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# Anticipated Handover over IEEE 802.11 Networks

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**Abstract**— The recent success of IEEE 802.11 networks and the increasing demand for real time services suggest a new usage of wireless devices. In particular, mobility management between access points and IPv6 networks must be fast enough to avoid loss of packets. In this paper, we propose a new mechanism to anticipate handovers. The movement anticipation consists of new potential access points discovery before the handover has even started. It also allows a station to set up in advance a new IPv6 configuration for the next location. We show by simulation that the anticipation mechanism strongly enhances both Link and Network Layers handovers and significantly reduces the loss of packets.

**Index Terms**—Mobile Networking, Anticipated handovers, Layer 2 triggers, IEEE 802.11, Mobile IPv6

## I. INTRODUCTION

IEEE 802.11 networks are widely deployed in many places such as campus, buildings or cafés. The low cost of the technology and the high data rates are part of the success of this technology. This popularity let envisage a new model of the Internet: most users will probably be mobile, due to the wireless nature of the technology. Furthermore, as the technology can be used in many places, Internet applications will be used more often in our daily life, and the demand for services will certainly change. More real time applications will be requested such as Voice over IP or video-conferencing. These applications need an optimized and scalable support of the user mobility, in order to reduce the interruption in data reception caused by handovers.

In the infrastructure mode of IEEE 802.11, a station can communicate with an IEEE 802.11 access point (AP) if both the station and the AP are in the range of each other. When a station moves outside the coverage area of its current AP, it needs to attach to another one. This movement is known as a Layer 2 (L2) handover. While station is performing a L2 handover, it can not receive nor send data packets. If the new AP is connected to the same IPv6 subnet as the old one, it will be able to continue its communications on the new AP as soon as the L2 handover is finished. Otherwise, if the new AP is in a dif-

ferent IPv6 subnet, a mechanism is needed to inform the correspondents of the station about its new location. Mobile IPv6 [7], [13] is the most popular solution to manage host mobility through IPv6 networks. This mechanism is based on a home agent in the home network of the station, which relays data packets to the current locations of stations.

Mobile IPv6 (MIPv6) however lacks of interaction with underlying layers and thus introduces long delay (up to 2.8s, Section II) to update locations after a movement. Typically, when a station moves across two IPv6 subnets, the total disconnected time would be the time to attach to the new AP plus the time to create a new address and register it. In this paper, we will propose new mechanisms to anticipate movements. The L2 triggers usage will allow to prepare both the Layer 2 and the Layer 3 (L3) handovers prior to effective movement.

In the next section, we describe the layer 2 handover in IEEE 802.11 and the MIPv6 mechanisms. Next, we present different Layer 2 triggers needed to anticipate movement and we describe our proposition to perform handover anticipation. In the following, we evaluate our proposition by simulation and compare the performance results with other solutions. Then, we finish with some concluding remarks.

## II. HANDOVER MANAGEMENT

### A. IEEE 802.11 and handover management

IEEE 802.11 series technology allow wireless data communication between hosts. Although IEEE 802.11 allows ad-hoc communication, i.e. peer to peer communication, we only focus on infrastructure mode where all communication between wireless hosts use an access point (AP). Should the station moves out of the coverage area of its AP, it will not be able to access the network anymore. If another AP is in the station's transmission range, the station may start an association procedure. Changing AP is known as a Link Layer handover, or L2 handover. The

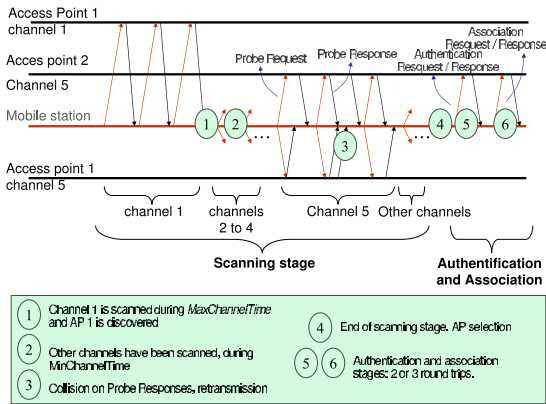


Fig. 1. IEEE 802.11 standard L2 handover stages

whole procedure of changing APs is subject to large variations, but is comprised between  $100ms$  and  $500ms$  depending on channel on which APs are operating, hardware and scanning phase efficiency [9].

A L2 handover is composed of three stages (see figure 1). First, a station is supposed to scan all 802.11 channels in order to discover available APs by sending Probe messages. If the station does not receive any response during *MinChannelTime*, it switches to the next channel. If at least one AP has responded with a Probe Response, the station continues scanning the same channel for *MaxChannelTime* in order to discover all APs operating on this channel. The end of this stage is not specified in the standard, it is implementation dependent. Usually, the scanning stage stops when the station has found an AP (without necessarily scanning every channels). An efficient method to select which channels stations can start scanning is to use a selective scanning algorithm [14]. This algorithm suggests to periodically update a mask of channels where APs are operating. This mask is used to determine which channels should be scanned first during a L2 handover.

Another method is to scan all channels to discover all neighboring APs, even if APs have been discovered on a channel. Although *MinChannelTime* and *MaxChannelTime* are not defined in the IEEE 802.11 standard,  $30ms$  and  $200ms$  are common values. If APs are operating on each channel and stations are scanning all channels, the discovery stage can take up to  $2.8s$ . That is the reason why stations usually stop scanning channels as soon as APs have responded. Anyway, this step constitutes the biggest part of L2 handover (more than 90% of the total L2 handover latency [9]). In section III, we will see that movement anticipation allows to skip this stage during the L2 handover. Thereafter the scanning phase, an authentication process takes place.

The authentication process depends on the security mechanism used on both the station and the target AP. In an

open system, the authentication is not used. In that case, the station and the AP only exchange empty Authentication frames. If WEP encryption is required on the AP, the station and the AP exchange either the WEP key if it is a public key, or a challenge text otherwise. If IEEE 802.11i [1] is used as security mechanism, the Authentication frames may be empty and the security association will be performed through an IEEE 802.1x port after association to the AP. If the authentication success, the station sends an Association Request to the AP. Then the AP sends an Association Response indicating if the association is accepted or not.

The L2 handover latency strongly depends on the number of scanned channels and the moment when a station stops scanning channels. In this paper, stations stop scanning channels as soon as an AP has been discovered (and then wait for *MaxChannelTime* and quit the scanning stage). In section III we will present our method which allows to skip the scanning phase during a L2 handover.

### B. Layer 3 handover management

L2 handover is independent from network topology. During a L2 handover, whether or not the new AP is connected to the same access network does not change the L2 handover process. The IP communication will however be affected if the new AP is attached to another IPv6 subnet. Mobile IPv6 [7], [13] is a generic solution to manage host mobility through IPv6 networks. While as long as a station remains in its home network, it communicates like any other static IPv6 node with its *home address*. Once it moves to a new point of attachment in another subnet, its home address becomes invalid and it must therefore acquire a new one, valid for the visited subnet. A MIPv6 handover can be viewed as a three steps process. A station would first detect that it is connected to a new IPv6 link (e.g. because of movement). It would then create and validate a new temporarily address referred to as a Care-of Address, based on information received on the new subnet. Finally, the station would update its location by sending a Binding Update to its home agent and correspondents.

Movement detection is a key stage in the L3 handover. It significantly influences total L3 handover latency as it determines when to trigger MIPv6 mechanisms. Station detects that it has moved to a new subnet through Router Advertisements (RAs) sent by routers [12]. RAs are periodically sent over IPv6 links, at a random frequency which varies from 3 to  $10min$  when routers are configured as specified in [12], or between 30 and  $70ms$  if routers are designed to support MIPv6 [7].

As we will demonstrate in Section V, the time needed to detect a new IPv6 link is a crucial stage in L3 handover.

TABLE I  
THE SIGNAL LEVEL MEASUREMENTS IN IEEE 802.11B, INDOOR TESTBED, CISCO AIRONET 350 CARD

Distance (m)	1	3	5 to 11	15 to 21	23 to 39	41 and more
Signal level (dBm)	-31	-42	-70	-75 to -78	-78 to -80	$\leq -82$
Levels	Level 1		Level 2		Level 3	
	Strong signal		Average Signal: start scanning		Anticipated Handover	
					Level 4	
					No signal	

The problem comes from the fact that there is no interaction between MIPv6 and underlying layers (the link layer in the OSI model). Movement detection, as suggested by MIPv6, is based on the reception of L3 messages (RA) and strongly depends on the frequency at which RAs are broadcasted [3].

### C. Optimization

Fast handover solutions [4], [8], [19] aim to enhance L3 handover latencies. A messages exchange between station, current access router and new access router allows to prepare a movement. This solution is based on movement anticipation which allows station to acquire a new valid Care-of address and transfer its context prior to movement. As this proposition is technology independent, L2 triggers are not specified but used for determining next point of attachment. Our purpose is close to this solution for the L3 management, but we propose a complete framework to enhance both L2 and L3 handovers.

When a station moves through IPv6 subnets, this is usually due to changing its point of attachment to the Internet as a consequence of a geographical movement. When this occurs, it is the direct cause of an L2 handover between wireless APs. Yet the interaction between the L2 and the L3 is limited and at the network layer, there is no awareness of L2 handover that has occurred. Several propositions such as [5], [2] enforce the interaction between these two layers to quickly respond to any change in network connectivity. For example, stations may explicitly request a RA by sending a Router Solicitation upon the end of a L2 handover. In that way, as soon as a L2 handover is finished, stations are requesting an RA in order to determine the network identification.

## III. HANDOVER ANTICIPATION

Our mechanism is based on a stronger interaction between L2 and L3 to enhance both L2 and L3 handovers. Several short anticipated discovery stages before an effective L2 handover allow to choose the target AP before starting the L2 handover. If a target AP can be identified before starting the handover, the handover only consists of the authentication and association stages, which

are very fast. On another hand, the introduction of L3 information into L2 frames allows a station to be aware of the new link's IPv6 prefix, without waiting for a RA. These two enhancements are based on L2 triggers, which are presented in the next subsection.

### A. Link Layer triggers

An L2 trigger is an information from the Link Layer used by the Network Layer [11]. It allows to quickly acquire knowledge of the L2 connections to the infrastructure. In our solution, we use two L2 triggers: the signal strength between a station and its AP, and the introduction of the IPv6 prefix into L2 frames.

The signal strength between a station and its AP is one major parameter used to determine the quality of a wireless link. Most of IEEE 802.11 network cards use the signal strength to determine whether a connection with an AP is still valid. In our solution, the station monitors the signal strength and starts an anticipated scanning process when the signal strength goes under a predefined threshold. This threshold should be low enough to avoid station to scan channels all the time, and high enough to let station enough time to discover all neighboring APs. Table I represents our measurements of the signal strength between a station and its AP, when the station goes away from its AP in an indoor testbed (Cisco Aironet 350 were used). From these results, we set the anticipated scanning threshold at -75dBm (Level 2) in the simulations presented in section V. This signal strength level indicates that the link between the station and its current AP is quite poor, and a handover may occur soon. Should the anticipated L2 scanning starts at that time, the station should have enough time to discover all neighboring APs before being disconnected from its current AP. Level 3 of signal strength (between  $-78$  and  $-80dBm$ ) will also be used to trigger next step of the anticipated handover process, as explained in next subsection. It has to be noted that the thresholds we chose depend on our configuration. For outdoor usage, the signal strength has a different behavior, and thresholds should be adjusted. The speed of the station is also a major factor to determine a signal strength threshold. In our experiments, we considered a walk speed, as we made our measures inside a building.

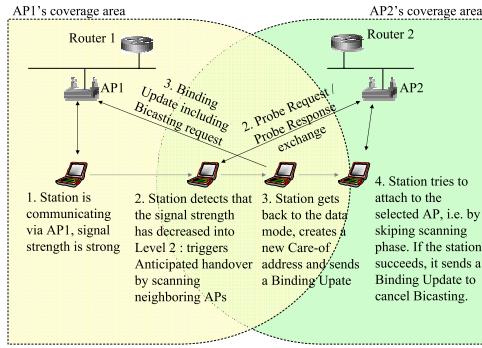


Fig. 2. Anticipated handover illustration

The second L2 trigger that we used is the IPv6 prefix added into L2 frames. We modified APs to make them include their IPv6 prefix into the Probe Response frames. This information will allow receiving stations to determine the new link's IPv6 prefix during the anticipated L2 discovery stage. This new information has two advantages: firstly it allows station to choose next AP according to the IPv6 identification. Secondly, as the IPv6 prefix is known before or at least during the L2 handover, no further delay is required to discover the new link after association with a new AP.

### B. Handover Anticipation Mechanism

In this subsection, we describe each stage of our mechanism, which is illustrated in figure 2 and in state diagram 3. We first assume a station connected to an AP in a visited network as illustrated in figure 2. We consider that the station already has a valid Care-of address registered with its home agent. Then, the station moves away from its AP, making the signal strength gradually decrease. At the moment where the signal strength is equal to the predefined threshold Level 2, the station triggers an anticipated handover: the station periodically scans each IEEE 802.11 channel in order to discover new APs. The station only probes one channel and then comes back to the data mode, connected to its current AP. This ensures a minimum loss of data packets, since a station can not receive data packets while scanning APs. As long as the signal strength with its current AP is situated in Level 2, the station periodically scans channels. During the scanning processes, the current AP buffers data packets intended to the station.

During this stage, the station discovers the identity of neighboring APs, but also parameters of each AP, including the IPv6 prefix used on the corresponding link (*scanned* state in diagram 3). These information are stored in a data base used by the station to select the target AP for the pending handover. Parameters that can be used to select

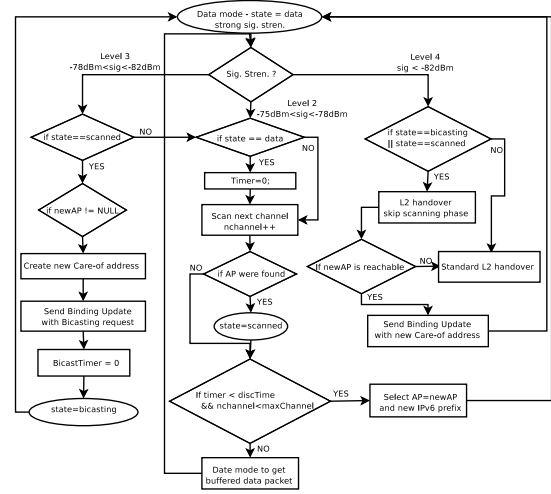


Fig. 3. States diagram of anticipated handover mechanism

APs may be the signal strength, the supported rates, the IPv6 prefix... If the IPv6 prefix of the next AP is the same as the station's current AP, L3 handover is not required.

When the station detects that the signal strength goes into Level 3, the station moves forward in the anticipated handover stages. After choosing the target AP from the discovery stage, the station determines if the target AP is connected to the same IPv6 link as its current AP. If yes, no further operation is required. Otherwise, the station will create a new Care-of address through the IPv6 stateless autoconfiguration mechanism [18]. Then, the station sends a Binding Update with a Bicasting bit set indicating that this new Care-of address must not change the Binding Cache of the home agent. From the reception of this Binding Update, the home agent will duplicate the traffic intended to the station to both current and future potential locations (*bicasting* state in diagram 3).

When the station disconnects from its current AP because the signal strength has become too poor for data communication (Level 4 in table I), it will try to associate with the selected AP. The scanning stage can thus be avoided and the station directly sends Authentication frames. If the AP responds, the L2 handover is very fast and the station will be associated to the new AP in less than  $5ms$  (see next section). As soon as the station will be associated with the new AP, data packets from home agent will be delivered to the station, without further delay (such as new link discovery or Binding Update/ Binding Acknowledgement exchange as required in MIPv6). The station will however have to send a Binding Update to its home agent to cancel the Bicasting, because all data packets are still sent to the old location of the station.

#### IV. LIMITATION OF OUR PROPOSITION

If anticipation is wrong, the lifetime of the Binding Update used to request Bicasting must be short to avoid packets forwarding while station is not changing APs. In our experiments, we set the lifetime of this Binding Update to 10s. If the station does not perform a handover (for example because it changes of direction), duplicated packets will only be sent during 10s. If a station has registered its Care-of address with a correspondent, we can not use the Bicasting process, unless the correspondent is modified and is able to manage Bicasting.

If the target AP is not available anymore at the moment of the handover, the Authentication Request will not be responded. If this is the case, the station must re-engage a scanning procedure in order to discover another AP. The station will then start a standard L2 handover. However, if the new AP supports our mechanism by including its IPv6 prefix into the Probe Response frames, the station would identify its new IPv6 link during the handover. Although the L2 handover will be the same as in standard IEEE 802.11 because of the wrong anticipation, the L3 handover will still be enhanced. Once the L2 handover is finished, the station creates and updates its new Care-of address without any further delay.

#### V. EVALUATION

We evaluated our proposition by simulation. We use *SimulX* [15], [16] which is a C++ simulator developed at Louis Pasteur University. *SimulX* is especially designed to simulate IEEE 802.11 networks and IPv6 mobility. It proposes a full implementation of IEEE 802.11 standard and MIPv6 mechanisms. We have upgraded the simulator with our protocol and values reported in table I in order to simulate movement anticipation. Simulation results of standard mechanisms are very close to those presented in [9], [10].

##### A. Evaluation 1: only one station

In the first evaluation, we set a testbed composed of three APs connected to three different IPv6 subnets and one station which is moving from one AP to another. A home agent (which can also be considered as a MAP if we assume that Hierarchical MIPv6 [17] is used) is located in another subnet, at a round trip time around 40ms. In figure 4, we compare the L2 and L3 handovers latencies when the station is using standard IEEE 802.11 and MIPv6 mechanisms, and our new solution. We distinguish two different scenarios for anticipated handovers: in the first case, the station connects to the selected AP (discovered during the anticipated scanning). In the second case, the target AP is not responding to the station

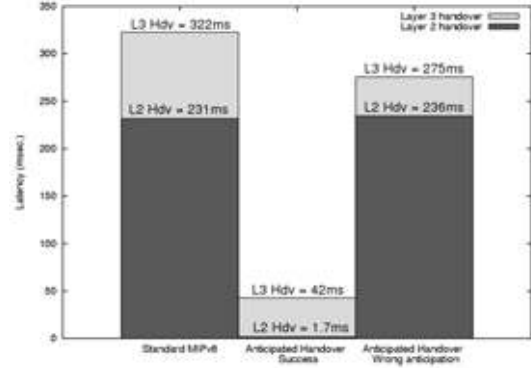


Fig. 4. Handover latency - one station

when the station starts the handover (the station changes its direction and finally goes to the third AP). In that case, the station must perform a standard IEEE 802.11 handover after determining the selected AP is not reachable. It has to be noted that we configured routers to send RAs between 30 et 70ms when MIPv6 is used and between 200 and 600s when our solution is used. We will see that our mechanism allows faster handover while avoiding to flood network with a high RA frequency.

With the anticipated handover, when the station succeeds to connect to the target AP, the L2 handover latency is quite fast, around 1.7ms. This corresponds to the exchange of Authentication and Association messages, as the neighboring APs discovery was done by anticipation. After the station is associated with the new AP, it is able to communicate through the new AP: since it has sent the Binding Update with its new Care-of address while still connected to the old AP, the home agent has already updated its Binding Cache. The L3 handover, that we measured at 42ms, is the time needed to change the old Care-of address and confirm the new Care-of address, but the station is already able to communicate as soon as the L2 handover is finished. However, these latencies do not show the time needed for the anticipated scanning stage, which is done before the handover. We may remind that the discovery stage is critical since the station can not exchange data packets. The impact of this stage is shown later, in figure 8.

The last case (on the right side in figure 4) represents an error case, where the selected AP found during the anticipated discovery is not available during the L2 handover. Therefore, the L2 handover is a little bit longer than in standard 802.11 process, since the station is first trying to associate to the selected AP. After it detects that the target AP is not reachable, the station engages a standard L2 handover, with first a scanning stage. The total L2 handover takes 236ms against 231ms in standard 802.11.

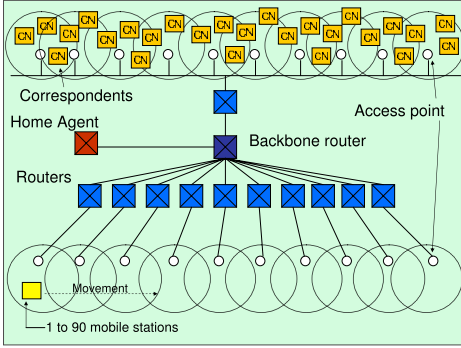


Fig. 5. Simulation testbed for the second evaluation

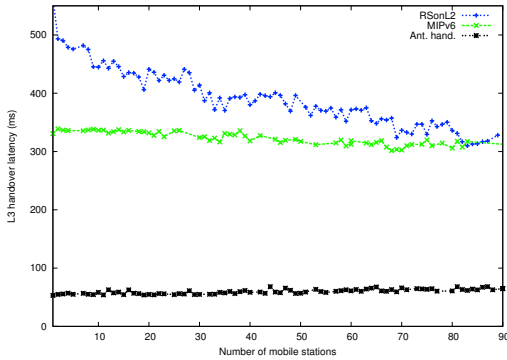


Fig. 6. L3 Handover latency scalability tests

After the L2 handover is complete, our mechanism allows to still enhance L3 handover: as the IPv6 prefix is contained into the L2 frames (Probe Response), the station discovers the new link while performing the L2 handover. Therefore, as soon as the L2 handover is over, the station sends a Binding Update with its new Care-of address. In standard MIPv6, the station needs to discover the new link first. The L3 handover latency when the anticipation was wrong is  $275ms$  against  $322ms$  in MIPv6.

### B. Evaluation 2: several stations

Now we have seen that our solution has good performance results in a basic scenario, we evaluate the scalability of our proposal. These scalability tests consist of measuring L2 and L3 handovers for up to 90 mobile stations (see figure 5). Stations start their movement at a random time in the same second and move through 10 APs. We will also consider scenarios where stations are receiving traffic from correspondents. We use the G711 codec [6] which corresponds to a voice over IP application (packets of 500 bytes in length at a rate of 50 packets per second). We also wanted to extend the comparison of our solution with others, that is why we have enhanced

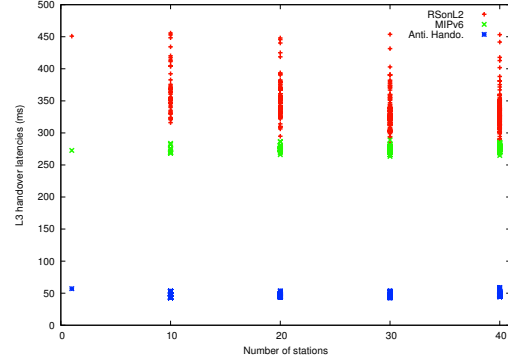


Fig. 7. L3 handover latency when stations are receiving traffic

features of the simulator to simulate L2 trigger-assisted handover presented in section II-C. This third solution (namely *RSONL2* in the following) aims to reduce the L3 handover latency by reducing the time needed to discover the new link: the station sends a Router Solicitation upon detection of the end of L2 handover. Moreover we also measure the L3 handover latency with a fourth solution, where standard MIPv6 is used without modifying the RA frequency. These results (called *RFC2461*) will show the influence of the movement detection in L3 handover. As in the previous scenario, only MIPv6 needs a high RA frequency (between  $30$  and  $70ms$ ) to produce good results. The standard RA frequency is used in the other solutions.

Figures 6 and 7 show L3 handover latency for MIPv6, RSONL2 and our mechanism. RFC2461 is not represented in these figures because the latency is around  $250s$  (against less than  $500ms$  for other solutions). This high handover latency is due to the fact that stations do not detect IPv6 movements because the RA frequency is low and they do not use any mechanism to detect a new link (such as L2 trigger). Figure 6 represents a scenario where 1 to 90 stations, which are not communicating, are simultaneously moving. MIPv6 and Anticipated handover solutions are quite constant and produce same latencies as in the basic scenario (figure 4). With RSONL2, the average of L3 handover latency tends to reduce as the number of simultaneous stations grows. It is because the RA requested by a station may arrive at a newly connected station which has not yet requested one. Therefore, the L3 handover latency of this second station is reduced because it receives the RA without requesting it. Figure 7 represents the average of L3 handover latency for each of 1 to 40 communicating stations. The same remarks apply in this case: MIPv6 and Anticipated handover solutions scale well and the more there are stations, the shorter the L3 handover latency is with RSONL2. It can be reminded that in the

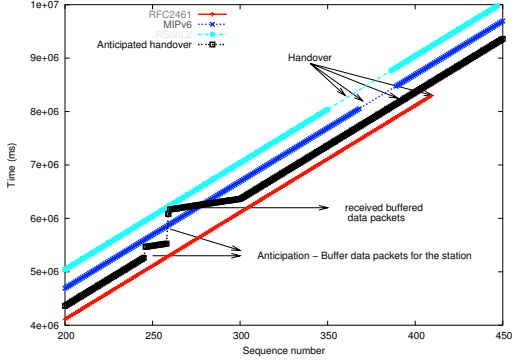


Fig. 8. Impact on flows

case of Anticipated handover, the L3 handover latency is given as a indication and is not the time for stations to receive data packets at the new location (since Bicastig is usually used).

Figure 8 shows the impact of L2 and L3 handovers on data flow received on stations. Each point of the figure represents the reception of a data packet. We can see in figure 8 that the number of lost packets when stations are using RSonL2 (top curve) or MIPv6 (second curve from the top) are quite similar with 36 and 29 lost packets respectively. The bottom curve represents standard MIPv6 however without modifying the RA frequency (kept between 200 and 600s as recommended in [12]). As we can see, once the station is disconnected from its current AP, it does not detect the new IPv6 link and all subsequent packets are lost (stations will discover they are connected to a new IPv6 link after 250s in average).

The second curve from the bottom represents the data packets reception on a station using anticipated handover. We can see perturbed reception at the time 5 and 6s. This is due to the anticipated scanning stage, because station is detecting that it is going to change AP. During these scanning stages, AP buffers packets for the station and sends them when the station is back to the connected mode. A Binding Update requesting Bicastig to the potential location is sent around the seventh second. Thereafter the station is performing L2 and L3 handover at the time 8.3s. As we can see, this is totally transparent in the data packets reception because the L2 handover is very fast (see previous section) and once the L2 handover is finished, the station starts to receive data packets thanks to the Bicastig.

Figures 9 and 10 represent the number of generated packets and the number of lost packets when 1 to 40 stations are simultaneously moving through 10 APs. Figure 9 represents both the total number of generated packets per simulation when stations are not communicating

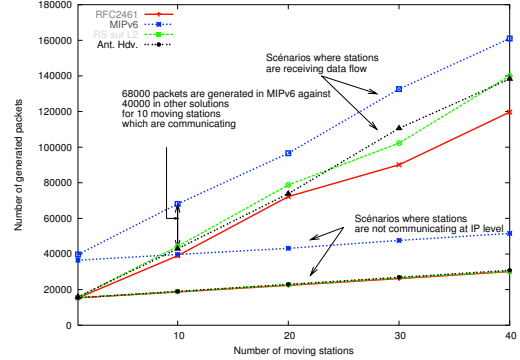


Fig. 9. Number of generated packets

at IP level (four bottom curves) and when stations are receiving data flow (four higher curves). This figure clearly shows the impact of the RA frequency: by reducing the frequency of RAs in MIPv6, the number of generated packets is very high, while other methods such as anticipated handover or RSonL2 allows to have better or at least equal (in the case of RSonL2) performance of L3 handovers.

Figure 10 shows the fraction of lost packets (data packets as well as control packets) per simulation. As we already said, if we use MIPv6 without modifying the RA frequency, the IPv6 mobility management is incomplete: we observe 40% of lost packets. Standard MIPv6 and RSonL2 are quite the same around 5% of lost packets. This corresponds to the loss of data packets during the 10 handovers. In our solution, when less than 20 stations are simultaneously moving, we do not observe any loss of packets, because of the anticipation of the handover, and the Bicastig. From 20 to 40 stations, the number of lost packets is increasing up to 13%. From the log files of simulations, we have seen that the lost packets are control frames sent during the scanning stage and not data packets. As many stations are simultaneously moving, they are approximately scanning at the same time. And the scanning process require stations to send Probe Request at a high frequency, that is why many collisions occur. As no data packets are lost, these collisions have not negative impact on the anticipation of movement.

## VI. CONCLUSION

IEEE 802.11 and MIPv6 handovers were investigated in this article. Although standard mechanisms allow to manage IPv6 host mobility between IEEE 802.11 networks, anticipation of movement consequently reduces the handover latency. IEEE 802.11 handover requires channels scanning, which constitutes the major part of the L2



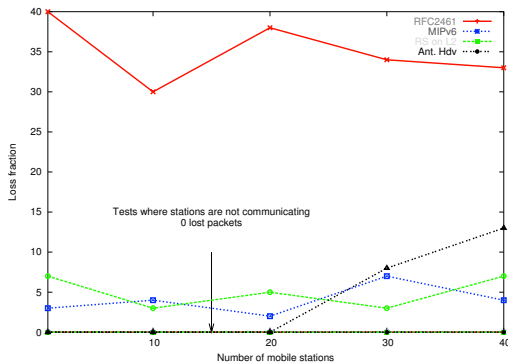


Fig. 10. Percentage of lost packets

handover. During this stage, station is not able to exchange data packets. MIPv6 suffers from its movement detection process, which is based on RAs frequency.

In order to allow real time applications on moving stations, we have proposed a method to anticipate MIPv6 handovers in IEEE 802.11 environments. Our solution is based on L2 triggers: station monitors the signal strength with its AP and triggers anticipated scanning process when the signal strength goes under a certain threshold. The anticipated scanning process is separated into several probes, in order to allow station to get back to the connected mode to receive data packets. After selecting the target AP, station is aware of the IPv6 prefix used on the target link, as we also introduce IPv6 prefix into Probe Responses. Therefore, station can create a new Care-of address and sends Binding Update while still connected to the old AP. The Binding Update is used to request Bicasting of data packets to both the old and future potential locations. When the station loses its connection to its current AP, it can avoid the scanning phase and immediately authenticates and associates itself with the new AP. As soon as the L2 handover is finished, station is receiving data packets on the new location thanks to the Bicasting.

We have evaluated performance of our proposal by simulation in several scenarios. The anticipated handover presents good performance results, with a L2 handover around  $1.7ms$  and 0 packets lost during the whole handover (L2 and L3). In the case where the anticipation is wrong, our solution is still better than standard MIPv6 because stations discover the new IPv6 prefix during the L2 handover. Next steps of this work is the implementation of this method and the extension of our protocol to fit IEEE 802.11i mechanisms.

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