A Simulation Study on the Performance of Hierarchical Mobile IPv6

Xavier Pérez-Costa, Marc Torrent-Moreno and Hannes Hartenstein

Network Laboratories, NEC Europe Ltd., Heidelberg

We performed a simulative evaluation of Hierarchical MIPv6 in comparison with standard MIPv6 using the network simulator *ns-2* for a 'hot spot deployment' scenario. The simulation scenario comprises four access routers and up to 50 mobile nodes that move randomly and communicate in accordance with the IEEE 802.11 wireless LAN standard. The study provides quantitative results of the improvements provided by HMIPv6 with respect to handoff latency, packet loss, signaling load and bandwidth per station. The simulation environment allowed us also to investigate the behavior of the protocol in extreme cases, e.g., under channel saturation conditions, and considering different traffic sources: CBR, Video, VoIP and TCP.

1. Introduction

Recently there is a strong convergence trend of Internet and cellular systems by using IP as the common network protocol. The IETF working group on Mobile IP is proposing Mobile IPv4 [1] and Mobile IPv6 [2] as the main protocols for supporting IP mobility. In addition, solutions have been proposed in order to extend Mobile IP for environments where the mobile nodes change their point of attachment frequently and the baseline Mobile IP protocol would result in a high signaling load as well as high handoff latency and packet losses. These proposals are commonly referred to as *micro-mobility* protocols, see [3] and [4]. On the cellular systems side there is currently an increased interest for providing improved bit rates in hot spot environments, e.g., as can be seen by the development of the so-called High Speed Downlink Packet Access (HSDPA) [5]. Wireless LAN technologies in combination with Mobile IP can serve as a competitor technology to provide high speed access in hot spot scenarios. Therefore, we have seen the need for a thorough study on the performance of a wireless LAN Mobile IPv6-based hot spot scenario to assess the suitability of this technology.

In this paper we study the protocol performance of Hierarchical Mobile IPv6 (HMIPv6) in comparison with the baseline Mobile IPv6 (MIPv6) protocol. Apart from measuring signaling load we are primarily interested in evaluating the degradation of service a mobile user observes during a handoff when receiving a continuous data stream (e.g., video or voice over IP). Thus, we are interested in performance metrics like handoff latency, packet loss, and obtained bandwidth per station. The scenario for this study was chosen to resemble a 'building block' of a potential wireless LAN hot spot deployment. It comprises four access routers and up to 50 mobile nodes that move randomly and communicate in accordance with the IEEE 802.11 wireless LAN standard. We consider the impact of different parameters like degree of mobility, number of mobile nodes, wired link delay and protocol options over the various performance metrics. Due to the complexity of the required study, simulation was chosen as the most suitable analysis method. We use network simulator *ns-2*. Mobile nodes move according to the Random Waypoint Mobility Model [6].

Previous work on simulative evaluations of Mobile IP almost exclusively dealt with IPv4 networks. Regarding HMIPv6, an analitycal study that focused exclusively on the update signaling messages frequency based on an early version of the HMIPv6 internet-draft can be found in [7]. Because of the significant differences between Mobile IPv6 and Mobile IPv4, e.g., Neighbor Discovery, results obtained for MIPv4 do not take over for MIPv6. Therefore, in our previous work [8], we performed a detailed study of Mobile IPv6 and a fast handoff procedure. Moreover, previous analysis usually studied a single mobile node without the interference of others. In [8] as well as in this paper a more realistic scenario with more than one mobile node and random movement patterns is considered. Our results show that consideration of an arbitrary number of mobile nodes and random movements significantly impact the obtained performance results.

The paper is structured as follows. Section 2 describes the simulation model. Simulation results are provided in Section 3. Finally, Section 4 presents the conclusions. Two sections had to be removed due to space restrictions. The first one recalled the basics of Neighbor Discovery, Mobile IPv6 and HMIPv6. The second one described the performance aspects subject of interest. These sections can be found in [9] which is an extension of this paper.

2. Simulation setup

The studied scenario was designed in order to be large enough to provide realistic results but to be small enough to be handled efficiently within *ns-2*. The chosen scenario, depicted in Figure 1, is composed by the Home Agent and the Correspondent Nodes that are connected via the ‘Internet’ (modeled by adjusting the link delay *ld*) to a central router (CR). Four access routers (AR) –each one representing a different IP subnet– are connected via two intermediate routers (IR) to the central router. When Hierarchical MIPv6 is considered, the functionality of the Mobility Anchor Point is placed on the central router and the CR, IRs and ARs form the micro-mobility domain. At simulation start the mobile nodes are uniformly distributed over the coverage area.

The access routers have been positioned in a way to provide total coverage to an area of approximately 700×700 square meters considering a transmission range of 250 meters, see Figure 2. The mobile nodes move randomly within the coverage area following the random waypoint mobility model [6]. This model has been previously used mainly for ad-hoc simulations but it is well suited as well for our purposes as we will explain in Section 3. As wireless medium the 2Mbps Wireless LAN 802.11 DCF [10] provided by *ns-2* [11] is used. The access routers use the same frequency band since no roaming process is standardized for 802.11 and thus, roaming protocols are proprietary.

Within the micro-mobility domain each wired connection is modeled as a 5Mbps duplex link with 2ms delay. The ’Internet’ connecting the central router and the HA or CNs is modeled also as a 5Mbps duplex link with a default link delay (ld) of 10ms. In the simulations, the *ld* value has been varied to model various ‘distances’ between the MNs and the HA and CNs.

In order to simulate a realistic case where a MN will receive packets from the shared AR queue and where a MN will also compete with other MNs and with an AR to access the channel, half of the MNs receive data from the CNs and the other half send data to the CNs. The CNs

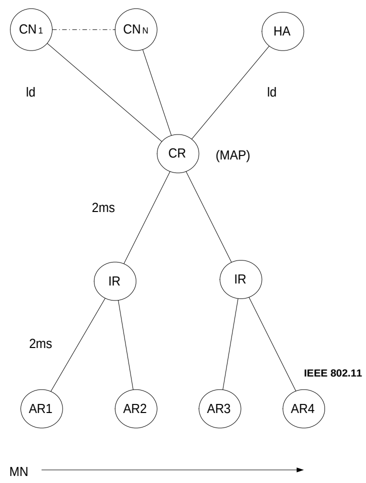

Figure 1. Simulation scenario

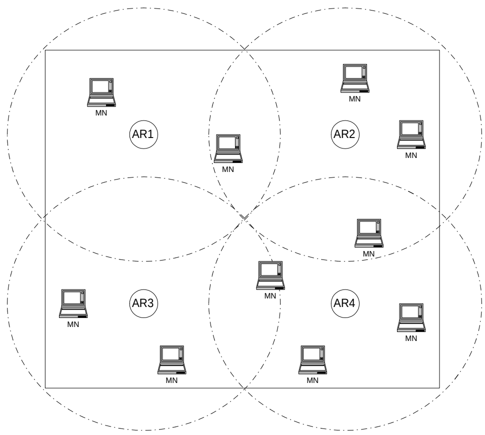

Figure 2. Access routers distribution

sending to the MNs introduce delay in the AR queue and the MNs sending to the CNs introduce delay in the wireless link. The study though focuses on the MNs receiving data from the CNs since the purpose is to analyze the degradation of the experienced quality of service due to mobility.

In our simulations different types of traffic will be simulated. UDP CBR sources provide constant traffic where no acknowledgments are required. This kind of traffic is usually generated by real-time applications and due to its deterministic characteristics, without recovery mechanisms, eases the protocols study and comparison. This will be the traffic source generally used in our performance evaluation.

TCP is the most widely used transport protocol. We simulate endless FTP sources to understand the impact of IP mobility on the congestion control mechanism of TCP using the different protocols.

One of the applications expected to be used with MIPv6 is VoIP. We have implemented a VoIP model based on [12]. The model assumes silence suppression and models each voice source as an on-off Markov process. The alternating active *on* and silence *off* periods are exponentially distributed with average durations of 1.004 and 1.587 s. As recommended by the ITU-T specification for conversational speech [13], an average talk spurt of 38.57% and an average silence period of 61.47% is considered. A rate of 88 kbps[1] in *on* periods and 0 kbps in *off* periods is assumed for a voice source that generates CBR traffic.

As a streaming application for real-time video traffic we have used a real H.263 [14] video encoding provided by [15]. The encoded video corresponds to the film "Star Trek: First Contact" for a target bit rate of 64 kbps. The obtained frame sizes (in bytes) of the individual encoded video frames are used as input for the *ns-2* real-time video traffic application. Since these traces include only the raw packetized video, additional streaming protocol overhead has been added.

[1] Assume 8KHz 8 bits/sample PCM codec was used with 20 s frame per packet. With 12 byte RTP header, 8 byte UDP header and 40 byte IPv6 header, the size of each voice packet is 220 bytes. The bandwidth required will be (220 x 8)/20=88kbps

As in the case of VoIP sources we consider a 12 byte RTP header plus 8 byte UDP header and plus 40 byte IPv6 header as the streaming protocol overhead.

The simulation code used for the experiments was designed on top of INRIA/Motorola MIPv6 [16] code for *ns-2* [11] implementation. We have extended the code with two main modules: Neighbor Discovery and Hierarchical Mobile IPv6. Some modifications have been done to the original release in order to extend the code to work with more than one mobile node.

3. Performance evaluation & discussion

With our *ns-2* simulations we study the impact of several system parameters over the performance metrics for the scenario described in Section 2. We analyze the degradation of the performance metrics from the point of view of a single mobile node that follows a deterministic path while all other mobile nodes in the system follow the random waypoint mobility (RWP) model. The RWP model is well-suited to represent movements of mobile users in campus or hot spot scenarios at moderate complexity. In Section 3.4 the random movement of the studied mobile node is considered. We have chosen a UDP probing traffic from the CN to our specific mobile node of 250 bytes transmitted at intervals of 10 ms. The other mobile nodes create background traffic sending or receiving data at a rate of 32 kbps.

All simulations have a duration of 125 seconds with a 5 seconds warm-up phase. Each point in the following graphs represent the average of at least 100 simulations. The sample size necessary to achieve a confidence interval of 99% with respect to the average value has been selected as indicated in [17]. This required in some cases to perform up to 1000 simulations, e.g., in the 50 mobile nodes or random movement case.

3.1. *Impact of number of stations*

We have studied the impact of the number of competing stations in the shared medium on the following parameters: handoff latency, packet loss and obtained bandwidth. The studied MN performs four[2] handoffs during a simulation run moving from center to center of the AR's coverage areas until it reaches again the starting point. The values represented in the graphs are the ones corresponding to the analyzed MN.

Figure 3 shows the increase in handoff latency due to an increase in the number of MNs sharing the wireless channel. We can observe that HMIPv6 performs almost always better or equal than standard MIPv6, as expected, since the wired 'distance' in order to update the respective agent that forwards packets to the mobile node is always shorter. For a small number of MNs, e.g., 20 or below, the dominating factor for handoff latency is the wired delay not the wireless one. Therefore, the latency obtained with HMIPv6 is much smaller compared to the MIPv6 one. However, for a higher number of MNs the wireless delay becomes more and more important decreasing the handoff latency advantage of using HMIPv6. However, when the wireless delay becomes very high due to saturation in the channel, e.g., 40-50 stations case, we see again a better latency performance of HMIPv6 due to two reasons. First, only one BU is sent to the MAP in the HMIPv6 case while MIPv6 sends a BU to the HA and afterwards one to the CN, i.e., introducing an additional wireless delay. This difference could be removed sending the BU first to the CN and then to the HA. Second, while the BACKs to HA and MAP

[2]In [18] a twelve-week trace of a building-wide local-area wireless network was studied. The results presented there showed that 2 handoffs per minute is a high handoff rate for pedestrian mobile users

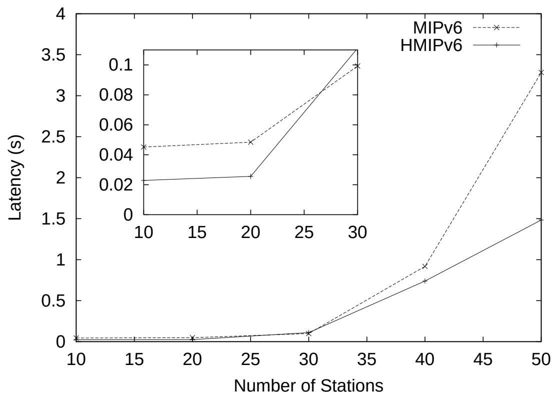

Figure 3. Impact of number of station on handoff latency

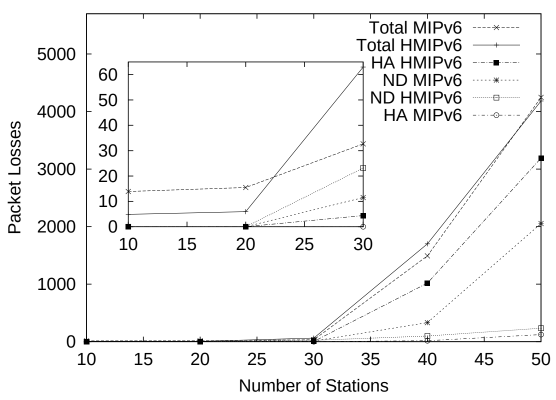

Figure 4. Impact of number of stations on packet losses

BUs are mandatory, the BACK to the CN BU is optional. In our implementation BACKs to CN BUs are not sent to avoid additional overhead. Under high saturation channel conditions the probability of a BU to be lost increases, therefore, when using standard MIPv6, if a BU to the CN is lost[3], it is not retransmitted, increasing significantly the latency value. On the other hand, when the BU to the MAP is lost, it will be retransmitted after a one-second timeout without receiving the corresponding acknowledge. An exceptional case can be observed for 30 MNs where MIPv6 shows a slight better performance than HMIPv6. The reason is the encapsulation that HMIPv6 always does from the MAP to the current point of attachment, increasing the load in the channel, i.e., 40 additional bytes per packet, and thus the saturation throughput is reached earlier by HMIPv6.

In principle, one would expect a direct relationship between handoff latency and packet losses. In Figure 4 we can see that this is not the case. From the graph we can observe that for up to 20 stations the usage of HMIPv6 results in reduced packet losses compared to MIPv6. However, when the number of MNs increases, the total number of packet losses is temporally higher for HMIPv6 due to its earlier channel saturation and tends to converge with MIPv6 for a higher number of MNs because of the high saturation conditions. In order to understand this effect we have differentiated between packets lost at the previous AR –the MN is no longer there to pick them up – and packets lost at the new AR due to Neighbor Discovery, i.e., address resolution[4]. While the usage of HMIPv6 shows less packet losses at the previous access router since the updating 'distance' is shorter than for MIPv6, the number of packets lost with HMIPv6 due to Neighbor Discovery will be larger than for standard MIPv6 as can be seen as follows. When performing a handoff with standard MIPv6 the MN first sends a BU to the HA and immediately after (one wireless delay) to the CN. The first packet that arrives to the new AR triggering the address resolution process of neighbor discovery is the BACK from the HA

[3] IEEE802.11 realizes when a packet was not correctly transmitted over the wireless medium due to the lack of a MAC layer acknowledgment and re-tries the transmission eight times before discarding it.

[4] During the address resolution process only a small amount of packets are buffered for the same destination address, e.g., three in our implementation [19].

and the first data packets arrive to the new AR after a wireless delay. However, if HMIPv6 is used, after performing a handoff the mobile node will send a single BU to the MAP which will send the corresponding BACK followed *without* delay by the next data packets. Since in this case there is no delay between the packet that triggers the address resolution process and the next ones, all the packets that will arrive during this process, once the buffer for this address is full, will be dropped. Therefore, when the number of MNs increases the address resolution process takes longer and more packets are lost due to Neighbor Discovery.

We have included the packets lost in the HA as a measure of whether the route updating mechanisms are working properly. Packet are lost by the HA only when the BU lifetime of both, CN and HA, have expired. Figure 4 shows that under channel congestion conditions, i.e., 30 or more MNs, HMIPv6 presents a higher rate of packet losses at the HA. The reason is that with HMIPv6 the MN must first send a BU to the MAP and wait until it is confirmed to send a BU to the HA. Therefore, under high saturation conditions where the possibility of a packet drop is higher, the expiration probability of the BU of the HA is higher for the HMIPv6 case resulting in a significant difference on the number of packets dropped by the HA.

For the following studies we have focused on the case of 20 MNs since this represents the case where the channel can be accessed without experiencing a high degradation in the quality of service due to competing nodes.

3.2. *Impact of handoff rate and number of correspondent nodes*

The main purpose of HMIPv6 is to reduce the signaling load outside of the micro-mobility domain when the number of handoffs increases. We have performed a simulation increasing the handoff rate performed by the studied station. Figure 5 shows that the goal of HMIPv6 is achieved. On the other hand, HMIPv6 increases the signaling load within the micro-mobility area. This is a coherent result as we can see as follows. When roaming within the local domain, HA and CNs do not realize any change in the point of attachment and receive the BUs periodically, therefore the signaling load is constant outside the local domain. However, with standard MIPv6 whenever a MN performs a handoff the periodic BUs are re-scheduled and thus, an increase in the number of handoffs can imply a reduction in the number of periodic BUs. Since with HMIPv6 the handoffs within a micro-mobility area are transparent to the HA and CNs, the periodic BUs are not re-scheduled, and therefore an increase in the number of handoffs does not imply a reduction in the number of periodic BUs. Additionally, the implementation of HMIPv6 results in an increase in the number of periodic BUs sent in the micro-mobility domain, i.e., additional one sent to the MAP plus BACK, and the BACKs originated by the HA have to be encapsulated which increases the signaling load. Note though that if a MN has more than one CN, when a handover is performed the number of sent BUs for standard MIPv6 increases linearly with the number of CNs while it remains constant for HMIPv6. This is shown in Figure 6 that illustrates the impact of increasing the number of correspondent nodes over the signaling load for the different protocols in the case of a mobile node performing 4 handoffs in 120 seconds. The difference though, is not very big since in our scenario the number of handoffs per periodic BU periods is small, resulting in a small differentiation of HMIPv6.

The signaling load corresponding to standard MIPv6 presents, a priori, a strange behavior having a local minimum for the case of 8 handoffs/min (Figure 5). However, if we recall that for each handoff the MN re-schedules the periodic BUs to be sent we realize that if the

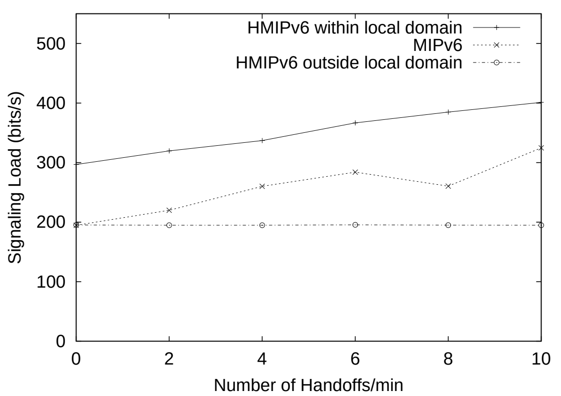

Figure 5. Impact of handoff rate on signaling load

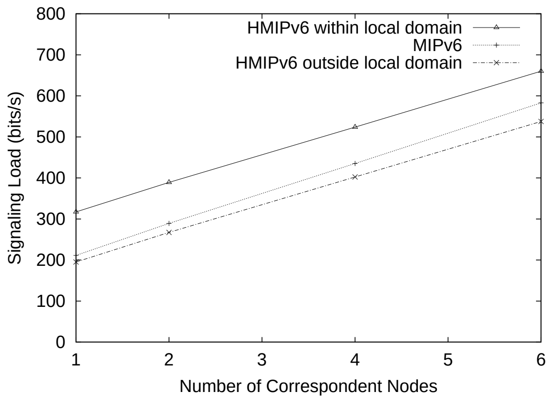

Figure 6. Impact of number of correspondent nodes on signaling load

timer of the periodic BUs is below the time between two consecutive handoffs we will observe the periodic BUs and afterwards the ones due to a handoff. On the other hand, if the time between two consecutive handoffs is below the timer of the periodic BUs the periodic BUs will be always re-scheduled without being sent during the whole simulation. Thus, in the case of 8 handoffs/min, considering a timer of 10 seconds for the periodic BUs, they are always re-scheduled due to a handoff and never sent, resulting in a reduction of signaling load compared to the previous case.

3.3. *Impact of wired link delay and of Previous Access Router Forwarding*

HMIPv6 eliminates the necessity of informing entities outside of the micro-mobility domain about the new point of attachment when performing a local handoff. Therefore, we have computed the differences in handoff latency and packet losses between HMIPv6 and MIPv6 when the wired link delay *ld* from the CR to the HA and CN is increased. The different *ld* values model different 'distances' to the HA and CNs. As we can see in Figure 7 the results are as expected: while an increase in the wired link delay implies an increase in the handoff latency for MIPv6, it does not affect HMIPv6 handoff latency.

We have repeated the experiment of the previous section but now using the previous access router forwarding option. As we can observe from Figure 8 the results for MIPv6 are quite different compared to the ones obtained before. MIPv6 and HMIPv6 perform in latency terms in a similar way since now the MIPv6 wired 'distance' to re-establish the packet flow has been significantly reduced. Note that to contact the previous access router is not necessary to go outside of the micro-mobility domain, reducing thus the wired 'distance' to the forwarding entity.

3.4. *Impact of random movement*

Mobile users are unaware of overlapping areas where handoff decisions are taken. This section studies whether the performance metrics differences observed between both protocols in previous sections still hold considering a mobile node moving randomly. Note that unexpected movements can have a quite negative effect on the packet losses experienced due to back and

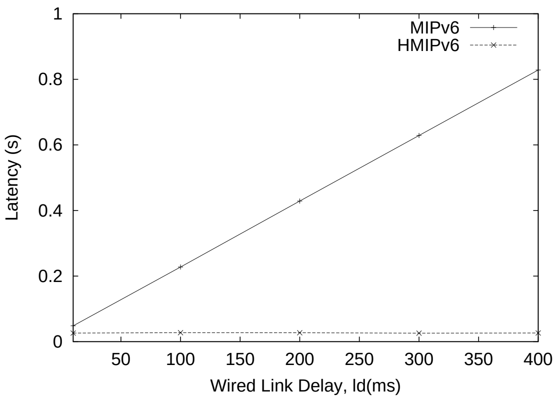

Figure 7. Impact of wired link delay on handoff latency

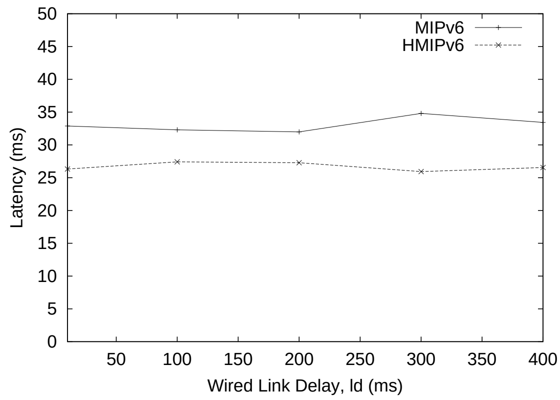

Figure 8. Impact of previous access router forwarding on handoff latency

forth movements around the overlapping areas. This effect could potentially prevail over the protocol enhancements. Figure 9 shows the histogram of total packet losses experienced by our mobile node moving randomly in the case of 20 mobile nodes and for MIPv6 and HMIPv6. The packet losses occurrences have been grouped in lower or equal than 1, 10, 100 and over 100. As we can observe in the figure, the results are consistent with the ones presented in Section 3.1. HMIPv6 outperforms MIPv6 keeping most of the packet losses on lower values than MIPv6.

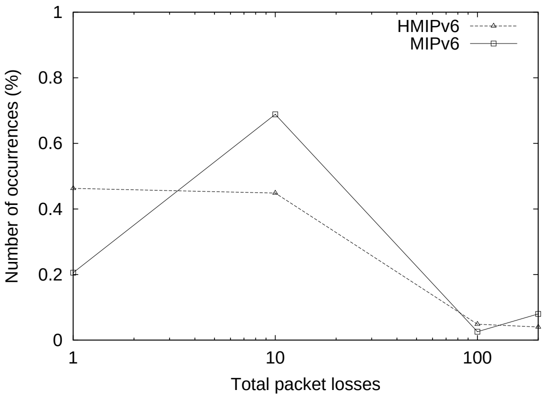

Figure 9. Histogram of the total packet losses considering random movement

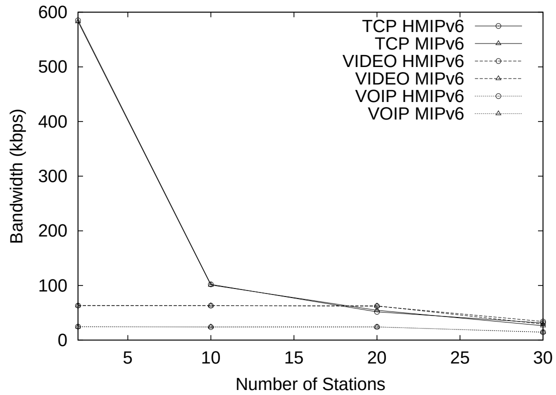

Figure 10. Impact of traffic sources on bandwidth

3.5. *Impact of traffic sources*

Until this section we have studied the impact of different parameters over the studied station receiving a high traffic load (*probe*) in order to obtain results with a significant precision and without the interference of source burstiness (VoIP, Video) or recovery mechanisms (TCP). In this section we consider real traffic sources and a simulation scenario where all the MNs send or receive using the same traffic source and rate. We study the impact of the number of stations over the received bandwidth until the desired level is not achieved for three different types of traffic: video, VoIP and TCP. Figure 10 shows the obtained results.

In the figure we can observe the TCP sources adaptation of the sending rate to the available channel capacity when the number of mobile users increases due to its congestion control mechanism. Although HMIPv6 presents better packet losses results than MIPv6 the bandwidth results are very similar. The reason is twofold, on one hand the number of packet losses saved compared to the number of packets received is very small, on the other hand the MAP encapsulates all the data packets addressed to the mobile nodes, this overhead reduces the available bandwidth in the wireless channel. The video sources used in our experiments require in average 64 kbps of bandwidth. As we can see in the figure the obtained bandwidth starts to decrease from 20 stations on, so no more than 20 mobile nodes could be accommodated. For the case of VoIP, even though we would expect that a higher number of mobile users could be accepted due to the lower sending rate compared to the video source, we obtain a number of users similar to the 64 kbps video case, 20 mobile nodes. The reason is the higher burstiness of the VoIP sources. As a conclusion, we can observe that enhancing MIPv6 does not allow a higher number of mobile users, although they experience a higher QoS.

4. Conclusions and Future work

During the design process of an IPv6-based wireless access network the question of whether it is worth to implement Hierarchical Mobile IPv6 instead of pure Mobile IPv6 should be analysed. In this paper we have provided quantitative results on the level of improvement one can expect by using Hierarchical Mobile IPv6 instead of pure Mobile IPv6 in a 'hot spot'-like IEEE 802.11-based scenario with four access routers and up to 50 mobile nodes. We performed a 'stress test' of the protocol where we studied how handoff latency, packet loss and obtained bandwidth are affected by the number of mobile nodes, i.e., by competition for the wireless medium, or by protocol interactions, e.g., with the Neighbor Discovery process of IPv6. These factors were shown to influence the packet loss rate of HMIPv6, and we indicated the points to be taken in account in an implementation. Handoff latency values of HMIPv6 outperformed the ones from MIPv6 in almost every case. We also quantitatively studied the trade-off between HMIPv6 signaling load reduction outside of the HMIP domain and the increase within. Furthermore, for our chosen scenario we showed that by using pure Mobile IPv6 and enabling the option of establishing forwarding from the previous care-of-address, latency and packet losses are similarly improved as with the use of HMIPv6, however, without HMIPv6's benefits of reducing wide-area signaling traffic. Finally, the behavior of the protocols considering random movements and different traffic sources, i.e., video, VoIP and TCP were studied.

Clearly, our results take over also for IEEE802.11 variants with higher bit rates when the values are adjusted accordingly with respect to the point where saturation throughput is achieved.

Future work will have to include header compression in order to judge the protocol overhead on the wireless link and to understand the corresponding protocol interactions with respect to the performance metrics analyzed in this study.

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