Soft Handovers over 802.11b with Multiple Interfaces

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***Abstract*—This paper describes an optimization of the handover process over WLAN networks, which allows nodes to simultaneously attach to more than one access point and thus avoid packet loss. The document also contains a description of protocol semantics specific to that optimization, a theoretical evaluation and performance results acquired by simulation.**

Keywords-component; WLAN; mobility; 802.11b; soft handover; IPv6; make before break

I. Introduction

Rapid development of wireless networks and the increasing popularity of real-time applications like VoIP Telephony and streaming media require network technologies to offer new functionalities such as seamless mobility.

Mobile IPv6[1] allows generic internet host mobility and roaming while maintaining connectivity between hosts. Yet, during the time between the moment where a Mobile Node (MN) moves from one network to another and the moment where location information is updated, packet loss occurs and communication quality becomes unacceptable [15], [16]. It is therefore critical to reduce or mask this interval.

In this document we describe some state of the art techniques currently employed for improving node mobility. We also propose an optimization that allows for Soft Handovers over Wireless LAN.

The rest of the document is organized as follows. Section II gives the basics of Wireless LAN and Mobile IPv6 [1] as well as some of the most popular methods to optimize their behavior during handover. Section III describes the solution itself, followed by an analytical evaluation in section IV. Section V show the results that we have obtained in our simulations. Section VII summarizes and concludes this article.

II. State of the Art

A. WLAN Basics

The IEEE 802.11 standard defines two major network topologies and modes of operation for wireless devices:

1) Infrastructure: Wireless devices are connected to a central entity called an Access Point (AP). Nodes communicate only with their corresponding AP and do not exchange messages directly.

2) Ad hoc: In this mode there is no central entity and nodes exchange messages directly.

During the rest of the document we will be concentrating on the infrastructure mode.

When a WLAN device needs to connect (associate) to an access point (either after power up, sleep mode, or simply upon entering an area covered by a new AP), it would fist need to discover nearby APs, then select one and attach to it.

To find out what APs are available in the region a node may either passively listen for Beacon Frames broadcasted by access points (passive scanning) or send Probe Request frames and wait for incoming Probe Response-s from APs.

Once the wireless device has determined which AP best responds to its selection criteria, it will go through the Authentication Process, which is the exchange of information between the AP and the station, where each side proves the knowledge of a shared secret.

When the station is authenticated, it will start the Association Process, which is the exchange of information about the stations and AP capabilities. Only after the association process is completed, a station is capable of transmitting and receiving data frames. This whole process is shown on Figure 1.

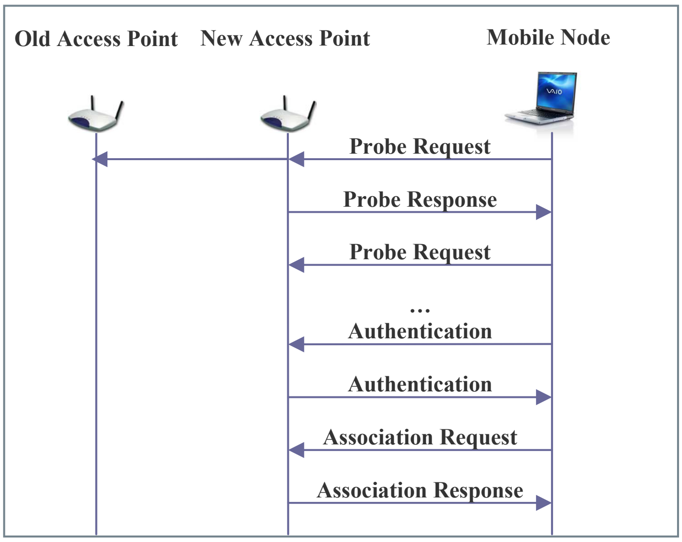

Figure 1. The WLAN Association Process (Active Scanning)

B. *Mobile IPv6*

Mobile IPv6 or MIPv6 [1] allows devices to remain reachable and maintain ongoing connections (both TCP and UDP) while moving within the Internet topology. For reachability a Mobile Node (MN) is provided with a permanent IP address, called Home Address. To maintain ongoing connections while moving, Mobile IPv6 uses a network layer entity called a Home Agent (HA).

While "at home" (i.e. in the same subnet as its HA), an MN behaves as a standardIPv6 node. It receives packets addressed to any of its home addresses and delivered via normal routing.

When a mobile node moves from its home to a foreign link, it first forms a *Care-of Address* based on the prefix of the foreign link using Stateless Address Autoconfiguration [6]. Next the mobile node informs its home agent of its movement by sending a *Binding Update* (BU) message. The BU contains the MN's home address and its care-of address. At that point the HA creates a tunnel to the MN's new location, replies with a Binding Acknowledgment message (BA) and starts redirecting packets bound for the MN's home address over that tunnel.

MIPv6 operation is shown on Figure 2.

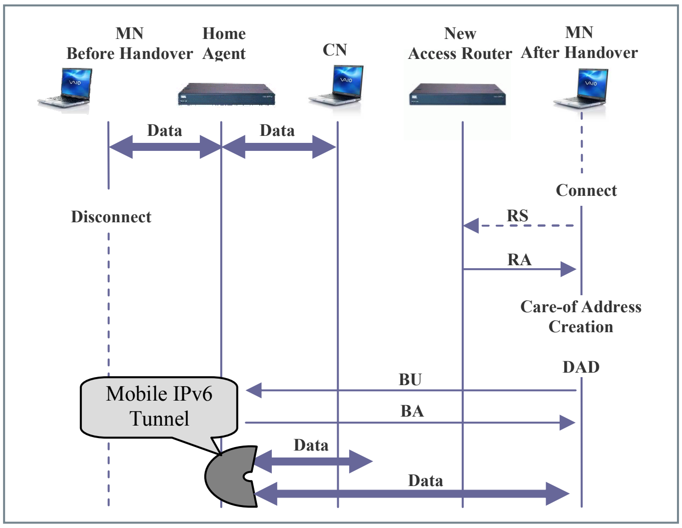

Figure 2. Mobile IPv6 Operation and data forwarding

C. *Handover Latency and Existing Optimizations*

When an MN moves to a new IP subnet it goes through the following two stages:

1) Link Layer Handoff: This is the stage where the MN associates to a new AP (The process described in Section II.A above)

2) Network Layer Handoff: The Network Layer Handoff comprises the following substages:

a) Movement Detection: This is the point where an MN's IP protocol implementation would determine whether or not the node has changed subnets.

b) Address configuration: This includes either stateful or, more often, stateless address autoconfiguration and DAD.

c) MIPv6 Location Update: This is the phase where mobility signaling procedures take place, with the MN sending a BU to its Home Agent.

During all of the above stages the MN is unable to communicate. This loss of connection has been the subject of many recent works that suggest various optimizations of all or some parts of the handover process. Solutions like RA Caching by APs [2], Fast RA [3] or dense RA emission [1] for example describe ways of accelerating movement detection, whereas others like FMIPv6 [4] and HMIPv6 [5] focus on the address configuration and location update phases.

In this document we choose a slightly different approach, also known as the "Make before Break" technique. We are not trying to bring handover time to a minimum but rather eliminate the connection loss. The following section explains this approach in more detail.

III. Solution Description

A major issue with 802.11b mobility is the fact that WLAN devices are not able to associate with more than one AP at a given moment. Most existing handover optimizations are therefore based on the assumption that the handover process is inherently accompanied by connection loss. In other words it is always considered that at a given moment a MN is bound to lose its network connectivity and would therefore become unreachable.

Soft Handover is the process where a MN will first connect at its new point of network attachment and will only then drop its previous link. In order to achieve this in an 802.11b environment we give MNs a second wireless interface. Furthermore, in order to eliminate power consumptions concerns, we try to avoid having both network interfaces functioning together for more than a couple of seconds (i.e. only during the handover process).

Compared to other mobility optimizations, the multi interfaces solution has the advantage of keeping to a minimum changes to existing protocols such as MobileIPv6 and 802.11b and does not require changes in existing standard Mobile IPv6 network topologies (i.e. it does not define any new network entities).

During the rest of the document we will be using the following terminology and abbreviations:

Double Interface Mobile Node (DIMoN) - A mobile node equipped with two (802.11b) network interfaces.

Access Router (AR) - A DIMoN's default router

Previous Access Router (PAR) - The DIMoN's default router prior to and during its handover

New Access Router (NAR) - The DIMoN's default router during and subsequent to its handover

Bicasting - The splitting of a stream of packets destined for a MN into two or more streams, and the simultaneous transmission of the streams to PAR and one or more NARs. We use this technique to reduce packet loss during handover.

While not on the move, or rather during its stay in a single BSS a DIMoN would behave as a standard mobile node. All application traffic would go through the currently default network interface. During that period the node's second interface may be in a power save mode or completely turned off.

When a DIMoN starts moving the signal that the AP casts upon it would gradually fade away. When signal intensity goes below a certain threshold the DIMoN will "wake" its second interface and begin with it the 802.11b synchronization procedure. The procedure is slightly different in that the selection of an Access Point after the scan has been completed would ignore the AP the Old Network Interface is currently attached to. If no other AP has been found during the scanning process the New Network Interface is shut down and the DIMoN would behave as a standard MN.

Once synchronized with the newly found AP the DIMoN will form its New Care-of Address based on the prefix of the foreign link. In case of using stateless address autoconfiguration [6] it is highly advisable for the DIMoN to use at least one of the movement detection optimizations described in section II.B above since the time that network connectivity would be available through the Old Network Interface is likely to be relatively short.

Next the DIMoN would be supposed to perform Duplicate Address Detection (DAD)[7]. However, given the time that DAD normally takes to complete, it might be a better option to either skip that part or run it in a non-blocking fashion.

It is important to notice that up to this point the Old Network Interface has remained operational and network connectivity has been uninterrupted.

Following address configuration, the DIMoN informs its home agent of its movement by sending a Binding Update (BU) message. The binding update message contains the mobile node's home address and its New and Previous care-of addresses. The home address is included in the home address option, the Previous Care-of Address is included in the source address field of the IP header and the New Care-of Address is recorded in an alternate-care-of address option. The bicasting flag of this message should be set to 1 as specified by [8].

From this point on, the home agent acts as a bicasting proxy for the DIMoN. It receives all packets addressed to the mobile node, and after duplicating them, sends a copy to both of the node's care-of addresses. The HA will then send a Binding Acknowledgement to the mobile node.

Data packets received by the HA from either of the DIMoN's care-of addresses are handled as in standard Mobile IPv6 – the HA decapsulates the packet and forwards the contents to its destination.

During this part of the soft handover process (the time when the HA is doing the bicasting), some packets would be seen twice by the DIMoN's upper layers. This should not add any complications since packet duplication is expected to happen according to [9].

Once the BA has been received by the DIMoN it is up to it to determine when to stop the bicasting. It could do so right after receiving the acknowledgement or when signal intensity from one of the interfaces has gone above a certain threshold and may therefore be considered as reliable. At that stage the node will send a second BU without including the alternate address option so that the HA would stop duplicating packets. The node would then turn off its other interface and the soft handover procedure is considered terminated.

Figure 3. illustrates the DIMoN behavior we just explained.

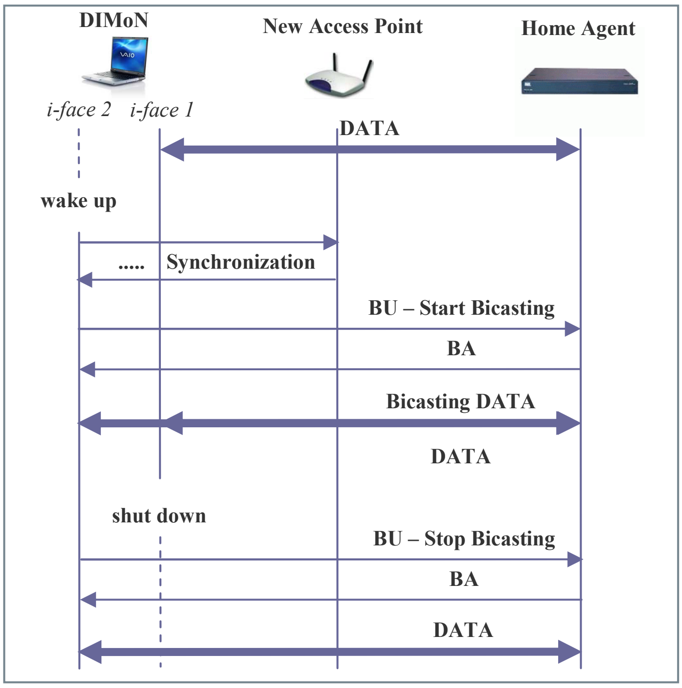

Figure 3. Standard DIMoN behavior.

Compared to other mobility optimizations such as FMIPv6 [4] and HMIPv6 [5] for example, the soft handover solution has the advantage of being extremely simple. It does not introduce any new entities in a network topology and completely reuses existing MIPv6 message semantics, header syntax and options. Furthermore it does not add enormous amounts of extra signalling traffic as in the case of MIPv6. The primary advantage of the soft-handover is that there is no actual disruption and no physical connection loss.

A major concern, often associated with multi interface nodes is elevated power consumption. We try to resolve that by only using both network interfaces for a very short interval – the time of the handover. In the following section we show that a worst case scenario would require both interfaces to stay simultaneously lit up for a period of approximately 2s.

According to [10] a wireless device that discharges for 202 minutes without using a network interface, would lose approximately 67 minutes of battery lifetime when constantly transmitting at a maximum rate through its wireless interface. This means that using the wireless interface during one minute would "cost" around 30 seconds of battery lifetime, or in other words, having our second wireless interface lit up during 2 seconds, would shorten discharge time with approximately 1 second. Needless to say this could hardly be a cause for concern.

IV. Analysis and Evaluation

When an active DIMoN moves to a new IP subnet, it changes its point of attachment to the network through the following soft handover process. First Link-layer handoff occurs to (maybe) change the wireless AP to which the DIMoN is associated. According to [11] the time needed for a node to attach to an AP is between 160 and 260 ms. This gives us:

$$T(L2) \approx 200 \text{ ms.} \quad (1)$$

Where T(L2) is the time needed for Link-layer handover mechanisms to complete.

After a new Link-layer connection is established, Network-layer handover is performed, which broadly involves movement detection, IP address configuration and location update. The time this stage takes may vary depending on the movement detection scheme employed by the DIMoN. In the case of a New Access Router configured in accordance with [1], it would take about 50ms (i.e., (MinRtrAdvInterval + MaxRtrAdvInterval)/2) until a RA is received by the node.

$$T(\text{MIPv6MoveDetect}) \approx 50\text{ms} \quad (2)$$

If using a Link Layer Triggered RS against a standard RFC2461 [7] router the node would get a RA in about 250ms (the RFC mandates a random delay between 0 and 500 ms when sending RAs in response to a RS). We will label this time as T(LLTriggerMoveDetect).

$$T(\text{LLTriggerMoveDetect}) \approx 250\text{ms} \quad (3)$$

Once the DIMoN discovers its New AR, it performs DAD. RFC2461 [7] default values stipulate a random delay between 0 and 1000ms before sending an initial NS and an extra delay of 1000ms before confirming address uniqueness. This would add another 1500 ms to the network layer handover.

$$T(\text{DAD}) \approx 1500 \text{ ms.} \quad (4)$$

Mobility signalling procedures are then started, with the DIMoN sending its first BU to the HA. The time needed for the first data packet to arrive after the BU leaves the mobile node may strongly vary depending on nodes' location. According to our experiments this interval comes close to 60 ms:

$$T(\text{TrafficRedirection}) \approx 60 \text{ ms} \quad (5)$$

Keeping all the above in mind, our best case scenario would be one where no DAD is performed (or it is run in a non blocking manner) and the New Access Router is configured to send RAs at the interval defined in [1] or it implements the FastRA [3].

$$T(\text{BestCase}) = T(L2) + T(\text{MIPv6MoveDetect}) + T(\text{TrafficRedirection}) \approx 310 \text{ ms} \quad (6)$$

The slowest possible setup, where no movement detection optimizations are implemented by the New Access Router and where DAD is completed before using the auto-configured address:

$$T(\text{WorstCase}) = T(L2) + T(\text{LLTriggerMoveDetect}) + T(\text{DAD}) + T(\text{TrafficRedirection}) \approx 2010\text{ms.}$$

Finally, a scenario that we find most realistic is where the DIMoN uses a link-up trigger for sending an RS and where DAD is run in parallel of network communication (or not at all). What makes this case interesting is that no special features are required from the network setup.

$$T(\text{Optimal}) = T(L2) + T(\text{LLTriggerMoveDetect}) + T(\text{TrafficRedirection}) \approx 510 \text{ ms.} \quad (7)$$

According to [12] the average speed of a walking adult person varies between 125cm/s and 150cm/s. The 510 ms from our third (optimal) case would thus require a minimal overlap interval length between 63.9cm and 76.9cm where network access will be available through both access points. For indoor areas this is close to 2% of a typical Access Point's range [13].

V. Simulation Results

To be able to completely evaluate and experiment with Soft Handovers we have used the SimulX network simulator. SimulX (Figure 4.) was designed and developed by the Network Research Team at the Louis Pasteur University – Strasbourg.

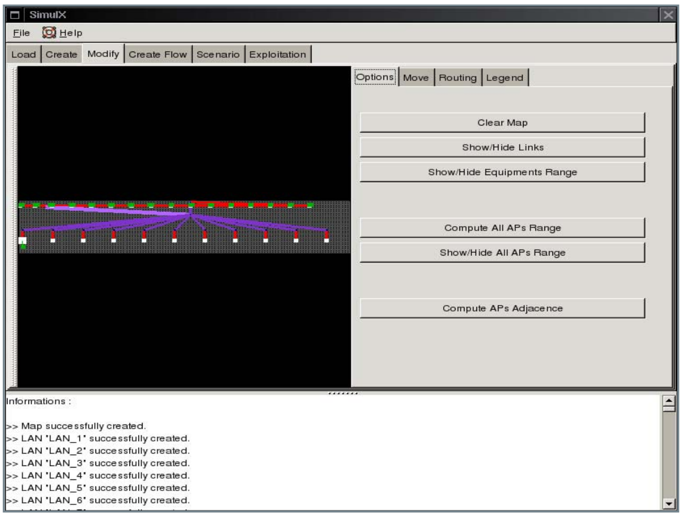

Figure 4. The SimulX Wireless LAN simulator.

At the time when we were working on the Soft Handover mobility optimization, the SimulX simulator did not support nodes with multiple network interfaces. We have therefore implemented the feature as well as the interface selection policies and the necessary behavior to be able to completely explore its potential.

In this section we present the results of a series of simulations run over the network topology and scenario presented on Figure 5.

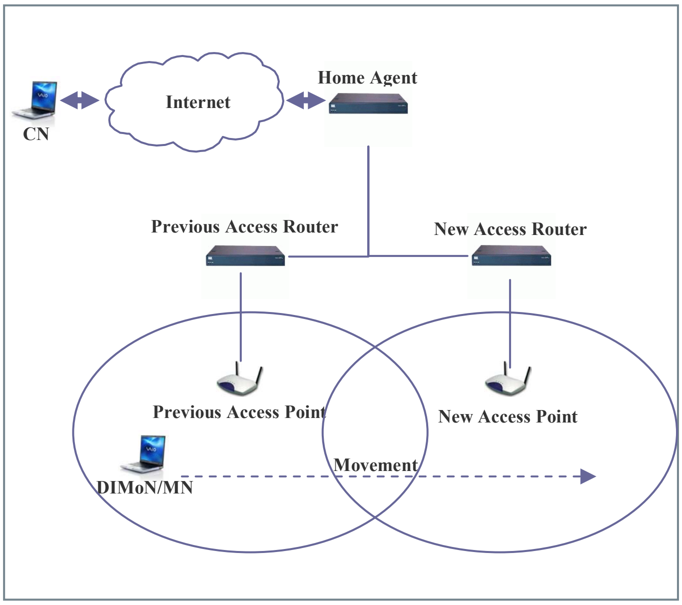

Figure 5. Scenario used in DIMoN evaluation tests.

Typically, handover duration is a key characteristic of Mobile IPv6 optimizations since it suggests loss of network connectivity. When performing a Soft Handover a mobile node remains constantly connected to at least one network. Yet it is still advised to keep the process short to lower the risk of leaving the area covered by the AP before actually completing the handover (not to mention risks reasons like elevated consumption of resources, such as processor time, power consumption and network load).Therefore we have also added to the DIMoN the capability to receive and handle Link Layer Triggers by sending a Router Solicitation.

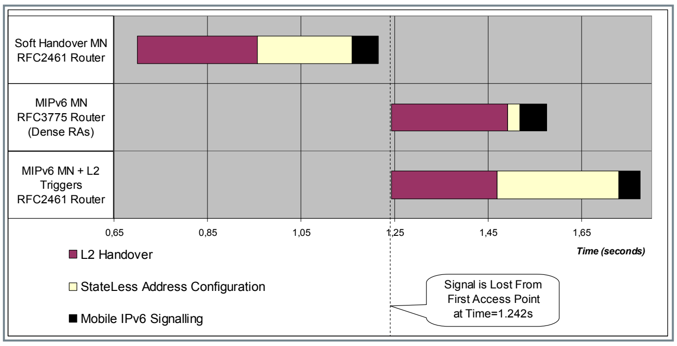

Figure 6. Duration of the handover process.

Figure 6. shows the following scenario: A mobile node would start moving at time 0 as shown on Figure 5. Exactly 1.242 seconds later it would lose the signal from its AP (i.e. signal intensity would drop below -82dbm). At that point signal from a second AP has already been available for some time. The same scenario is run for three mobile nodes, each handling mobility in a different manner.

- Node 1: implements Soft Handover and is located on a link with an RFC2461 compliant router. It is represented by the topmost bar on Figure 6.

- Node 2: implements standard MIPv6 and is on a link with an RFC3775 (MIPv6) compliant router (i.e. RAs are sent every 50 ms). The node is represented by the middle bar on Figure 6.

- Node 3: implements MIPv6 mobility + the ability to send RS messages upon reception of Link Layer notifications, and it is on a link with an RFC2461 compliant router. The node is represented by the bottom bar on Figure 6.

As we can see from the figure, Node 2 (MIPv6 MN on a MIPv6 router's link) has managed to perform the fastest handover of all three nodes. Yet it was in a disconnected state for a period of about 330 ms.

The handover for Node 1 and Node 3 (Figure 6.) dured approximately the same time (Node1: 532ms and Node3: 515ms). Node 1, however started handover 694 ms after beginning its movement and at the time when the signal from the first AP faded away, it was already associated with the next one.

Next we analyze packet loss during handover. Figure 7. represents the same three nodes and the number of data packets that were emitted for each node and did not get to their destination due to connection loss. All three nodes are in the middle of a media session using a G.711 [14] stream.

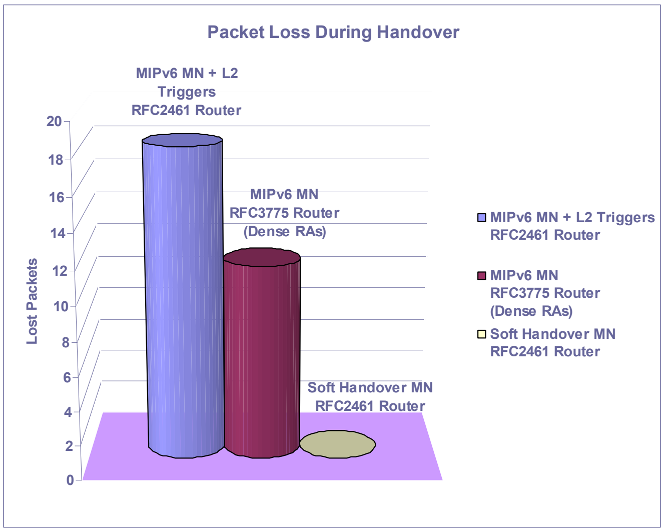

Figure 7. Packet loss duting handover.

Given the short handover duration for (the middle) Node2, packets that got lost on their way to it are fewer than in the case of (the leftmost) Node1. As expected, the (rightmost) DIMoN, going through a soft handover has not lost any data regardless of the relatively longer period needed to complete the transition.

Flow bicasting, inherent to Soft Handover algorithms, is often pointed out as increasing network load and therefore pointed out as a major disadvantage. Figure 8. shows the amount of extra network traffic caused by signaling or bicasting for the same three mobile nodes. Each column on Figure 8. shows the number of extra packets during the handover and an enclosing second. As we can see the rapidity of the (middle) Node2 comes at a cost. RAs broadcasted to aid movement detection generate excessive signaling traffic. Duplicating the data flow, quite on the contrary, turns out to be a more economical solution since it goes on during a relatively short interval.

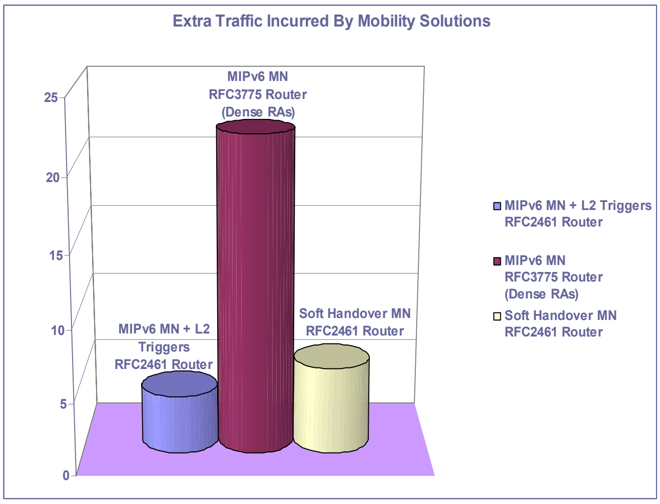

Figure 8. Extra traffic incurred by the different hadover soludions.

VI. NECESSARY FURTHER ANALYSIS

Though simple to implement, instantly switching to a new Access Point upon signal intensity drop, is not always the best strategy. It is necessary to explore further constraints. For example, prior to requesting ceasing of bicasting, a node should make sure that at least one of the two APs has signal intensity higher than a certain threshold. This may turn out to be crucial for certain network topologies and non-linear node movement. Another example constraint would be Access Point load. It would also be of interest to define a means for the Access Point or other network equipments to initiate handover as a way of implementing a load sharing policy.

Combining Soft Handover with existing MIPv6 extensions such as FMIPv6 and HMIPv6 (described in section 3 of this document) is another promising field of research as it would allow for better centralized network control.

VII. CONCLUSION

This article proposes an optimization of the handover process over WLAN, employing a model from cellular network architectures (soft handover) with the aid of an extra Wireless LAN interface. After an analytical evaluation and some simulation based performance testing it proved to be a quite successful as it succeeds to virtually eliminate packet loss during handover in our simulation scenarios. Yet further work would have to prove the optimization merits by experimenting in real world conditions with an actual implementation. Existing mobility optimizations would probably be needed to widen applicability of the solution.

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