thus, a two-tier solution, both ensuring seamless handoff between network attachment points and retaining IP connectivity at all times, is necessary. Unfortunately, mobility in IP networks brings about a number of problems that need to be solved if IP-based services are to be offered to end-users with a satisfactory quality.

Changes of network attachment points can vary from a simple change of the access point in a homogeneous network (a horizontal or intra-technology handover), through a change of access technology (a vertical or inter-technology handover) to the most advanced handover requiring the change of network layer information like IP addressing (inter-AN handover). Handover efficiency oriented algorithms concentrate on data path optimization, which reduces transmission latency, packet loss during handover and consumption of network resources.

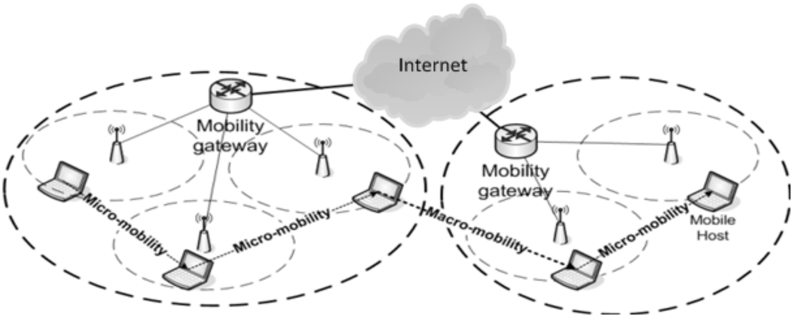


Fig. 1. Micro and macro-mobility.

User mobility can be classified as inter- and intra-domain (Fig. 1), where the term *domain* refers to a network under single management and authority. Such a distinction opens up the possibility to apply methods designed for a specific functionality.

Inter-domain mobility (also called macro-mobility) is related to a movement from one domain to another. Since it involves full low-layer handover, full authentication, new IP address acquisition and verification, mobile node registration and possibly radical data path changes, the necessary handover procedures are more complex.

On the other hand, intra-domain mobility (also called micro-mobility) refers to a user's movement within a domain. In this case some of the handover steps can be simplified e.g., fast re-association can be performed instead of a full association/authentication procedure and no IP address change is needed.

2.1. Layer 2 handover requirements

The most popular wireless local area network (WLAN) technology is the IEEE 802.11, commercially known as WiFi. Mobility in the IEEE 802.11 standard means the change of a physical access point (AP) when an MH moves between the APs. The handover detection phase at the MH can be defined as the time interval between starting preparations to move to another and actually moving. In practice, this phase is hard to specify and measure. During the handover the MH scans all the channels to detect nearby APs. After this, authentication and association processes can be conducted with a new AP. Moreover, 802.1X authentication can be used on top of the 802.11 association. In such a case, an additional 4-way handshake is performed for key exchange and derivation. The QoS reservation refers to the resource reservation procedures introduced by the IEEE 802.11e amendment.

Layer 2 handover delay (T802.11) can be expressed as

$$T_{L2\text{-}802.11} = T_{detect} + T_{scan} + T_{open\text{-}auth} + T_{(re)assoc} + T_{802.1X} + T_{key} + T_{QoS}. \tag{1}$$

Sample empirical values of handover parameters are presented in Table 1. The delays can differ depending on implementation, network equipment interoperability and environment conditions during conducted measurements.

The most time-consuming operations are detection, scanning and 802.1X authentication. Dedicated solutions reducing the time consumed by each of them have been proposed in several publications [7, 10, 11].

The detection time T_{detect} can be minimized by introducing AP-initiated or client-initiated handover. In the former case the AP monitors the current connection quality and compares it with that possible to achieve on other channels. The MH is then switched by the AP according to the measured qualities. In the latter case, the client decides to change the AP based on available metrics [7]. In this scenario, dual-radio devices can be used to perform out-of-band signaling. The detection time is quite critical in that its reduction brings a significant benefit.

Minimization of the scanning time T_{scan} can be achieved with one of the algorithms proposed in the literature e.g., [10]. 802.1X Authentication also introduces a significant temporal overhead caused by an AAA server. Reduction of the related delay $T_{802.1X}$ is addressed in the IEEE 802.11r standard dedicated to efficient handoff [11]. Other dedicated and proprietary solutions provided by hardware vendors could also be used (most often based on dedicated wireless network controllers).

Table 1. Empirical results for handover procedures, after [2].

Parameter	Value
T_{detect}	0 – 1600 ms
T_{scan}	58 – 400 ms
$T_{open\text{-}auth}$	1 – 10 ms
$T_{(re)assoc}$	1 – 10 ms
$T_{802.1X}$	200 – 700 ms
T_{key}	5 – 50 ms
T_{QoS}	1 – 10 ms
$T_{802.11}$	267 – 2790 ms

2.2. Layer 3/4 handover requirements

In order to provide handovers in the higher layers of the ISO/OSI model, there is a need for additional mechanisms apart from L2 handover procedures. Their specification depends on the required mobility type and scope. For host-based mobility (HBM) all the functionalities are included and implemented in the IP protocols suite. A radio access link is used to transport mobility signaling and tunneled packets. Additional tunneling overhead causes bandwidth reduction. In the network-based mobility (NBM), a network-side proxy mobility agent replaces the client-side agent. It is responsible for signaling and management on behalf of the MH. NBM imposes an additional requirement of consolidated management of all the network devices.

Regardless of the considered mobility protocol, the following components of Network Layer (L3) handoff delay can be specified: the movement detection delay T_{MD}, the address configuration delay T_{AC}, the delay of an AAA procedure T_{AAA} and the location registration delay T_{REG}:

$$T_{L3} = T_{MD} + T_{AC} + T_{AAA} + T_{REG} \tag{2}$$

The most popular mobility solutions for HBM and NBM, Mobile IP and Proxy Mobile, are detailed in the next section enabling a comparative analysis.

In general, the Transport Layer (L4) delay T_{L4} is the sum of T_{L2} and T_{L3}. If User Datagram Protocol (UDP) is in use, the delay also includes the transmission delay between two consecutive packets. If Transmission Control Protocol (TCP) is used, in addition to lower layer handoff delays $T_{L2}+T_{L3}$, a function of it represented by TCP retransmission delay T_{L4} makes an additional overhead. Thus, the duration of the total connectivity gap is equal to:

$$T_{CG} = T_{L2}+T_{L3}+T_{L4} \tag{3}$$

3. Mobility support in IP networks - Network based mobility

3.1. Mobile IP

The IETF Mobile IP [12] is the oldest and the most widely known approach to mobility support in IP networks. It is also an example of host-based macro-mobility. There are two versions of the standard specified by the IETF: IPv4 and IPv6 mobility protocols. Mobile IP offers mobility support in L3 and isolates the higher layers from mobility awareness. The key idea introduced in Mobile IP is the use of a couple of addresses in order to manage user movement. The MH owns its fixed address, in the Mobile IP terminology called home address, which can be regarded as the traditional IP address. Each time the MH connects to a new access network (AN), a temporary IP address for the current network is assigned. The MH remains reachable by binding, via the registration procedure, of both home and temporary addresses. For Mobile IP the temporary IP address is named Care-of Address (CoA). A correspondent host (CH) sends datagrams destined to the MH using its IP home address and the datagram is tunneled via Mobile IP infrastructure to the MH's current location.

In the Mobile IPv6 the MH is able to create its own CoA using its link-local address and automatic address configuration (i.e. merge subnet prefix with own hardware address). Mobile IPv4 adds Foreign Agents (FA) that are located in any network that can be visited by the MH and facilitates CoA generation.

Moreover, Mobile IP extends the IP infrastructure by the concept of Home Agent (HA). HA is located in the home network, defined as the network that the MH's IP address belongs to. It must be provided with current information about current CoA of the MH. It is up to the MH to notify appropriate MIP entity of its location. In the case of MIPv4, the MH informs its HA of its current CoA with the assistance of the local FA. In MIPv6 the process is simplified, and MH informs HA directly.

The HA intercepts traffic addressed to the MH home address and, if the MH is not in the home network and thus cannot receive such traffic directly, sends the traffic to a network where the MH is currently located by means of tunneling. In the case of MIPv6, the procedure is simplified, such that the tunnel is created directly to the MH.

Moreover, to provide low latency handovers for the micro-mobility scenario there are some enhancements e.g. Hierarchical Mobile IP [13], which introduces a regional mobility agent and simplifies registration procedures.

3.2. Proxy Mobile IPv6

PMIPv6 extends and reuses the proven MIPv6 idea, yet it does not require any modification of a standard mobile node’s IPv6 stack. A network-side proxy mobility agent is used in place of MIP client-side agent, and performs signaling and management on behalf of the MH. As a result, PMIPv6 provides an efficient solution without tunneling and signaling overhead on radio access link. Nevertheless, Proxy Mobile IPv6 cannot be deployed as a standalone global mobility system, due to the lack of standardized macro-mobility procedures and mechanisms.

Proxy Mobile IPv6 (as defined in [14]) uses two specialized network elements: Media Access Gateways (MAGs) and Local Mobility Anchors (LMAs), cf. Fig. 4. MAG is responsible for tracking the MH's movements, creating a bidirectional tunnel to LMA and managing connectivity between MH and LMA. LMA is similar to HA in Mobile IPv6. It is responsible for maintaining routes and forwarding information for all MHs within a domain. The communication between LMA and MAGs is organized into PMIPv6 protocol messages – Proxy Binding Updates (PBUs) and Proxy Binding Acknowledgements (PBAs).

Proxy Mobile IPv6 supports stateless and statefull autoconfiguration modes. In the former mode, the MH generates an IPv6 address from the HNP by standard mechanisms – Stateless or Privacy Extensions (RFC4862 or RFC4941, respectively). In the latter mode, IPv6 addresses can be configured by a DHCPv6 server located in the Proxy Mobile IPv6 domain (RFC3315). In this situation MAGs must provide the functionality of DHCPv6 relay agents.

In contrast with standard Mobile IPv6's shared-prefix model, Proxy Mobile IPv6 has each Home Network Prefix assigned only to one Mobile Node (MN) i.e., provides a per-MN-prefix addressing model. From the perspective of the MH, the entire PMIPv6 domain appears as its home network.

3.3. Performance analysis

Equation (3) presents the delay T_{L3} in a general form. Its specific form depends on the mobility system being considered.

The address configuration procedure could be the most time-consuming especially when DAD is performed, in which case it could consume more than 1 s. To reduce the related delay T_{AC}, some optimizations have been undertaken. The optimistic DAD (oDAD) bases on the premise that DAD procedures succeed more often than fail. However, using oDAD does not exclude address collision. As mentioned earlier, PMIPv6 uses per-MN-prefix, thus this restriction allows to avoid triggering the time consuming DAD procedures and shortens the handover latency.

In PMIPv6, the system registration process is very simple and includes only PBU/PBA message exchange. By comparison, in MIPv6, both MH and CN should register and in HMIPv6 it is only simplified for MAP registration. The registration delay is calculated in a different way for each system, depending on its configuration and state.

MH movement detection is only required in MIPv6 and HMIPv6. A different approach to decrease the handover delay uses link layer triggers. The Mobile IP extensions called fast handovers [15] or low latency handovers [16] aim at forecasting a handover and preparing the transition to a new Access Router (AR) before the connection to the old AR is lost. In Proxy Mobile IPv6, each MAG acts as a default router, and for the MH the network appears as its home network. However, in this case there is a requirement for detection of attachment to the new MAG. In all these systems, detection should be performed as soon as possible.

It can be assumed that AAA performance is similar for all these systems.

4. QoS/QoE requirements for streaming transfers – methods and measurement tools

In regard to media streaming in mobile systems, handoff affects transferred data. As a result, QoS parameters such as packet loss ratio, packet delay and inter-arrival jitter at the recipient may become intolerably large. In particular, since mobility solutions are typically bufferless, all the packets transmitted during the handover are lost. The impact of this varies depending on the streaming media type. In the case of audio streaming, all data packets are of equal importance. In addition, audio streaming systems are expected to provide better quality than conventional telephony. These two facts make for strict bounds on tolerable packet loss, which should be even lower than what is acceptable in telephony. The same applies to packet delay jitter even though it can be reduced by a re-jitter buffer, given that a typical listener is highly intolerant of speech delay variations. Faced with these expectations, a mobility system should provide as efficient handoff as possible in order to minimize both packet loss and jitter.

Video streaming is prone to impairments such as video blocking, blurriness, freezing, jerkiness and blackout. Most of them are specific to MPEG encoding [17], in which three types of frames, differing in importance, are used. The most important are I-frames (key frames). All the following frames describe only differences in the picture during the decoding of the MPEG stream. The ITU-T Recommendation G.1010 [18] specifies the levels of acceptable packet characteristics required for media streaming, in particular limits the packet loss ratio to 3% for audio streaming and to 1% for video streaming. In [19] a brief study of packet loss impact on video quality is presented. In this approach even an efficient handover with a short connectivity gap may result in a significant loss of quality. It should be noticed that even a short e.g., 50 ms interval caused by packet loss may result in image distortion, a so-called artifact, which lasts longer than 0.5 s.

For video signals, methods based on the Peak Signal to Noise Ratio (PSNR) [20], the J.144 recommendation [21], and the Structural Similarity index (SSIM) [22] have been proposed along with a variety of objective methods that compare the referenced and the processed videos frame by frame. Unfortunately, most of these methods can only be successful in a lossless environment (e.g., when used for evaluation of encoding algorithms). The reason is that when a frame is lost, the immediately following frame is compared with the lost frame's counterpart in the reference video; comparisons of misaligned frames thus produce misguiding results. This is true e.g., for the method based on the J.144 recommendation, suitable for high-quality (768 kbps to 5 Mbps) video transmissions in lossless transmission environments such as cable TV. A measurement method dedicated for lossy environments was presented in [23].

Considering the complexity and resource consumption of the above methods, relatively simple subjective methods remain the most popular, among them Absolute Category Rating (ACR) and Degradation Category Rating (DCR) [24]. Both these methods use a five-point MOS (Mean Opinion Score) scale. DCR requires that the test sequences be presented in pairs: the first is the source content used as a reference, and the second is the same content after the passage through the transmission system under test. In ACR, the reference content is not known to viewers when they are evaluating the transmitted content.

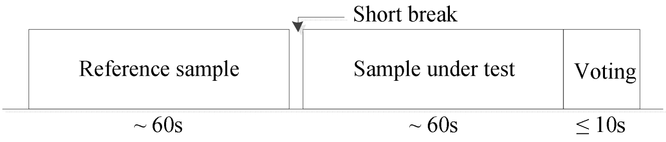


Fig. 2. Stimulus presentation in the DCR method, (after [24]).

As we were primarily interested in assessing the quality degradation of the original video content, we employed the DCR method in our research. We decided to use the services of a relatively small group of experts (four to eight) in accordance with the DCR recommendation for systems and methods in their early implementation phase. For a more mature solution, a meaningful evaluation by a larger group of testers should be conducted.

5. PMIPv6 testbed environment

To verify the functionality of PMIPv6 mechanisms, an original implementation of its complete set of mechanisms has been developed, including tunneling and security related mechanisms.

While MIPv6 provides the wireless client with an unchanging IPv6 address, thus enabling applications which would be infeasible without it, such as running application servers, the quality of the resulting IPv6 connectivity is disturbed during handovers. For many multimedia related services it is a significant handicap. To deal with this problem, we supplemented our base PMIPv6 implementation with handover optimization procedures dedicated for an IEEE 802.11 network environment.

The proposed handover optimization solution does not modify PMIPv6 mechanisms and can also be utilized independently or in conjuration with different layer 3 mobility support mechanisms. Its goal is to minimize network detection (T_{detect}) and scanning (T_{scan}) phase duration, which constitute a majority of IEEE 802.11 handover time, taking up to 2 s (about 70% of overall handover time).

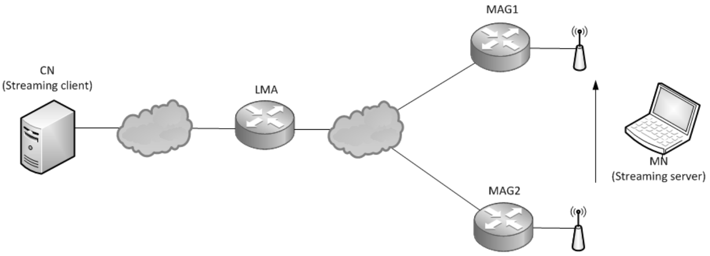


Fig. 3. Testbed architecture.

Out proposed mechanism utilizes two physical IEEE 802.11 interfaces; one is used for carrying network traffic, whereas the sole task of the other is to gather handover support information. This additional information is then used to perform handover decision and preconfigure the network interface prior to the handover itself, thereby minimizing the connectivity loss. The previously discussed scanning phase is significantly shortened while the detection phase is eliminated entirely for such prepared handovers.

The necessity of employing the second network interface may seem like a significant handicap, but it allows the solution to be implemented above the level of network device driver, making it compatible with wide variety of network hardware. It is also possible to integrate its mechanisms into said device drivers, which would allow it to function using a single network interface. Unfortunately, apart from significant compatibility loss, it would also result in slight degradation in user traffic transmission performance.

The testbed used to verify the above mentioned optimized IEEE 802.11 handover mechanism is presented in Fig. 3. It consists of a portable computer configured as a streaming server, which provides streamed media to a stationary computer configured as a streaming client. As such operation is impossible without an IP Mobility solution, a full PMIPv6 infrastructure has been implemented between these two elements.

The portable computer performs handover between two wireless APs, functioning purely in ISO-OSI L2 and connected to PMIPv6 MAGs. A client-side handover optimization mechanism is employed to support handover performance.

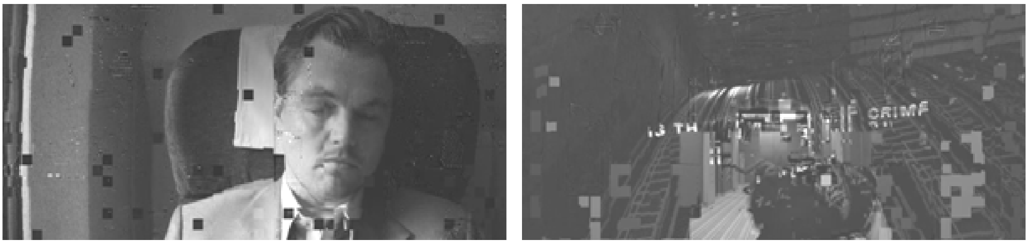
The experiments were performed in accordance with one of three scenarios. In the first, one, serving as a reference, media were streamed in a fixed wireless network in which the MH was connected to one AP. In the second one the streaming was performed with a PMIPv6 handover without any optimization. The last one examined an implemented mechanism of handover delay minimization.

For media streaming (server-side) and capturing (client-side), Video LAN Connector application [25] was used. Received videos were compared with their originals and graded according to Degradation Category Rating [24] with marks in the range 1 to 5 for QoE evaluation. Moreover, all RTP packets were captured and their statistics calculated.

The described testbed experiments provide representative results describing PMIPv6 handover performance in network environments with different layer 2 handover quality. They also allow us to illustrate the impact of such handover performance differences on popular multimedia services.

6. Measurements of QoS/QoE and example results for streamed media

The performed experiments aimed to examine the quality of media streaming for different scenarios. For each scenario, measurements were repeated 30 times. Two metrics were used, namely network oriented QoS and user-centric QoE. This section presents sample as well as overall results.



a) blocking or pixelization

b) freezing and ghosting

Fig. 4. An example of video impairments experienced.

Examplary frames with artifacts due to the effects of RTP packets loss are presented in Fig. 4. In the case of only one I-frame affected, the decoder does not have enough information to reconstruct the image and consequently, pixelization might be observed (Fig. 4a). A freezing effect may occur when a sequence of frames is lost. Whenever an I-frame is lost in such a sequence whereas the following frames convey a new scene, a ghosting effect can be observed (Fig. 4b).

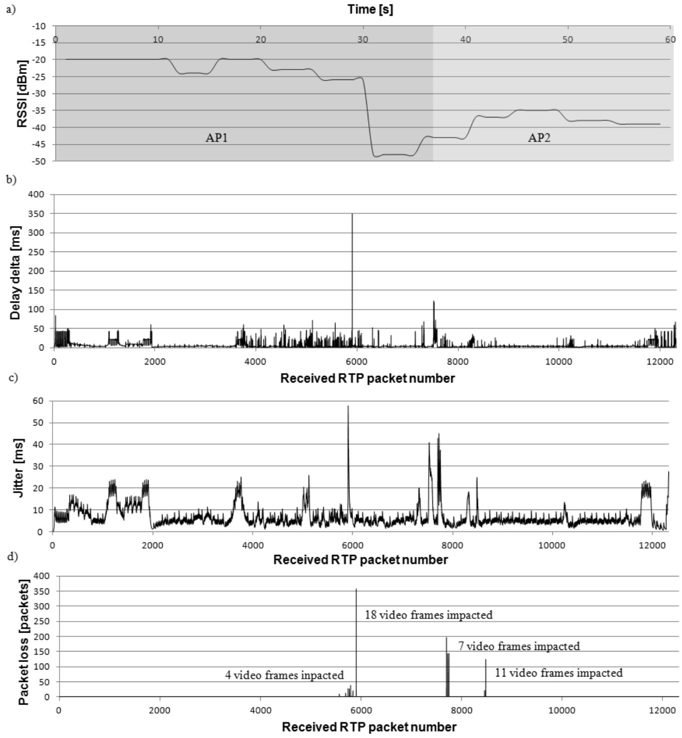


Fig. 5. Examplary results – handover optimization scenario, pessimistic case.

Figs. 5 and 6 present examples of streaming characteristics of a video transfer with high and low MOS (the pessimistic and more frequently occurring optimistic case), respectively. In charts 5a and 6a, the strength of a radio signal (RSSI) is shown and the handover point is marked. Charts 5b and 6b, and 5c and 6c, respectively depict the packets' *delay delta* (defined as the spacing between a pair of packets at the receiver compared to one at the sender) and jitter for a sequence of RTP packets. Charts 5d and 6d depict the number of lost packets during the transfer. Near the peaks are indicated the numbers of frames exhibiting artifacts as a result of packet losses. Moreover, some video frames might be lost following RTP packet losses. Packet losses, and large delay delta and jitter values clearly coincide with an RSSI decrease (Fig. 5).

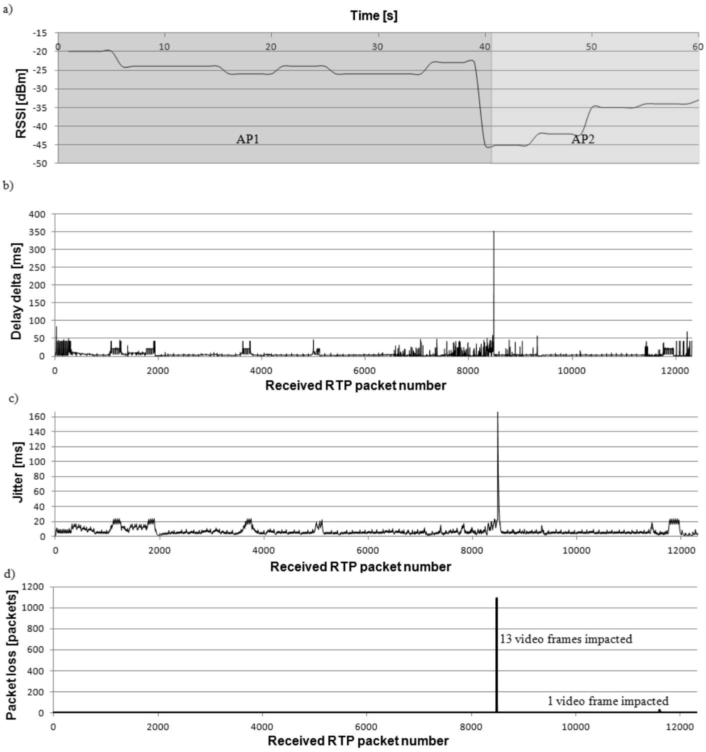


Fig. 6. Examplary results – handover optimization scenario, optimistic case.

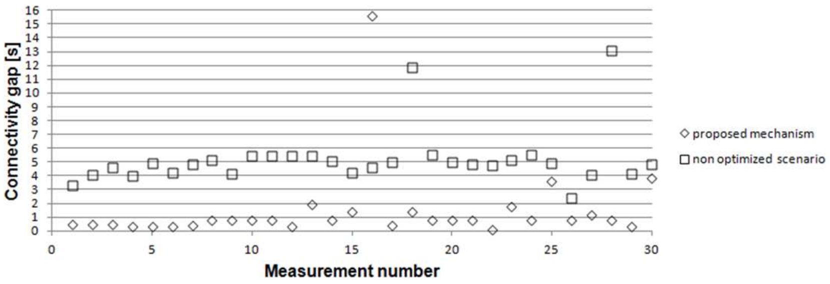
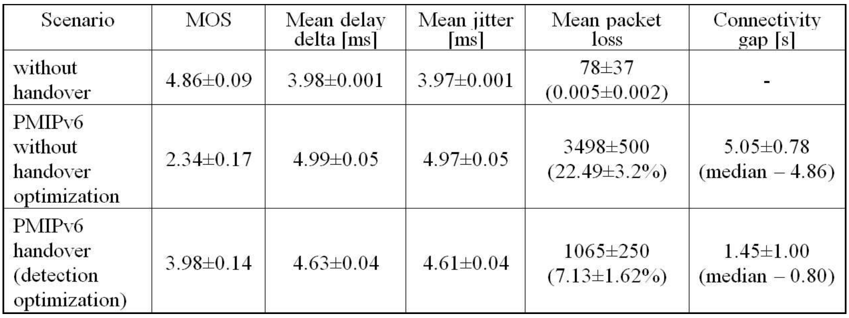


Fig. 7. Comparison of the total connectivity gap T_{CG} (3) during handovers.

Fig. 7 plots the total connectivity gap T_{CG} (3) for all the regular and optimized handover scenarios. The parameter T_{CG} comprises both the layer 2 and layer 3 handoffs. As can be seen, the connectivity gap is significantly minimized by the proposed solution (diamonds) in comparison to the original one (squares).

The overall results of our experiments are presented in Table 2. The MOS values refer to the QoE evaluation, whereas the mean delay, jitter and packet loss values represent QoS measurements. Without handover optimization the perceived quality of the video transfers was significantly degraded. The evaluated video quality scored 2.34 MOS points on average, which is a low score. Although the mean delay delta and jitter did not vary much, the handover delays affected the number of lost packets. The proposed delay minimization mechanism resulted in a MOS increase by more than 1.5 points.

Table 2. Results of experiments – Quality of Experience and Quality of Service parameters.



Scenario	MOS	Mean delay delta [ms]	Mean jitter [ms]	Mean packet loss	Connectivity gap [s]
without handover	4.86±0.09	3.98±0.001	3.97±0.001	78±37 (0.005±0.002)	-
PMIPv6 without handover optimization	2.34±0.17	4.99±0.05	4.97±0.05	3498±500 (22.49±3.2%)	5.05±0.78 (median – 4.86)
PMIPv6 handover (detection optimization)	3.98±0.14	4.63±0.04	4.61±0.04	1065±250 (7.13±1.62%)	1.45±1.00 (median – 0.80)

All the confidence intervals are stated at the 95% confidence level.

7. Conclusions

In this paper, measurements of handover effectiveness under the Proxy Mobile IPv6 protocol have been performed. The tests concerned the regular PMIPv6 version as well as its optimized version developed by the authors. It was shown that the proposed modification of the handover procedure has a great impact both upon the flow parameters and the MOS metrics. The improvement in MOS was by one point on the five-point scale, amounting to over 25%. Hence the evaluation of the video streaming moved from the nearly "annoying" class (2.4 points on average) to the "perceptible but not annoying" class (3.9 points on average). The objective metrics also showed a significant improvement. The packet loss metric dropped from 22% to 7.1%, an improvement by 68%. Not so significant, but also visible was the gain in the case of packet delay delta and jitter, where the corresponding metrics improved by 7%.

It has been proved, therefore, that the proposed solution significantly improves the handover procedure. The main gain lies in the minimization of layer 2 ISO/OSI detection time, which constitutes one of the most time-consuming operations during the handover. Future work will focus on minimizing the handover delay by applying an additional wireless card on the MH side. One of the interesting directions is a logical interface built on top of physical interfaces to provide soft-handover. Although this approach requires L3 and L2 synchronization, it can significantly reduce the total connectivity gap duration.

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