AMP – A NOVEL ARCHITECTURE FOR IP-BASED MOBILITY MANAGEMENT

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Summary
In this research, an architecture called the Agent-based Mobility Protocol (AMP) comprising a multi-agent system residing in both the mobile host(s) and the access networks has been developed for the purpose of enhancing mobility management in IP-based networks. The agent system on the mobile host was designed and subsequently built using an agent development platform called Agent Builder Pro. The core of the AMP architecture is the access network agency and both its specifications and the corresponding mobility management were designed using a combination of collaboration and operation diagrams. Given the scope and complexity of computer networks generally, and the Internet, specifically, the use of a network simulator was considered appropriate in providing a wider and comprehensive understanding of how the AMP architecture and protocol would perform in supporting a mobile host roaming over multiple network domains or autonomous systems. Hence, this paper presents our work in developing the AMP architecture including its implementation over a discrete-event network simulator called ns-2 where customized objects have been built into the simulator. In addition, using different simulated scenarios, the architecture and protocol operations of AMP for mobility management were evaluated against Mobile IP as a basis for comparative analyses.
Key words:
Mobility management, multi-agent systems, Mobile IP, location registration, handover management, network simulation.

1. Introduction

Mobility management is a set of operational functions that allows networks to maintain the current location of roaming users, enable mobile hosts to send and/or deliver data, and to initiate or terminate sessions while in those locations. Typically, mobility management may be divided into two distinct functions – location management and handover (or handoff) management. Location management occurs when the mobile host is in standby state (without any active connection), while handover management occurs when the mobile host has on-going or active connections and roams into a different subnet or a visited access network.
Location registration is done every time a mobile host (while in standby and active states) roams into a new visited access network, while location updates are done upon expiry of the registration period. Location registration includes discovery of any mobility agent in the new location i.e. network (or mobility agent) discovery, creation of new IP address bindings or mappings based on the new location, and detection of movement at both the link and network layers. Handover management involves operations for maintaining on-going connections or calls/sessions while moving (call delivery), and these include creating new IP address binding/mapping at the visited location (binding updates) and re-routing data packets from the previous location to the new one. In most cases, mobility management is handled by special entities generically called mobility agents. In the IETF's Mobile IP protocol, these refer to the Home and Foreign Agents, while in the Session Initiation Protocol (SIP) these refer to SIP user agent and registrar agent, amongst others.

This paper is organized into several sections – Section 1 gives a definition of mobility management and the organization of the paper while Section 2 discusses the features of our AMP architecture. In Section 3,

2. Features of AMP

The proposed architecture and mobility management in AMP differ from the standard IETF's Mobile IP and SIP mobility management protocols. Among the key features of AMP are:

i. The use of a hierarchical architecture to facilitate mobility management in AMP. The use of a hierarchical architecture allows registration of movements within an autonomous system (intra-network movement) to be localized where the mobility agent in the user's home network need not be involved. This eliminates the round-trip-time

Manuscript received December 5, 2008
Manuscript revised December 20, 2008

(RTT) and authentication latencies that would be incurred typically in home registration procedures. These delays may be quite significant especially if the home network is located multiple hops away.

ii. The absence of packet (or datagram) encapsulation (IP-in-IP) and tunneling in AMP – this is unlike Mobile IP versions 4 and 6 where packets are encapsulated and tunneled to the new location. The absence of packet encapsulation results in a smaller sized datagram and consequently, lower overheads for packet processing. Packet delivery to the current location of a mobile host is achieved through the use of database lookups and packet header replacement/switching at the mobility agents in each subnet, network or cell location, where appropriate.

iii. Confidentiality of the mobile host's current location is preserved in AMP – this reduces additional risks of malicious calls and/or denial-of-service attacks against the user. The current location i.e. IP address is never made public or known to any end system i.e. including the mobile host itself and any corresponding host. In AMP, the current valid IP address, also called the temporary co-located address, is only made known to the mobility agents (typically residing in network nodes or access routers) in the home and access networks when necessary. In addition, it is assumed that exchange of messages between mobility agents residing in network nodes are authenticated (similar to the OSPF routing protocol authentication procedure).

iv. Direct mode of packet delivery in AMP. Packet re-routing or re-direction is not used since packets are usually delivered directly to the current location of the mobile host. As such, a reduction in transport overheads is further achieved which translates to more efficient utilization of network resources. In Mobile IP versions 4 and 6, route-optimization has been proposed to reduce triangular routing, however, security considerations may not allow this to be implemented.

v. Application-layer transparency is maintained since mobility management in AMP is operating primarily at the network layer. Although the mobile host and access networks are mobile-aware through the multi-agent architecture (residing at the application and network layers), distributed applications residing in end-systems need not be mobile-aware and thus, neither application adaptation nor any specific application-layer protocol is required, unlike in SIP.

vi. Mitigation of packet loss through buffering of packets to the next location in AMP. Through agent collaboration between neighboring access networks, pre-registration and buffering of packets to the next location may be done before host movement (inter-network movement). Presently, in hierarchical Mobile IP version 6, packet buffering is only possible for intra-network movement.

vii. A network-layer tracking mechanism (with flag indicators) that monitors the current location of a particular mobile host as it moves from one subnet to another has been proposed in the AMP architecture [1]. The enables faster detection at the IP layer, and allows state information to be maintained by the access network while the mobile host roams.

The AMP architecture presented in this paper extends an earlier work proposed by [2] – especially with reference to parts (ii), (iii) and (iv) above. However, unlike the work in [2] where different radio access systems need to be considered, the AMP architecture is designed as an overlay architecture, and may be extended to the higher layers of the protocol stack to allow personalized features to be maintained.

3. Location Management

3.1 Location Registration Operations

Location registration in AMP is similar to Mobile IP [3] when a mobile host is in standby state. The exact mechanism for location registration in AMP may be explained using the following Figure 1.

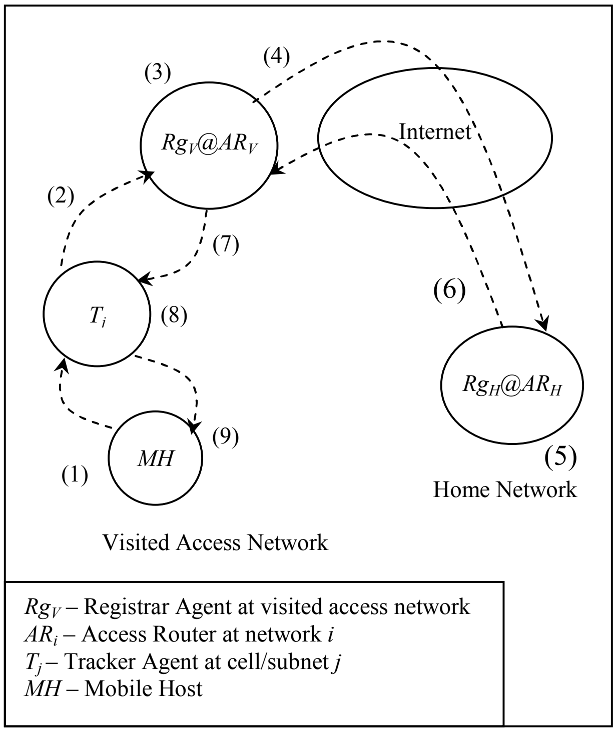

Figure 1: Location registration operations of AMP

The main differences between Mobile IP and AMP are that a hierarchical architecture is used in AMP, and that registrar agents (in the mobile host, and in the home and visited networks) and tracker agents in the relevant cell/subnet are all involved in the registration procedure. In addition, a temporary co-located address is used to locate the mobile host [2]; however, this temporary address is not made known to the mobile host since encapsulation is not used in AMP (unlike Mobile IP). Referring to Figure 1, the operations for location registration may be described as a series of steps below:

Step (1) A mobile host, *MH*, arrives in a new visited access network, and sends a registration request message to the associated tracker agent, T_j, of the cell/subnet. The request message contains user context information including the address of the mobile host i.e. IP_{MH}, the address of its home network registrar (IP_H) and any other relevant information for authentication procedures, etc.

Step (2) Tracker, T_j, then relays this information to its registrar agent, Rg_V, for registration purposes. This registrar agent is located at the access router of the visited network, $Rg_V@AR_V$.

Step (3) The registrar agent, Rg_V, performs validity checks, and obtains a temporary co-located address for *MH* from a local DHCP server. A mapping entry in the registrar agent's database is created in the form of [$IP_{MH}@IP_{CO}$: IP_{Tj}] which essentially means that IP_{CO} is an alias IP address of the *MH* in this network and it is located within the subnet of tracker T_j. This temporary co-located address is used to deliver packets to the current location of the mobile host through tracker T_j.

Step (4) The registration request message is sent to the registrar agent at the home network, Rg_H, where authentication procedures will be made. The request message also includes the alias or associated temporary IP address of *MH* i.e. $IP_{MH}@IP_{CO}$

Step (5) Assuming that the *MH* has been validated, an entry is created at the home registrar's database to indicate the current location of the mobile host i.e. [$IP_{MH}@IP_{CO}$: IP_{RV}], where IP_{RV} is the address of the registrar agent in the visited network.

Step (6) A registration acknowledgment message is sent to Rg_V confirming the registration operations.

Step (7) Similarly, an acknowledgment is sent to T_j which includes the mapping $IP_{MH}@IP_{CO}$

Step (8) An entry $IP_{MH}@IP_{CO}$ is created by T_j in its record.

Step (9) A registration acknowledgment message is sent to *MH*, but without the need to inform of the co-located address, IP_{CO}, since encapsulation is not used in AMP.

3.2 Packet Delivery

In this section, the mechanism for IP-packet delivery to a mobile host located in a visited access network is described. In this case, it is assumed that a mobile host (*MH*) has been successfully registered in a visited access network and another host i.e. a correspondent host (*CH*) located in another domain initiates correspondence to the *MH*.

In order to facilitate packet delivery from the *CH* to the *MH*, the access network needs to ascertain the current valid IP address of the *MH*. The steps involved are as shown in Figure 2. Hence, the steps necessary for packet delivery in the AMP architecture are as detailed below:

Step (1) A correspondent host, *CH*, sends a datagram to the *MH* using the usual IP_{MH} as the destination address, and this datagram is received at its access router AR_C.

Step (2) Before delivering the datagram to *MH*'s IP address, however, the registrar agent of the correspondent network, Rg_C, sends a *location request query message* to *MH*'s home regisrar agent, Rg_H. This is done based on the IP address of the *MH*.

Step (3) Rg_H receives the query message, and does an address lookup in its database, and finds an entry [$IP_{MH}@IP_{CO}$: IP_{RV}].

Step (4) A *location response message* is sent by Rg_H to Rg_C, with the required mapping [$IP_{MH}@IP_{CO}$: IP_{RV}]. Rg_H also enters Rg_C into its database as a correspondent host to *MH*.

Step (5) Rg_C makes an entry for the current location of *MH* in its database, and creates a new IP header datagram with source address IP_{CH}, and destination address IP_{CO}, but with the same payload for *MH*.

Step (6) This datagram and subsequent datagrams destined for *MH* will be sent using IP_{CO} as the destination address. Unlike Mobile IP, AMP does not use any encapsulation, and for security reasons, *CH* never knows the location of *MH*.

Step (7) The datagram arrives at AR_V, and Rg_V does a lookup to determine the cell/subnet location of IP_{CO}, and finds the entry [$IP_{MH}@IP_{CO}$: IP_{Tj}].

Step (8) The datagrams are then sent to tracker T_j

Step (9) T_j does a lookup and finds the entry $IP_{MH}@IP_{CO}$. It then creates a new IP header for all the datagrams, replacing IP_{CO} with the original destination address of IP_{MH}.

Step (10) The datagrams are then sent to *MH* without any encapsulation.

Step (11) *MH* may respond directly to *CH* without encapsulation, sending datagrams with the *CH*'s IP address as destination. Subsequent messages from *CH* to *MH* will be sent in a similar manner as described above, but without any more lookups at the home registrar since the current location of *MH* is known to all the relevant network mobility agents i.e. registrar and tracker agents.

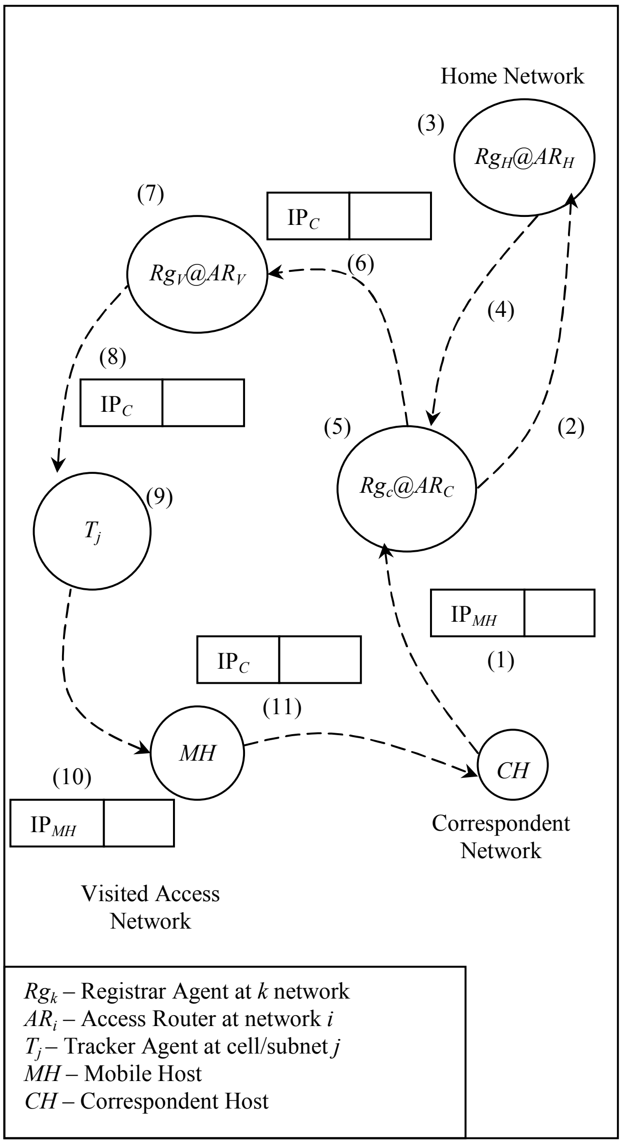

Figure 2: Packet delivery operations of AMP

4. Handover Management

4.1 Inter-Network (Global) Movement

Inter-network movement requires location updates to the home network and any correspondent host's network. In such cases, a global update is required. However, movement may be anticipated with the use of border trackers, as shown in Figure 3. In this figure, a mobile host, *MH*, moves from one cell/subnet location in Access Network 1, to another in Access Network 2.

If a mobile host, *MH*, is located in a border tracker's subnet, then the registrar agent may inform its peer in the neighbouring access network and pre-registers the *MH*. If necessary, packets may be buffered in both locations, hence reducing packet loss during handovers.. The operations are described in the following steps:

Step (1) The mobile host, *MH*, is now located at a border tracker's cell/subnet, Tb_{1j}. The tracker informs its registrar, Rg_1, and this information is updated in the registrar's entry i.e. [$IP_{MH}@IP_{C1}$: $IPTb_{1j}$], where IP_{C1} is the co-located addresses assigned to the *MH* in the visited Access Network 1.

Step (2) Knowing that the *MH* may cross to another domain, Rg_1 sends a pre-registration message on behalf of *MH* to its peer, Rg_2. Rg_2 obtains the necessary mobile user profile and reserves a new co-located address IP_{C2} for *MH*.

Step (3) *MH* moves from Access Network 1 to Access Network 2.

Step (4) *MH*'s movement is detected by the new border tracker in Access Network 2 i.e. Tb_{2p}.

Step (5) This information is relayed from this border tracker to Rg_2.

Step (6) Rg_2 creates an entry for the *MH* i.e. [$IP_{MH}@IP_{C2}$: IP_{Tb2p}]

Step (7) Rg_2 then sends *notification of change in access* to its peer role in the previous access network 1 i.e. Rg_1. This notice will also include the new temporary co-located address for the mobile host i.e. IP_{C2}.

Step (8) Rg_1 then sends a registration update message to the registrar, Rg_H, in the home network i.e. [IP_{MH}@IP_{C2}: IP_{R2}] informing it of the current location of *MH* with the new registrar.

Step (9) Rg_H updates it entry for the mobile host, changing it from [IP_{MH}@IP_{C1}: IP_{R1}] to [IP_{MH}@IP_{C2}: IP_{R2}], where IP_{C1} and IP_{R1} are the previous co-located address and visited access network address respectively, and IP_{C2} and IP_{R2} are the new co-located and visited access network addresses.

Step (10) Rg_H sends a new location update message to any correspondent host, Rg_C, and similarly will ask the previous registrar, Rg_1, to remove its binding for *MH*.

Step (11) Any datagram destined for the *MH* sent by the correspondent host through Rg_C will now have in its header, the new IP_{C2} as the destination address, without any encapsulation.

Step (12) Upon receipt of the datagram, Rg_2, forwards the packets to the current tracker agent, Tb_{2p}.

Step (13) Tb_{2p} will now replace the datagram header with the *MH* original IP address, IP_{MH} and send it to the mobile host.

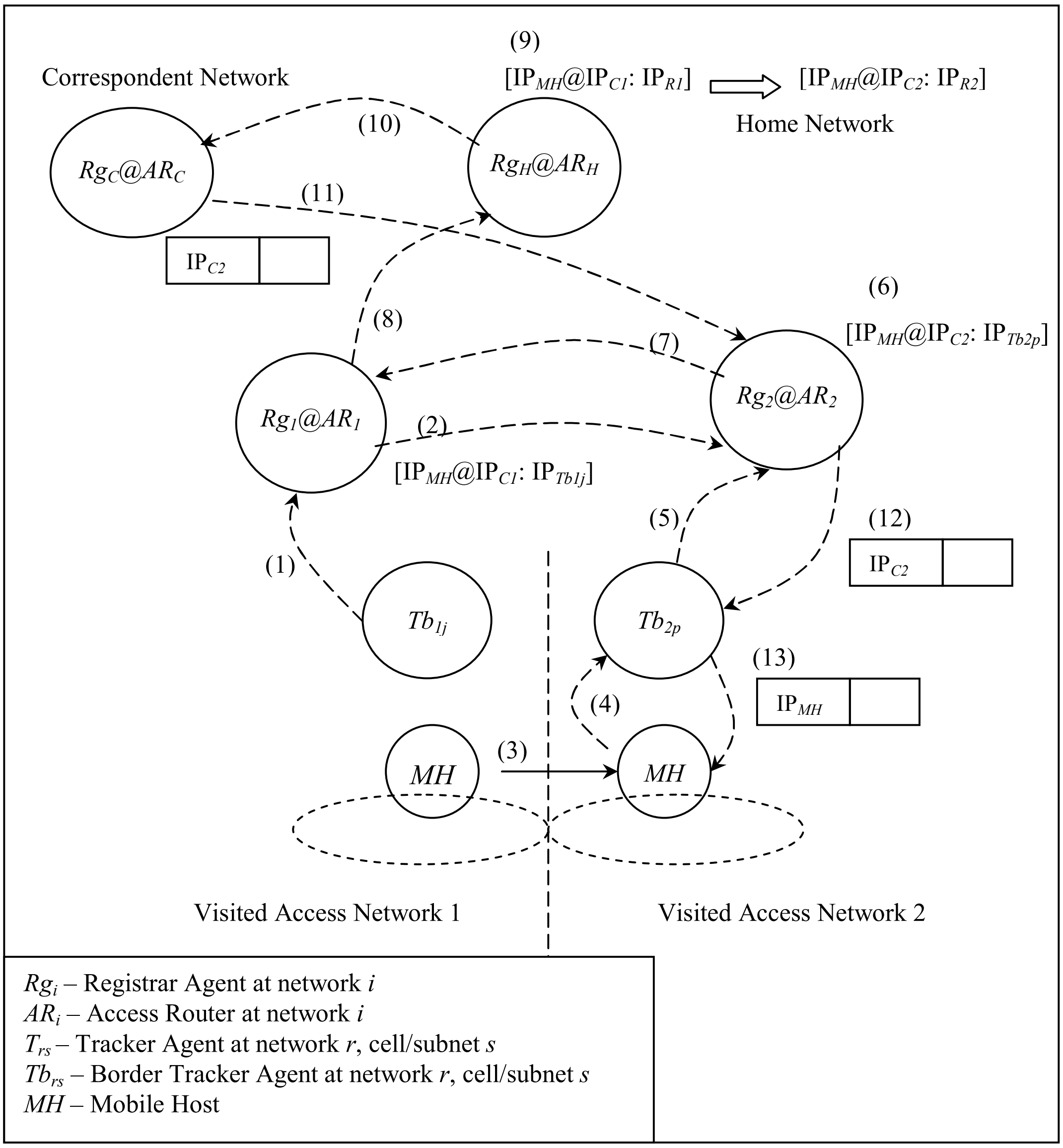

Figure 3: Inter-network (global) handover operations

5. Simulation Results & Discussion

5.1 Total Signaling Cost

This section presents the evaluation of the proposed AMP using ns-2 simulator. From the simulation, the total signaling cost is evaluated against the call-to-mobility ratio (CMR) for both AMP and Mobile IP, as shown in Figure 4.

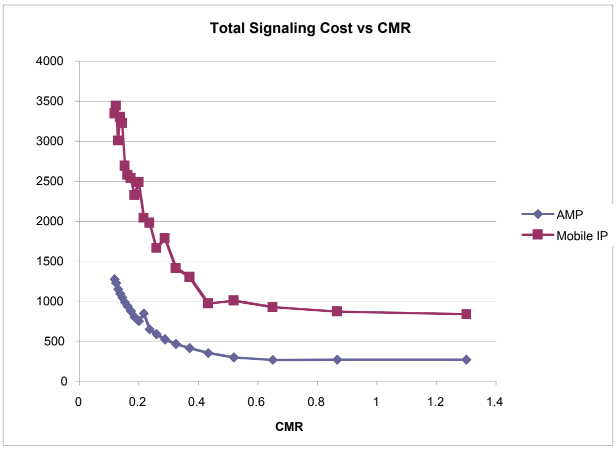

Figure 4: Total signaling cost vs. call-mobility ratio

The total signaling cost is the total number of control packets transmitted for the purpose of creating new address bindings for registrations and handovers, refreshing existing address bindings, and for packet delivery to the mobile host as it roams. Generally, small values of CMR means that the rate of movement of the mobile host is much higher compared to the arrival rate of calls or sessions. As such, the signaling cost will be larger as the mobile host crosses over many cells/subnets triggering registrations and handovers as it moves. As the CMR increases such that CMR ≥ 1, the mobility rate is less than or equal to the call or session arrival rate, and this translates to less binding updates that need to be done since the number of crossovers and handovers are small. Hence, the signaling cost decreases as the value of CMR approaches 1, and becomes almost constant when CMR exceeds or equals to 1.

When compared to Mobile IP, AMP has a smaller signaling overhead due to the hierarchical architecture of AMP. Mobile host movements between cells/subnet that are within the same access network are considered local and binding updates need not be sent to the home network – thus reducing the number of control packets that need to be sent. In Mobile IP, however, movement across cells requires registration and binding updates to be sent to the home network regardless whether the cells are located within the same domain or in a different access network. In addition, packet delivery cost in AMP is much lower since buffering of packets is possible resulting in less packet loss and the need for packet re-transmission as the mobile host moves from one location to another.

5.2 Packet Delay

The packet delay is the average time required to transmit a packet from the correspondent host to the mobile host as it moves from one location to another over a period of time. Figure 5 shows the packet delay in AMP while Figure 6 shows the packet delay in Mobile IP. The simulation time represents the distance in which the mobile host moves from his home network to other subnets and visited access networks.

For AMP, there are six intervals reflecting packet delays within a particular cell or subnet (since there are 6 cells/subnets in the simulation scenario). In each interval, the average packet delay is almost constant within the range of 0.010 seconds to 0.015 with the occasional spike or increased delay at the start of the interval i.e. subnet 2 with initial delay of 0.018 sec, subnet 3 with 0.020 sec initial delay, subnet 4 with 0.027 sec initial delay and subnet 6 with initial delay 0.026 sec. This initial delay is due to handovers as the mobile host moves from one cell/subnet to another. The key consideration is that in AMP, packet delay is not significantly affected by the mobile host's distance from his home network.

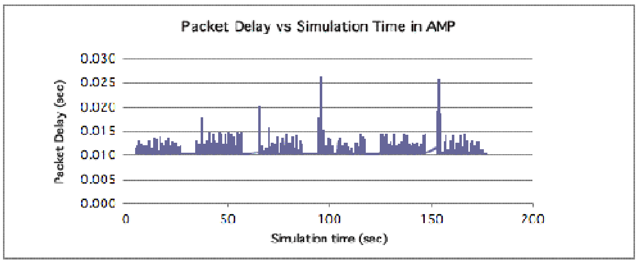

Figure 5: Packet delay versus simulation time in AMP

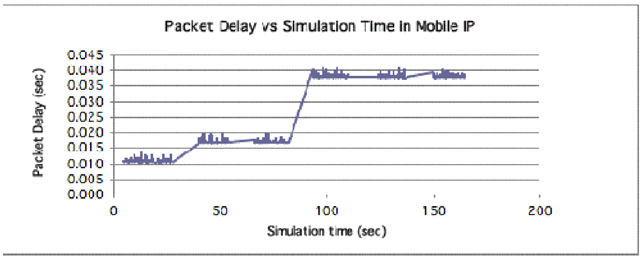

Figure 6: Packet delay versus simulation in Mobile IP

In Mobile IP, the average packet delay increases as the simulation time progresses where the mobile host moves further away from his home network. Initially, the average packet delay while the mobile host was in his home subnet is about 0.013 sec. However, as the mobile host moves to the second and third subnets, the average packet delay increases to about 0.018 sec. When the mobile host moves to another access network domain i.e. subnets 4 to 6, the average packet delay has increased exponentially to about 0.038 sec. This is due to the fact that all registration and binding updates for handovers must be done through the home network and this incurs significant delays, as the mobile host moves further away from his home network. Figure 7 compares the average packet delay between AMP and Mobile IP against the distance of the mobile host from his home network.

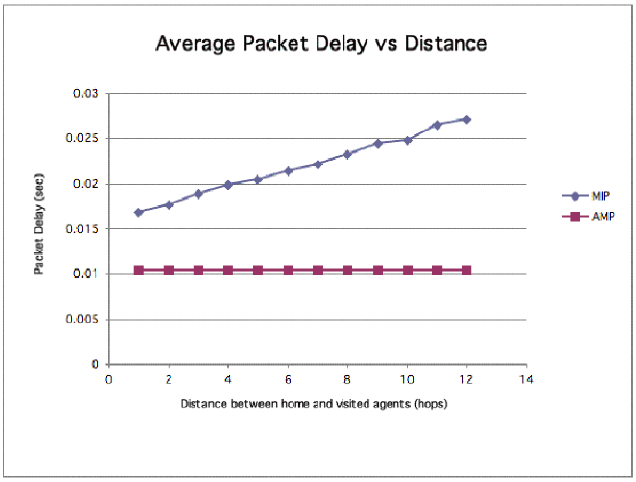

Figure 7: Average packet delay in AMP and Mobile IP

5.3 Packet Loss

Packet loss is an important mobile QoS parameter for loss-intolerant applications. In the AMP architecture, packet loss is mitigated by the use of buffers in the access routers, and lower latencies during handovers. Figure 8 shows the packet loss for both AMP and Mobile IP as the mobile hosts roams to different subnets.

In both architectures, packet loss will still occur as a result of handovers and delays. However, generally, the number of packet loss in AMP is less than in Mobile IP and when they do occur, the duration period for the packet loss is shorter. These are mainly for two reasons – firstly, in AMP, packets are buffered between movements to the new locations, and secondly, handover procedures are faster than in Mobile IP since a hierarchical architecture is used where there is a distinction between local (intra-network) and global (inter-network) movements.

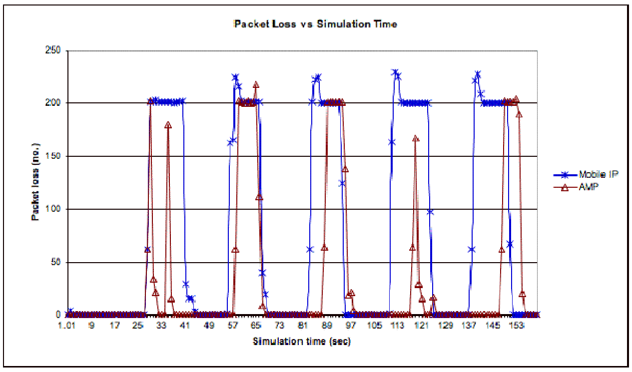

Figure 8: Comparison of packet loss in AMP & Mobile IP

6. Conclusion

In this paper, the AMP architecture and its associated protocol for mobility management for an IP-based network have been described. The proposed architecture may be thought of as an overlay network with specific mechanisms to support host and user mobility such as location registration, packet delivery, movement detection and handover management for both local and global movements. The key distinguishing features of AMP include an agent-based hierarchical architecture, the absence of encapsulation and tunnelling, direct-mode of packet delivery without re-routing, application-layer transparency, buffering of packets to mitigate packet loss, and a network-centric tracking mechanism for movement detection. All these features add towards providing a comprehensive set of services for handling mobility albeit it in a more complex manner than the standard IETF's Mobile IP protocol – however, this complexity is justified given the anticipated performance gains. It was shown that the AMP architecture was developed and implemented over the network simulator ns-2. During the evaluation of the proposed architecture, several mobile QoS parameters were considered including the total signaling cost, the average packet delay and packet loss. These simulations were also done in comparison to the IETF's Mobile IP protocol for comparative performance evaluation. Simulation results indicate that the AMP architecture generally performed better in reducing signaling cost, packet delay and packet loss when compared to Mobile IP.

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