Abstract—When a number of mobile networks, e.g. networks on vehicles, travel together, they can be interconnected in a dynamic mesh structure, here called Ad hoc Interconnected Mobile Network or AIMNET. The mesh topology interconnecting the mobile networks not only facilitates communication among the networks themselves, but more importantly allows sharing of Internet access available to individual mobile networks. AIMNET is expected to move in a heterogeneous wireless access environment where ubiquitous Internet access demands handovers. In this paper, we examine delays experienced at various levels of AIMNET in different types of handovers and identify main contributors of these delays. Based on this examination, we discuss methods to reduce handover delays. We also present simulation based evaluation of handovers in AIMNET employing these methods. The results of these simple simulations demonstrate the acceptable performance of AIMNET under proposed methods.

Index Terms—Network Mobility, Ad hoc Networks, Vehicular Networks, Handover, Delay Estimates.

I. INTRODUCTION

The use of small mobile computing devices to access Internet is becoming common. For users moving together, it seems natural to group their devices into a network and provide internet connectivity to that network rather than individually to all devices. Cars, trains, ships and aeroplanes can easily be equipped with such mobile networks. A mobile router is used to connect to access network(s) and provide Internet connectivity to the devices forming the mobile network.

In a heterogeneous wireless access environment it is reasonable to assume that not all access technologies are available everywhere and that a mobile router is compatible with only selected access technologies. Therefore a single mobile network is unlikely to maintain ubiquitous Internet connectivity on its own. However, in a scenario where a number of mobile networks are moving together, Internet connectivity of one mobile network can be shared with other mobile networks if all the mobile networks interconnect to form a larger network. Since this cooperative network is not permanent but formed in ad hoc manner, we call it ‘Ad hoc Interconnected Mobile Network’ or AIMNET. The AIMNET can be used for a wide range of applications, e.g. in disaster recovery where emergency vehicles and personnel communicate amongst themselves and with the emergency response control centre, in a battlefield where military vehicles and personnel moving together communicate with each other as well as with other components of the Command and Control hierarchy, or on roads where multiple vehicles interconnect to take advantage of the heterogeneous wireless Internet access.

To maintain ubiquitous Internet connectivity, the mobile networks in AIMNET connect to different access networks at different times. This results in a mobile network changing its point of attachment to the Internet along the course of its mobility, known as handover.

When a mobile entity executes handover, its communication may get disturbed or even break off. The effects of handovers have been studied from different perspectives in the literature. These studies are mostly concerned with discrete mobile hosts, and to some degree discrete mobile networks as well. However, here we are concerned with our Ad hoc Interconnected Mobile Networks architecture in which communicating hosts reside in mobile networks and the mobile networks are not completely independent from each other. Thus the communication requirements and mobility characteristics of AIMNET are different from discrete mobile hosts or networks.

In this paper, we examine the handovers experienced by AIMNET. The main contribution of this paper is the original analysis of handover delays experienced at various levels of AIMNET moving in homogeneous and heterogeneous networks (sec. IV & V). We use this analysis to identify main contributors of these delays and propose methods to reduce them (sec. VI). In the end, we present simple simulation

![Fig. 1: Ad hoc Interconnected Mobile Networks](image-url)
results on AIMNET performance with these methods (sec. VII). Before examining handover delays, we also present the baseline AIMNET architecture (sec. II) and an overview of mobility and handover management in AIMNET (sec. III).

II. BASELINE AIMNET ARCHITECTURE

The Ad-Hoc Interconnected Mobile Network (AIMNET) is formed when mobile routers (each servicing its own mobile network) interconnect to facilitate sharing of internet access available to one or more of them. A mobile network is a network segment that is able to change its point of attachment to the Internet. A mobile network can only be accessed via one or more ‘mobile routers’ (MRs) that act as gateway for the mobile network. The devices that belong to the mobile network or obtain connectivity through the MR are called mobile network nodes (MNNs). With Mobile IPv6, any node that moves into a foreign network can continue its communication by configuring a care-of address (CoA) and registering this address with its home agent (HA).

In AIMNET, the MRs without direct Internet connectivity have to rely on border routers (BR). Border routers are mobile routers connected to Internet. Any mobile router that establishes a direct connection with an access router (AR) becomes a border router and announces this status in the AIMNET. When a border router loses its external connection, it ceases to be a border router and becomes a simple MR.

The mobile routers in AIMNET face two kinds of mobility, mobility of all mobile routers as a group and mobility of mobile routers within the AIMNET. The first type of mobility causes changes in location of the entire AIMNET with respect to the Internet topology and results in changes of the global IP address of the AIMNET. The second type of mobility results in changes in the AIMNET’s internal topology. Thus the internal topology of AIMNET is volatile, however the internal topology of each mobile network remains relatively stable.

III. OVERVIEW OF MOBILITY AND HANDOVER MANAGEMENT

Mobility management refers to mechanisms that ensure minimal disruption to node’s communication due to its mobility. One goal of mobility management is to ensure that a node is reachable regardless of its current location. The other is to provide seamless mobility i.e. movement from one network to another without unacceptable data loss and disconnection periods. These goals lead to two aspects of mobility management, namely location management and handover management. Location management enables a mobile entity to be located and reachable along the course of its movement. Handover management enables a mobile entity to maintain its connection to the Internet when it moves from one point of attachment to another.

For a mobile entity, a handover is a multi-step process where steps are neither completely sequential nor completely parallel. A handover involves movement detection at link layer (L2) i.e. detection of a loss of connection to a point of attachment (PoA), followed by search for a new PoA and then connection establishment with the new PoA. A handover also involves movement detection at network layer (L3) e.g. via detecting a loss of connection to a router, followed by search for a new access router and finally an attachment to a new access router. The L3 attachment phase includes duplicate address detection (DAD) for IP addresses and sending binding updates.

IV. AIMNET HANDOVER IN HOMOGENEOUS NETWORKS

A mobile node detects movement at layer 3 when it determines that its default router is no longer reachable, using Neighbor Unreachability Detection [1]. However, this detection is only possible when the mobile node has packets to send. If there are no packets to send then movement can only be detected by the mobile node when it does not receive any router advertisements for a period of time. Once it detects that it has moved, a node performs DAD for its new link local address, solicits advertisements (to avoid delay of waiting for a periodic advertisement from a potential access router) and selects an access router. Finally, in the attachment phase, the mobile node generates a CoA based on the information obtained from the selected router, performs DAD for the CoA and updates home agent and correspondent nodes of its new location.

The above mentioned details of a layer 3 handover are typical of a mobile node that directly connects to the access routers. In case of AIMNET, this node is a Border Router (BR). However, in AIMNET the primary users of BR-AR link reside in the mobile networks forming the AIMNET. Even though these mobile network nodes (MNN) have no direct layer 2 or layer 3 connection with the access routers, a network layer handover at BR may also result in a network layer handover at these MNNs. Since MNNs are not directly
connected to access routers, they need to have separate mechanisms operating in movement detection, search and attachment phases.

A MNN receives router advertisements from its mobile router periodically and also in reaction to a change. A mobile router informs its MNNs about the unavailability of an access router by setting the lifetime of the care-of prefix provided by that access router as zero in its router advertisement (RA) messages. This means that the MNNs can no longer use that care-of prefix for their CoA, implying that they have moved away from that access router. Following movement detection, MNN cannot actively search for a new access network because it is a part of a mobile network, incapable of directly connecting with external networks. Thus the search phase of a MNN is passive in nature where a MNN can only wait for RA messages from its own mobile router. Once a MNN receives a new care-of prefix (part of an RA message), it forms a new CoA, performs DAD and sends binding updates to the home agent and correspondent nodes. A timeline of these events is summarised in figure 3.

A. Analytical model

A border router receives periodic router advertisements (RA) from an access router to which it is connected. The Neighbor Discovery protocol for IPv6 [1] defines that there should be a random period $R$ between each broadcast of an unsolicited RA where $R$ is in the interval $[r_{min}, r_{max}]$. RAs contain Router Lifetime $l$ which informs the BR for how long the sending router should be considered useful. By default $l = 3 \times r_{max}$, i.e. the period of time a BR waits for a RA before realising that its current access router is no longer available. We define the movement detection delay $D_{L3-M}^b$ as the time from losing L2 connection with an AR ($C_{loss}$) to the time L3 realises the loss of connection ($l$). Hence,

$$D_{L3-M}^b = l - C_{loss} \tag{1}$$

The delay in search phase $D_{L3-S}^b$ of a BR is composed of delay for DAD ($d_{dad}$) of link local address, sending RS message and receiving RA message. The delay of sending and receiving RS and RA messages depends on the propagation delay $p_{b-ar}$ between the BR and AR. Also, an AR sends RA message after waiting a random time $S$ from receiving a RS message. Therefore,

$$D_{L3-S}^b = d_{dad} + 1 \times p_{b-ar} + (S + 1 \times p_{b-ar}) \tag{2}$$

Once an AR is discovered, the attachment phase begins by configuring a CoA which requires exchange of DHCP messages. This is followed by DAD for the newly formed CoA and finally sending binding updates to the home agent and the correspondent nodes. Delays for binding update messages depend on propagation delay between the BR and its HA ($p_{b-ha}$) and between the BR and CN ($p_{b-cn}$). Therefore,

$$D_{L3-A}^b = 2 \times p_{b-ar} + d_{dad} + 2 \times p_{b-ha} + 2 \times p_{b-cn} \tag{3}$$

Please note that the models described above are valid for a mobile entity that is directly connected to the access router i.e. a border router of AIMNET. For mobile network nodes the delay models are different. When a border router detects that it has lost connection with an AR, it informs other mobile routers in AIMNET by sending a BR Advertisement message with relevant details. Once a mobile router receives this information, it stops advertising the care-of prefix obtained from the concerned AR to nodes inside its mobile network. This involves immediately sending a RA message inside its mobile network with lifetime of the concerned care-of prefix set to zero. Thus the movement detection delay $D_{L3-M}^m$ at MNN is $D_{L3-M}^b$ plus the propagation delay $p_{mr-b}$ of a BR Advertisement in AIMNET. Here, we assume that the time taken by a mobile router to process the BR Advertisement and the time taken by the RA message to reach a mobile network node are negligible.

$$D_{L3-M}^m = D_{L3-M}^b + p_{mr-b} \tag{4}$$

The search phase of a MNN does not involve active search for an AR as the MNN is already connected to its mobile router. However, a MNN can only resume its communication to nodes outside AIMNET once it has a topologically correct care-of address. Thus the search phase of a MNN extends from knowledge of unavailability of a care-of prefix to the availability of a new care-of prefix. During this time, the border router searches for a new AR, configures a new CoA, performs DAD and informs mobile routers in AIMNET about the availability of this new AR. Once a mobile router knows about the new AR, it obtains a care-of prefix and advertises this prefix inside its mobile network. Therefore delay of search phase of a MNN is

$$D_{L3-S}^m = [D_{L3-A}^b - 1 \times p_{mr-b}] + [2 \times p_{b-ar} + d_{dad}] + [1 \times p_{mr-b} + 2 \times (p_{mr-b} + p_{ar})] \tag{5}$$

Once an MNN knows about the new care-of prefix, it configures a CoA with this prefix. This is followed by DAD for the newly formed CoA and finally binding updates to the home agent and the correspondent nodes. Delays for binding update messages for HA and CN depend on the propagation delay on the paths MNN-MR-BR-HA and MNN-MR-BR-CN respectively. Considering the MNN-MR delay as negligible, the total delay a MNN experiences during the attachment is

$$D_{L3-A}^m = d_{dad} + 2 \times (p_{mr-b} + p_{b-ha}) + 2 \times (p_{mr-b} + p_{b-cn}) \tag{6}$$

<table>
<thead>
<tr>
<th>TABLE I: A summary of main delay variables</th>
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<td>$D_{L3-M}^b$</td>
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B. Delay estimates

Let us consider ad hoc interconnected mobile networks moving through homogenous access networks, receiving packets from a correspondent node in the Internet. The border router is connected to an access router which sends periodic router advertisements (RA). The minimum allowed values for inter-RA interval \([r_{\text{min}}, r_{\text{max}}]\) in Neighbor Discovery protocol for IPv6 [1] is in the range of \([3, 4]\) seconds. This results in a minimum router lifetime \(l\) of 12 seconds which is too high for mobile applications. Mobility Support for IPv6 [2], [3] has relaxed the inter-RA interval limits and allows them to be fractions of a second. We consider the inter-RA interval \([0.5, 1.0]\), which leads to router lifetime \(l\) of 3 seconds [4].

The time at which BR loses its L2 connection with AR \((C_{\text{loss}})\) has to be in \([t_{\text{ra}}, t_{\text{ra}} + r_{\text{max}}]\), where \(t_{\text{ra}}\) is the time at which last RA was received before the connection was lost. To simplify the estimation of \(C_{\text{loss}}\) we assume that it has uniformly distributed probability, thus the average value for \(C_{\text{loss}}\) will be \((2t_{\text{ra}} + r_{\text{max}})/2\). If we consider \(t_{\text{ra}}\) to be the starting point of the timeline for this analysis, its values can be taken as zero. Thus the average value for \(C_{\text{loss}}\) is \(r_{\text{max}}/2\).

The random time \(S\) a router waits before sending a solicited router advertisement is by default in \([0.0, 0.5]\) seconds. We assume \(S\) to be uniformly distributed thus its mean value is 0.25 seconds. The delay for duplicate address detection is by default 1 second. For propagation delays we consider the values from the testbed defined in [5]. A summary of main variables and their values is presented in tables I and II respectively.

From the above values and equations 1 – 6 we obtain the following results.

\[
\begin{align*}
D^b_{L3-M} &= 2.500 \text{ sec} \\
D^m_{L3-M} &= 2.500 \text{ sec} \\
D^b_{L3-S} &= 1.254 \text{ sec} \\
D^m_{L3-S} &= 2.280 \text{ sec} \\
D^b_{L3-A} &= 1.192 \text{ sec} \\
D^m_{L3-A} &= 1.224 \text{ sec} \\
Total \ D^b_{L3} &= 4.946 \text{ sec} \\
Total \ D^m_{L3} &= 6.007 \text{ sec}
\end{align*}
\]

These estimates show that a border router is expected to face handover delay of approximately 5 seconds at layer 3 when following the standard parameters of IPv6 Neighbor Discovery protocol. Similarly, a node in a mobile network of AIMNET will face a handover delay of approximately 6 seconds. Both these delays are quite high. For mobile network nodes, specially the ones using real time applications like VoIP, delays of more than few hundred milliseconds become unacceptable [6].

V. AIMNET HANDOVER IN HETEROGENEOUS NETWORKS

In heterogeneous access networks, generally there is considerable overlap in the coverage areas of access networks. Thus any mobile entity that has physical interfaces compatible with

![Diagram of Handover Delays in Homogeneous Networks](image)

**TABLE II: A summary of variable values**

| \(r_{\text{min}}\) | 500 msec | \(p_{b-ar}\) | 2 msec |
| \(r_{\text{max}}\) | 1000 msec | \(p_{b-ha}\) | 52 msec |
| \(d_{\text{dad}}\) | 1000 msec | \(p_{b-cn}\) | 42 msec |
| \(S\) | 250 msec | \(p_{m-v-b}\) | 3 msec |
the access networks present at its location, can be simultaneously connected to these access networks. The mobile entity can also configure CoAs from the care-of prefixes provided by all the connected access routers. However, Mobile IPv6 allows only one CoA to be registered at home agent at any time; this CoA is called the primary CoA. Thus despite the availability of multiple CoAs, a mobile entity may use only one primary CoA at a time.

When AIMNET moves in a heterogeneous environment, a border router with multiple physical interfaces can connect to multiple access routers at the same time. Whenever a border router connects to a new access router, it can immediately configure a CoA and opt not to use it as primary CoA. It can also inform other mobile routers in AIMNET about the newly available access router, which in turn can obtain care-of prefixes as well. The method of obtaining care-of prefixes remains the same as described previously for the homogeneous networks.

Movement detection in heterogeneous networks is done in a similar manner as in homogeneous network, i.e. movement is detected by a border router when it does not receive any router advertisements for a certain period of time. However the search phase generally does not exist because connection to the target access network is already available. The attachment to another access router involves only binding updates. Similarly for mobile network nodes, the movement detection is done in a similar manner as in homogeneous network, i.e. movement is detected after the BR detects it and informs the mobile network nodes. The method of obtaining care-of prefixes as well. The method of obtaining care-of prefixes remains the same as described previously for the homogeneous networks.

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A. Analytical model
Here we will use the same variables as described previously to define delay models in heterogeneous access networks. The movement detection delay $D_{L3-M}$ at a border router is the same for homogeneous and heterogeneous networks, i.e. the time from losing L2 connection with an AR ($C_{loss}$) to the time L3 realises the loss of connection (l). Hence,

$$D_{L3-M}^b = l - C_{loss} \quad (7)$$

When a border router has simultaneous connections with more than one access router, it does not need to search for a new one when connection to its primary AR is lost. Therefore there are no delays for the search phase. Once the current primary access router is detected to be unavailable, the attachment to another access router involves only binding update process with the home agent and correspondent nodes. As defined before, the delays for binding update messages depend on the propagation delay between the BR and its HA ($p_{b-ha}$) and between the BR and CN ($p_{b-cn}$). Therefore,

$$D_{L3-M}^b = 2 \times p_{b-ha} + 2 \times p_{b-cn} \quad (8)$$

For mobile network nodes the movement detection delay is the same when AIMNET is moving in heterogeneous networks as it is in homogeneous networks. Therefore,

$$D_{L3-M}^m = D_{L3-M}^b + p_{mr-b} \quad (9)$$

The search for a new care-of prefix does not take any significant amount of time since the mobile routers already have this information and propagate it inside their mobile networks as soon as they need to. Once a MNN knows about the new care-of prefix, it configures a CoA, performs DAD on it and sends binding updates to its home agent and correspondent nodes. The delays for the attachment phase of a MNN are the same as described for homogeneous networks.

$$D_{L3-A}^m = d_{dad} + 2 \times (p_{mr-b} + p_{b-ha}) + 2 \times (p_{mr-b} + p_{b-cn}) \quad (10)$$

B. Delay estimates
Considering the values presented in table II and equations 7 – 10, we obtain the following results. A description of the variables is provided in table I for reference.

$$D_{L3-M}^b = 2.500 \text{ sec} \quad D_{L3-M}^m = 2.500 \text{ sec}$$
$$D_{L3-A}^b = 0.188 \text{ sec} \quad D_{L3-A}^m = 1.224 \text{ sec}$$
$$Total \ D_{L3}^b = 2.688 \text{ sec} \quad Total \ D_{L3}^m = 3.727 \text{ sec}$$

The delays faced by border routers and mobile network nodes are shorter when handover is across heterogeneous wireless access networks as compared to the homogeneous networks. This is because a border router connects to different access networks using different interfaces. This allows the border router to discover new access networks while connected to the old one on the other interface. Nevertheless, delays of 3.7 seconds during a handover for mobile network nodes are still very high.

VI. REDUCING HANDOVER LATENCY
The analysis of handover delays presented in the previous sections demonstrates that if standard network layer mechanisms are used for movement detection, search for new access networks and attachment to an access network, they lead to very long delays in handover. The handover delays are longer in homogeneous networks where it is assumed that the border router has only one physical interface. The delays are shorter in heterogeneous networks as events that are sequential in homogeneous networks can occur simultaneously in heterogeneous networks, reducing the overall handover time. The analysis has also revealed that delays encountered by a mobile network node are longer than those faced by a border router.

It can be seen that the delays are mainly caused by two factors: the movement detection and various delay requirements of Neighbour Discovery protocol. The movement detection contributes to 50% of the total handover delay experienced by a border router and 40% of the total handover delay experienced by a mobile network node when moving in homogeneous access environment. In heterogeneous network, the...
movement detection causes 93% and 67% of the total handover delays at border router and mobile network node respectively. Therefore movement detection is the largest contributor to handover delays. Reducing this delay can dramatically reduce the total handover delay.

A. Reducing Neighbour Discovery Delays

For the IPv6 Neighbour Discovery related delays, the main contributors are the random delay requirements during router discovery and duplicate address detection procedures. Since wireless environments are very volatile and mobile nodes require immediate knowledge of a router’s presence or absence, the value of random delay between two unsolicited router advertisements should be reduced. Also, instead of waiting for DAD procedure to complete before starting to use an IP address, the nodes should start using the IP address immediately and run DAD procedure in parallel. Its highly unlikely that two nodes will have the same care-of address in AIMNET because their link-local or manet-local addresses have already been tested. IPv6 local addresses are half well known prefixes and half interface ID on the node. The new care-of address is configured by combining the care-of prefix from the access router and the interface ID of the node. Since the interface ID is already checked, the care-of address formed on its basis is unlikely to have a duplicate on the same network.

B. Reducing Mobility Detection Delays

The analysis presented in the previous sections shows that up to 93% of handover delays are due to late mobility detection. The mobility detection at layer 3 consumes significant time even after layer 2 has already detected loss of connection. Therefore, layer 3 mobility detection time can be significantly reduced if layer 3 can get the connection/disconnection information directly from layer 2 rather than waiting for layer 3 messages (router advertisements etc.). In heterogeneous access environment, it can be of further help if the mobility can be predicted in advance so that a node can search for and connect to a new access router before its current one becomes unavailable. This would reduce the handover delays up to 93%, depending on underlying link technology and how early it can detect mobility.

There are a number of works found in the research literature that address these issues. However, the only standardised solution is the IEEE Media Independent Handover (MIH) framework (IEEE 802.21 standard) [7]. The goal of the IEEE 802.21 Media Independent Handover standard is to provide link layer intelligence and other related network information to upper layers in order to facilitate optimisation of handovers between heterogeneous access networks. The standard specifies Media Independent Handover interfaces to support handovers featuring 3GPP, 3GPP2 and both wired and wireless IEEE 802 family of media. The 802.21 standard does not specify interfaces supporting handovers to and from satellite systems. To overcome this limitation, extensions to the 802.21 protocol have been proposed in literature, e.g. [8].

VII. PERFORMANCE EVALUATION

Mobile routers in AIMNET can change the access network through which they connect to the Internet. When they change the access network, they perform vertical handover. The ob-
jective of the simulations presented here is to examine the effects of vertical handovers on the mobile routers when the border routers and the mobile routers of AIMNET are using mechanism for early handover prediction discussed in the previous section. These simulations also allow us to examine the time it takes from an access network becoming available to AIMNET to a mobile router in AIMNET being able to use it.

A. Simulation Setup

For this experiment, we define two simulation scenarios in OPNET. In both scenarios an AIMNET with 10 mobile networks is moving at a speed of 15 m/sec. The area of AIMNET is 500m × 500m. The AIMNET first moves into the coverage area of first access router (AR1) and then to a second access router (AR2), as shown in the figure. Two mobile routers in AIMNET can become border routers when they come into the coverage area of an AR compatible with their wireless access technology. We name the border router that connects with AR1 as BR1 and the border router that connects with AR2 as BR2. We monitor the activity of two other mobile networks and the nodes in them that want to communicate with correspondent nodes in the Internet. The mobile routers of the mobile networks are called MR1 and MR2 and are connected to nodes MN1 and MN2 respectively. Both MN1 and MN2 communicate with CN1 and CN2 respectively. All communicating nodes (MNs and CNs) send data at the rate of 1024 bytes per second divided into 50 short packets sent at 50 packets per second.

The coverage area of AR1 is 1.9 km and that of AR2 is 2.4 km. The access routers are placed such that they have an overlapping zone of approximately 600 meters. Each simulation scenario starts with AIMNET placed well outside the coverage areas of both access routers. As AIMNET starts to move from West to East, it goes across the coverage areas of first AR1 and then AR2. Following is a description of the two scenarios.

Scenario a: AR1 is preferred by both MR1 and MR2. Therefore, both mobile routers will try to use it as long as possible. They will shift to AR2 only when the BR1 will indicate that its link with the AR1 is going down soon.

Scenario b: AR1 is preferred by MR1 and AR2 is preferred by MR2. Initially, when the AIMNET is in the coverage area of AR1 only, both MRs will access Internet via AR1. As soon as BR2 makes a connection with AR2, the MR2 will shift its communication to AR2. When AIMNET moves out of the range of AR1, MR1 will also shift its communication to AR2.

Apart from the initial connection/configuration delay, we also observe the handover delays when a mobile router switches between access routers of different preference levels. When a mobile router is connected to an access router and finds a new more preferred access router, it immediately wants to switch to it. On the other hand, when a mobile router is connected to the access router of high preference, it wants to remain connected to it as long as possible, and switches to an access router with lower preference only when a loss of the current access router is imminent.

B. Results

The communication through border routers (BRs) for the two scenarios is shown in figures 6 and 7. It can be observed that in scenario a where AR1 is preferred by both mobile networks, all communication to and from AIMNET takes place via BR1. However, when BR1 comes to the edge of AR1’s coverage area, the communication is shifted to BR2. In scenario b, MR2 switches to AR2 as soon as it becomes available, therefore BR2 begins to receive data traffic immediately after it announces its connection to AR2.

The results demonstrate that mobile routers get information from BRs in a timely manner. In both scenarios, BR1 is able to inform MRs that its link with AR1 is about to go down. The mobile routers that are still using BR1 act on this information and transfer their communication to the other available border router i.e. BR2. The lack of interruption in data communication is evident from the continuous streams of packets received by MNs and CNs. This is in part thanks to the fact that when a mobile router changes its BR and AR, it continues to receive packets from its previous BR. This is because IPv6 addressing mechanism allows a node to have multiple addresses and care-of addresses simultaneously. Thus, when a mobile router is either in the process of configuring a new care-of address or already has configured a new care-of address, it can still be reachable at its previous care-of address if the corresponding access router is still connected to a border router of AIMNET.

Average delays incurred during first connection and subsequent handovers are shown in figure 8. The error bars in the results represent the standard error of means. The results show that after a border router realises presence of an access router, it takes less than 200 msec before a correspondent node can begin to receive packets from a node in a mobile network of AIMNET using this access router.

Subsequently, when a mobile router is currently using an access router and finds a more suitable access router, it takes
around 193 msec for the mobile router to change its access router and for a correspondent node to start receiving packets through the new access router.

The handover from the most preferred access router available to a less preferred one takes less time. This handover delay is calculated from the time a mobile router gets the information that its current access router is going to be unavailable soon, to the time a correspondent node starts to receive packets from the new access router. The handover delay is in this case shorter because the new access router is usually known to the mobile router but not used because there is a more suitable access router available. However, a mobile router gets a care-of prefix from the new access router well in advance so it can save time whenever a handover becomes necessary. As a result, when a mobile router starts using the the new access router, it only needs to inform nodes in its mobile network about the change in the global (care-of) address prefix so they can use their mobile IPv6 mechanisms to continue communication with their correspondent nodes.

The results of the experiments show that in all three types of delays measured, the average delay remains well under 200 msec. It should be noted that (apart from initial connection) mobile networks continue to use their old care-of addresses as long as possible during and after the handover process to receive packets that were addressed to their old location. Therefore the effect of handover and delays (in terms of service interruption) is minimal.

VIII. CONCLUSION

In this paper, we have analysed handover delays in AIMNET. We have shown that the most prominent contributors to the delays are the delay requirements of Neighbour Discovery Protocol and the time taken by a node to discover movement. We then recommended methods to reduce these delays. To support efficient handovers across heterogeneous networks, we recommend the IEEE 802.21 framework that will assist mobile nodes (including mobile routers) in performing efficient handovers. We observed various delays incurred during the operation of AIMNET, namely the delay in initial connection, delay in handover to a preferred access router and delay in handover from the preferred access router. The results of the experiments demonstrated that the delays remained acceptable in all observed cases.

These preliminary results encourage us to further investigate mobility management, and in particular handover management, in AIMNET. In future, other aspects of handovers can be considered as well. For example, in this paper we only considered the MR controlled handovers. It will be interesting to also examine network initiated and network controlled handovers in AIMNET.

REFERENCES