Seamless Mobility of Senders Transmitting Multi-user Sessions over Heterogeneous Networks

Luis Veloso[1], Eduardo Cerqueira[1], Paulo Mendes[2], Edmundo Monteiro[1],

[1] Department of Informatics Engineering, University of Coimbra,
Polo II – Pinhal de Marrocos, 3030-290 Coimbra, Portugal
{lmveloso, ecoelho, edmundo}@dei.uc.pt
[2] Internet Architectures and Networking Telecommunication and Multimedia Unit,
INESC Porto, Rua Dr. Roberto Frias, 378, 4200-465, Porto, Portugal
pmendes@inescporto.pt

Abstract. The development of wireless technologies together with the increasing portability of telecommunication devices lead to the necessity to develop communication systems capable of supporting a seamless mobility experience to end-users. Moreover, the arising of multi-user real-time services has emphasized the importance of the multicast communication to deliver content to multiple simultaneous receivers. The simultaneous increase in the production and distribution of multimedia content by both mobile service providers and consumers requires an efficient solution for the mobility management of multicast sources. This way, mobility management of multicast senders is a challenging and unsolved task for the successful development of next generation user-centric mobile networks, where the nomadic user is not only a consumer but also a provider of multimedia content. A proposal to constraint losses during the handover of multicast senders, and consequently, to avoid the service degradation perceived by receivers is presented in this paper. Simulation results confirm the ability of the proposed mechanism to reduce or completely avoid packet losses, increasing the perceived quality of the received sessions.

Keywords: User-centric Mobile Communications, Multicast, Seamless Multimedia Experience, QoS.

1 Introduction

Wireless networking represents the future in terms of connectivity and ubiquitous access. The current wireless landscape is characterized by distinct radio access technologies developed to fulfill the requirements and expectations of users. From the traditional cellular networks (e.g. GSM, EDGE, UMTS, CDMA2000) to the local area networks (e.g. IEEE 802.11 b/g/n) and wide area networks (e.g. IEEE 802.16 d/e, DVB-T/H, DAB), wireless technologies represent a rapid area of growth and importance. This progress creates a demand for mobility management techniques able to provide a mobile communication without perceived quality degradation in user-centric systems.

The future Internet architecture will also need to support applications aimed to multiple simultaneous users (multi-user), such as mobile IPTV, voice and video conferencing, push media (e.g. news headlines, weather updates), file distribution and monitoring (e.g. sensors, stock). Multicast communication is the most appropriate technique to distribute the content of multi-user real-time services, because it is more efficient than unicast in terms of resource utilization for services shared by groups of receivers.

Since multicast protocols were not developed to support seamless mobility, mobility management is necessary to provide seamless handovers involving this type of communication. For this reason, the *Seamless Mobility of Users for Media Distribution Services* (SEMUD) [1, 2] approach was previously proposed to provide seamless mobility of multicast receivers based on the combination of caching and buffering mechanisms together with mobility prediction and session context transfer among access routers.

Mobility management of multi-user receivers is not a trivial task, and the challenge increases when trying to manage seamless source mobility. This occurs because the movement of a multicast sender has higher impact in the shape and efficiency of the multicast tree than the movement of multicast receivers. The key challenge is that while the receiver movement on a multicast delivery is complex but has a local impact in the multicast distribution tree, the source movement brings more problematic issues since it is global, affecting the complete reconstruction of the multicast tree. The subsequent subscription of a new multicast tree by the receivers will lead to packet losses, and consequently, to the related degradation of session quality.

This work presents an approach named *Seamless Mobility of Senders for Media Distribution Services* (SEMSE) to address the sender mobility challenge. The seamless movement of senders expresses the ability to protect receivers from packet losses which could occur during handover. SEMSE is supported by buffering mechanisms responsible to assist the movement of senders between different access routers in order to guarantee communications without packet losses, taking advantage from the capability of buffers to store packets. The foundation of the proposed mechanism is the combination of a buffer denominated *Holder* and located in mobile nodes with a buffer denominated *Virtual Multicast Root* (VMR) which is placed at the egress edge of the access network. The cooperation between these components will permit to reduce or completely avoid packet losses during the movement of mobile sources. The proposal was evaluated regarding the packet losses avoidance and their influence in the quality of a video session perceived by the final receiver. The *Peak Signal to Noise Ratio* (PSNR) was the metric chosen to measure the quality of the received video sessions.

The referred mechanisms were developed under the *QoS Architecture for Multi-user Mobile Multimedia* (Q3M) architecture [3]. This architecture controls the quality level, connectivity and seamless mobility of multi-user sessions across heterogeneous wired and wireless environments. As a brief overview, the Q3M architecture controls the flow of multi-user sessions across heterogeneous networks through the use of an edge networking approach, in which the functionality of each network is controlled by a group of organized edge devices.

The remainder of this document is organized as follows. Section 2 gives a survey of the related work and section 3 describes the mechanism specification. Next, the simulation scenario and experimental results are discussed in the Section 4. Finally, conclusions are presented in Section 5.

2 RELATED WORK

The most relevant mobility management techniques intended to support the mobility of senders transmitting multi-user sessions are described in this section.

To support multicast transmission over *Mobile IP* [4] networks, the IETF proposed the *Home Subscription*. In this approach, the mobile source uses its *Care of Address* (CoA) to tunnel the multicast data to its home agent. The enclosed data contains the *Home Address* (HoA) as the source address and the multicast group address as the destination address. In the home agent, the data is decapsulated and forwarded to the multicast tree. This approach gives transparency to the handover of a mobile source, since a source-specific tree will be built with reference to the fixed HoA. This is, the multicast tree is rooted in the HoA, and consequently, there is no need to reconstruct the multicast tree whenever a handover of the mobile source occurs. However, this proposal introduces sub-optimal routing and a central point of failure as well as it lacks in seamless support. Moreover, the processing task of the home agent increases with the number of mobile sources, wasting system resources in this entity.

Mobicast [5] proposal introduces a *Domain Foreign Agent* (DFA) aimed to support the mobility of multicast users within a foreign network. In the case of mobile receivers the amount of packet losses is reduced since the multicast tree is subscribed not only by the current base station of the mobile receiver, but also by the adjacent base stations where the arriving packets will be stored. A main drawback of this approach is the inefficient network resources utilization. Furthermore, when the mobile node is sending a multicast session, it encapsulates the multicast packets and sends them to the DFA. The DFA will decapsulate and send them to the multicast tree on behalf of the mobile sender. This way, the reconstruction of the tree is avoided when the mobile source moves but no mechanism is provided to constrain the packet losses occurring during handover. This scheme leaves to the multicast application the course of action regarding the packets lost during handover. On the contrary our proposal places the loss control on the edges of the access network.

Another scheme proposed by the IETF to manage multicast transmission was the *Remote Subscription*, in which the multicast tree is established towards the new location of the mobile source. That is, the mobile source uses its current CoA as the source address of the multicast group. The advantage of this scheme is to provide a shortest multicast forwarding path, thereby avoiding triangle routing across the home network, and to avoid the utilization of tunnels when the mobile node moves between access routers. However, this approach requires the reconstruction of the entire multicast tree when the sender moves, causing service disruption. Two worthy proposals for source mobility exist based on this latter approach: the *Source Mobility support Multicast* [6] (SMM) and the *Mobile SSM Source* [7] (MSSMS).

In the SMM approach, the multicast tree is build over a Cellular IP micro-mobility network, in which a *Shortest Path Tree* and *Rendezvous Point Tree* are combined into one multicast tree. The *Rendezvous Point Tree* is used to minimize the overhead in the tree reconstruction caused by source movement and the *Shortest Path Tree* is used to eliminate redundant routes for the members between the source and rendezvous points. This scheme has the advantage to suppress the overhead of the multicast tree reconstruction. Nonetheless, it depends on the Cellular IP technology and requires enhancements to be applied to other IP networks, not providing seamless mobility control.

The MSSMS describes enhancements to MIPv6 that can be used to solve the problems introduced by mobile *Source Specific Multicast* [8] (SSM) sources. In this scheme, when the mobile source moves into a new network, it notifies the multicast receivers about its *new CoA* (nCoA). Upon reception of this notification, receivers initiate a join operation towards the new channel (nCoA, G) but only prune the old channel when they start receiving packets on the new channel. To ensure consistency at higher layers, the notification must also indicate the HoA of the source to permit the correct identification of the SSM session. At the new foreign network the mobile source sends packets with the source address nCoA to the new multicast tree, and encapsulates the multicast packets to the *old Access Router* (oAR) with the *old CoA* (oCoA) address at the inner header. At a point in time, two multicast trees coexist but for a given receiver, only one branch is active at a time. The source only stops encapsulating the data to the old tree when it is notified by the previous access router that there are no receivers listening to the old channel (oCoA, G). Finally, the new multicast tree with origin at the new CoA of the source is completely formed. With this proposal a smooth transition is accomplished between the two multicast trees. Nevertheless, this approach suffers from redundant routing that causes packet routing delay and network bandwidth consumption during the process of handover.

The analysis of related work reveals that none of the solutions provides an acceptable compromise between seamless mobility and network resource utilization. Therefore, it would be interesting to investigate how the usage of buffers as custodians of multicast packets can provide a good trade-off between limiting the service degradation perceived by the final user and limiting network resource usage.

3 Mechanism Specification

The objective of the *Seamless Mobility of Senders for Media Distribution Services* (SEMSE) approach is to provide seamless mobility to senders of multi-user sessions while limiting the usage of network resources, when senders move between different attachment points. The seamless movement is supported by buffering mechanisms responsible to assist the transmitting mobile nodes on changing the attachment point between different access routers, without or with reduced packet losses. This is achieved through the combination of a buffer in the mobile node referred as *Holder*, and buffers in the access network called *Virtual Multicast Roots* (VMR). Figure 1 presents a generic scenario where the location of the referred components can be identified.

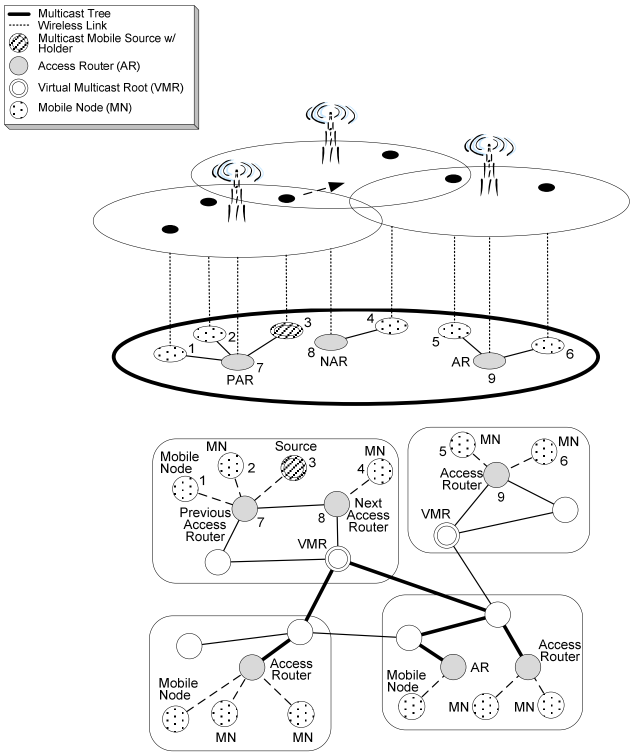


Figure 1 - Scenario describing the location of SEMSE components

Each access network will contain at least one VMR composed by a cluster of buffers, being each buffer dedicated to a single multicast session. Hereinafter, a single session will be used for illustration purposes, and consequently, the respective VMR will be composed of a single buffer.

The multicast session is sent from the mobile sender to the VMR via a tunnel, where it is stored and sent to the multicast tree. From the view point of the receivers, the multicast source is the VMR being the multicast tree defined by <VMR, G> and not <Sender, G>. This way, the source movement will be concealed from the receivers, which avoids the reconstruction of the entire tree each time the sending mobile source executes a handover. During handover, and despite the lost of connection with the mobile source, the VMR continues sending the buffered packets, avoiding in this manner the interruption of the session flow. This capability depends on the amount of packets buffered by the VMR, on the transmission bit rate and on the handover duration. The role of the *Holder* is to store the packets produced by the sender application during handover, in order that after this period, its interaction with the VMR will constrain/eliminate packet losses.

When the distance from the mobile source to the VMR becomes excessive, it could be advantageous the joining of a new VMR by the mobile source.

A detailed description of the SEMSE mechanism, along with an example illustrating its functionality, will be presented in the following section.

3.1 SEMSE Operation

As described in Figure 2, the multicast mobile source sends packets towards the VMR via a tunnel (step 1 in Figure 2), from where they are delivered to the multicast tree. This way, the mobile source can send multicast packets even when connected to an access network that does not support IP multicast. It is assumed that each access router has a database with the IP address of the local available VMRs. This database can be created manually or on-demand by performing periodic message exchanges between neighbor access routers as happens in the *Fast Mobile IP* (FMIP) [9] proposal, though the VMRs discovery (and maintain) process is out the scope of this paper.

When the handover decision is taken, a *HandoverBearer* message is sent to the mobile source with information regarding the connectivity in the next access router, namely the CoA of the sender in the new access router (step 2 in Figure 2). During handover, the data produced by the application will be stored in the corresponding *Holder* while the VMR will continue to feed the multicast tree. The occupation of the *Holder* will increase up to a level that depends on the duration of the handover and on the bit rate used by the sender application.

On the other hand, the occupation of the VMR buffer will diminish and the capacity to nourish the multicast tree will depend on the amount of packets stored in the VMR before the handover, on the session rate and on the handover duration. After handover, the mobile source sends an *UpdateMNLocation* message to notify the VMR that its address associated with a session has changed (step 3 in Figure 2). Afterwards, it pushes the packets contained in the *Holder* towards the buffer located in the VMR (step 5 in Figure 2). This way, the seamless mobility will depend on the amount of data available on the VMR to feed the multicast tree during handover and on the *Holder* size to store the packets produced by the application. Subsequently, the session continues to be delivered from the mobile source node to the VMR (step 6 in Figure 2).

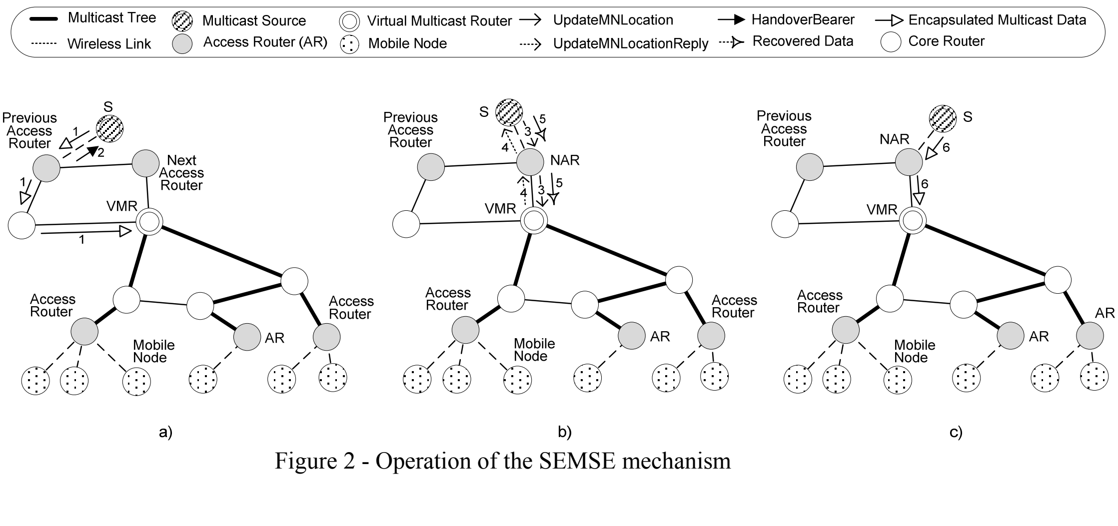


Figure 2 - Operation of the SEMSE mechanism

In this manner, not only the reconstruction of the multicast tree is avoided since the respective source address remains the same from the view point of the receivers, but also packet losses are constrained/eliminated. The SEMSE mechanism is supported by the following messages:

- *UpdateMNLocation*: message sent from the sender mobile node notifying a VMR about its new address;
- *UpdateMNLocationReply*: acknowledge message sent from VMR to the mobile source;
- *HandoverBearer*: message sent by the current access router to the mobile source (after handover decision), providing information related to the future access router and VMR.

3.2 Interfaces and Components

The SEMSE mechanism contains several interfaces and components needed for seamless source mobility procedures. Firstly, an interface is needed for the interaction with session control mechanisms. When the handover decision is taken, the interaction with session control mechanisms aims to transfer the session context to the new access router, install the session in the new access router and path, as well as to release resources on the old path. Moreover, an internal interface is used to allow the interaction between SEMSE components. For example, when the sender moves a message is sent towards the VMR to update the sender new location.

*Holder*s and VMRs are the components which compose the SEMSE mechanism. As referred before, the first ones are comprised by a buffer used to store packets produced by the sender application whilst a VMR is composed by a cluster of buffers, being each buffer dedicated to a single session.

3.3 Advantages

Between the most relevant benefits of the SEMSE proposal it should be referred its ability to keep media transmission during the handover of a multicast sender, to support micro and macro-mobility and to assure the operation of multicast senders in unicast or multicast domains.

Therefore, it provides transparent support for receivers, which do not perceive any interruption of the flow during the source mobility, by avoiding or significantly reduce packet losses during the handover. This allows network operators to increase the level of satisfaction of users by improving the user experience during handovers.

Moreover, the operation of SEMSE introduces low communication overhead and has low complexity.

4 EVALUATION

The discussion that follows tackles the evaluation of the SEMSE mechanism. First, the scenario of the simulations is addressed. Then, the amount of packets that is possible to recover with SEMSE is presented. Afterwards, the impact of the improved packet loss avoidance in the quality reception of a video session is analyzed. Finally, the VMR buffer occupation is captured during the simulation time and presented for a broad understanding of the dynamics involving the system behavior.

4.1 Scenario

The simulation was implemented following the scenario described in Figure 2, where a mobile node is sending a video sequence composed of 300 frames denominated *News*. Those frames were originally in the raw YUV format with 4:2:0 sampling and CIF (352x288) size. They were compressed using a MPEG4 encoder into a video sequence with a *Group of Pictures* (GOP) structure composed by one I-frame and twenty nine P-frames, and transmitted with a 30 frame/s rate. Each frame was fragmented into blocks with 1024 bytes length which were transported in RTP [10] packets. Those packets were sent using a *Variable Bit Rate* (VBR) with an average rate of 86 KB/s

The intra and inter-network links have a bandwidth of 100 Mbit/s and the wireless link has a capacity of 11 Mbit/s. A handover has been generated at the middle of the simulations being its duration indicated at each of the following descriptions regarding the obtained results. The simulation was implemented using the discrete event simulator NS2 [11] and the open source framework Evalvid [12].

Since in this case a video sequence is considered, the PSNR metric was used to measure the quality of the received session. Considering the luminance (Y) of the received and sent frames and assuming frames with MxN pixels, PSNR is expressed through the following expression:

$$PSNR = 20\log_{10}\left(\frac{255}{\sqrt{\frac{1}{MxN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left\|Ys(i,j) - Yd(i,j)\right\|^2}}\right)$$

In this equation, while Ys(i,j) designates the pixel in the position (i, j) of the original frames, the Yd(i,j) represents the pixel located in the position (i, j) of the received frames. With this metric each received frame will be compared with the original one, given the obtained value a measure for the degradation of the original frame.

4.2 Packet Losses

The quantity of recovered packets versus the VMR buffer size and the handover duration is depicted in Figure 3, where the source buffer and receiver buffer sizes (150 KB) remained constant. As expected, the amount of recovered packets is low and irregular for small VMR buffer sizes (< 28 KB), which are insufficient to accommodate the variable bit rate of the session.

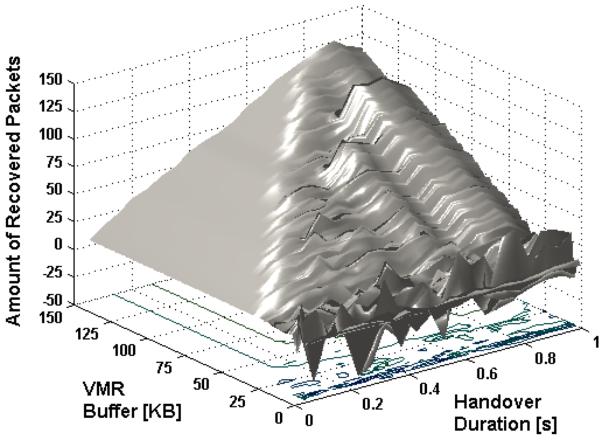


Figure 3 - Recovered packets versus the VMR buffer size and handover duration

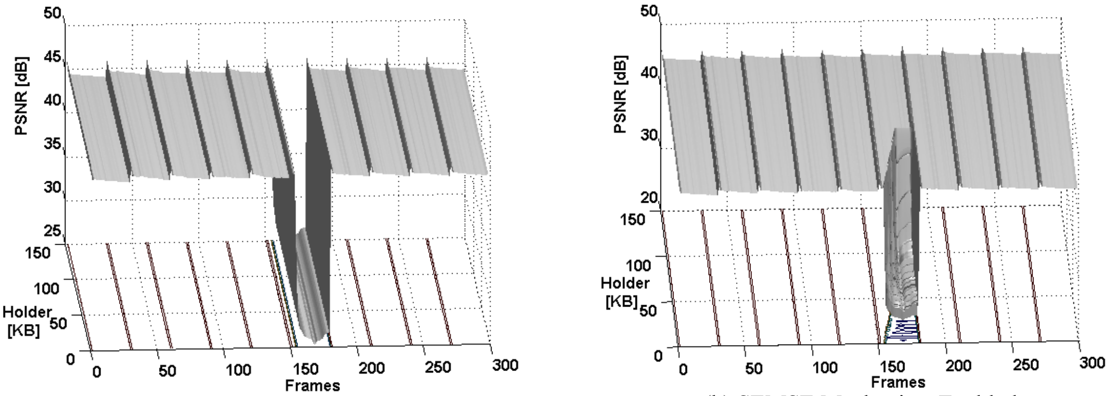
For higher values the results show that, considering a constant VMR buffer size, the amount of recovered packets increases with the handover duration and then becomes approximately constant with an oscillating behavior. This oscillation is motivated by the variable bit rate of the transmitted session. This is, for those handover durations which cause the fluctuation, the VMR buffer becomes full with the packets sent after handover by the mobile source buffer. Subsequently, the variable bit rate of the session leads to buffer overflows, thereby causing packet losses whose amount varies as the handover duration increases.

A different behavior occurs when considering a constant handover. The amount of recovered packets increases initially with the VMR buffer size. However, this increase occurs not linearly but with an oscillation due to the variable bit rate of the session, together with a VMR buffer size too small to accommodate the packets sent after handover from the mobile source.

4.3 Peak Signal to Noise Ratio (PSNR)

This section investigates the influence of the proposed mechanism in the quality of a received video session. For this reason the PSNR of the received video sequences was analyzed versus the *Holder* and VMR buffer sizes. PSNR values higher than 37 dB reflect a good quality video, whilst values between 20 and 25 dB indicate a poor video reception.

Figure 4(a) depicts the obtained PSNR versus the *Holder* size when the SEMSE mechanism is disabled. These results were obtained considering a constant VMR buffer size (150 KB), receiver buffer size (150 KB) and handover duration (500 ms). The quality degradation due to packet losses occurring during handover is noticeable.



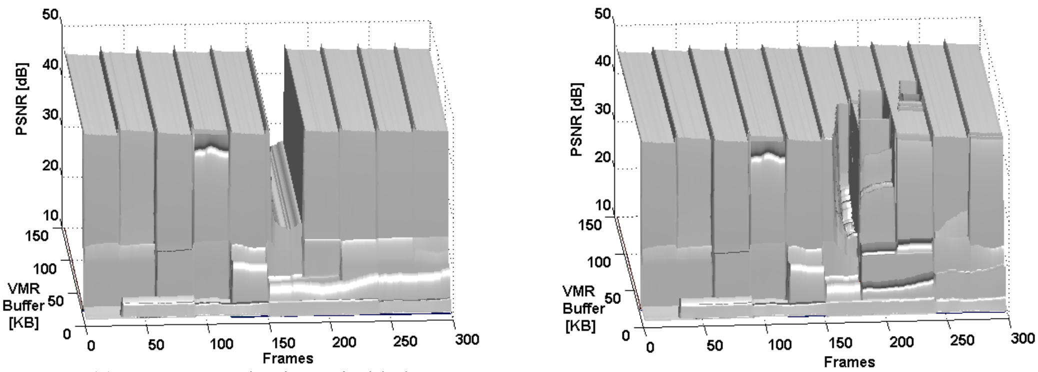
(a) SEMSE Mechanism Disabled (b) SEMSE Mechanism Enabled

Figure 4 – PSNR versus the Holder buffer size

The improvement introduced by SEMSE is shown in Figure 4(b). In this situation, as the *Holder* size increases more packets are stored during handover and posteriorly sent to the VMR. Consequently, more frames are correctly received and decoded.

The impact of packet losses in the quality of the received session was also evaluated versus the VMR buffer size, considering a constant Holder buffer (150 KB), receiver buffer (150 KB) and handover duration (500 ms). Figure 5(a) depicts the obtained PSNR when SEMSE is disabled. The influence of the handover related losses is perceptible in the PSNR of the frames transmitted during this period.

When SEMSE is enabled, the packets stored during handover in the source buffer are sent to the VMR. As the VMR buffer size increases more packets can be recovered, and consequently, a better PSNR will be expected. Figure 5(b) confirms this supposition since the quality of the previously degraded frames increases when SEMSE is enabled.



(a) SEMSE Mechanism Disabled (b) SEMSE Mechanism Enabled

Figure 5 - PSNR versus the VMR buffer size

However, some frames have an unexpected low quality. This occurs because in these cases the VMR buffer size is too small to accommodate all the packets sent by the *Holder* after handover. When this occurs, the variable bit rate of the arriving packets may cause overflows, and consequently, quality degradation in the corresponding frames. Additionally, if an I-frame is one of the lost frames it will not be possible to decode all the frames pertaining to the same GOP, due to the interdependency existing between them.

4.4 VMR Buffer Occupation

In this section, the VMR buffer occupation is depicted providing an enhanced perception of SEMSE dynamics. When SEMSE is disabled the occupation of the VMR buffer oscillates during the simulation interval due to the variable bit rate of the session. On the other hand, when SEMSE is enabled the behavior of the buffer occupation is significantly different as described in Figure 6.

The occupation of the VMR buffer versus the *Holder* was obtained considering a constant handover duration (500 ms) and receiver buffer size (150 KB). The higher peaks result from the fragmentation and transmission of I-frames which are the ones with larger sizes. When the mechanism is enabled, the occupation of the VMR buffer suffers an abrupt increase after the handover procedure, proportional to the *Holder* size. This occurs, because as the *Holder* size increases, more space is available to store packets during handover. Consequently, after handover more packets will be sent from the source to the VMR. Nonetheless, for a constant handover duration this increase is not infinite since the number of packets to recover is finite

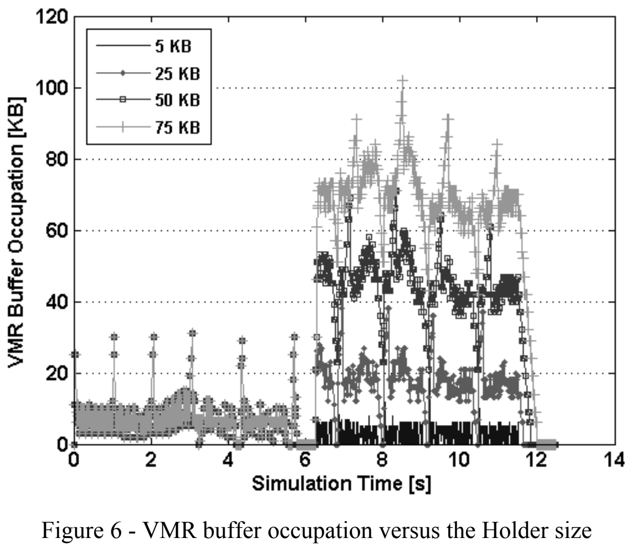


Figure 6 - VMR buffer occupation versus the Holder size

5 Conclusion

This paper presented the SEMSE approach to support the seamless mobility of multicast senders. The obtained results confirm the proposal ability to avoid packet losses during the movement of a mobile source. In addition, it was observed the dramatic impact of the improved packet recovery in the quality of a video sequence. Nevertheless, SEMSE buffers should be correctly dimensioned to absorb rate variations and to efficiently recover the missing packets. For example, for an average rate of 86 KB/s, a handover duration of 500 ms, and source and receiver buffer sizes with 150 KB, the losses will be totally avoided for VMR buffer sizes above 102 KB.

As future work, further evaluation will be done to the mechanism efficiency when the movement of the mobile source leads to a change of the active VMR. Moreover, the optimal number of mobile sources that a VMR is able to cover while supporting seamless mobility will be also investigated. In addition, the proposed mechanism will be analytically modeled to obtain an even better insight of its performance.

Acknowledgments. This work was supported by the NTT DoCoMo Euro-labs, by the Portuguese *Ministry of Science, Technology and High Education* (MCTES), and by European Union FEDER under program POSC (projects Q3M and SAPRA).

References

[1] L. Veloso, E. Cerqueira, P. Mendes, and E. Monteiro, "Selective Mobility support of Multi-user Services in Wireless Environments," presented at 18th Anual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07), Athens, Greece, September, 2007.
[2] L. Veloso, E. Cerqueira, P. Mendes, and E. Monteiro, "Seamless Mobility of Users with QoS and Connectivity Support," presented at WiMob, New York, USA, October 2007.
[3] E. Cerqueira, L. Veloso, A. Neto, M. Curado, E. Monteiro, and P. Mendes, "A Unifying Architecture for Publish-Subscribe Services in the Next Generation IP Networks," presented at Globecom 2006, San Francisco, California, 2006.
[4] D. Johnson, C. Perkins, and J. Arkko, "Mobility Support for IPv6," IETF RFC 3775, 2004.
[5] C. Tan and S. Pink, "Mobicast: a Multicast Scheme for Wireless Networks," Mobile Networks and Applications, Vol 5, Issue 4, pp. 259-271, 2000
[6] K. Sato, M. Katsumoto, and T. Miki, "A New Multicast Technique Supporting Source Mobility for Future Vision Delivery Service," presented at International Conference on Advanced Information Networking and Application, 2004.
[7] C. Jelger and T. Noel, "Supporting Mobile SSM Sources for IPv6," presented at Globecom, Taiwan, 2002.
[8] H. Holbrook and B. Cain, "Source-Specific Multicast for IP," IETF RFC 4607, 2006.
[9] R. Koodli, "Fast Handovers for IPv6," IETF RFC 4068, July 2005
[10] H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson, "RTP: A Transport Protocol for Real-Time Applications," IETF RFC 3550, July 2003.
[11] C. Ke et al, "An Evaluation Framework for More Realistic Simulations of MPEG Video Transmission," Journal of Information Science and Engineering, pp. 425-440, March 2008.
[12] J. Klaue, B. Rathke, and A. Wolisz, "EvalVid - A Framework for Video Transmission and Quality Evaluation," presented at TOOLS 2003, Urbana, Illinois, USA, September 2003.