Dynamic Mobility Agent Protocol (DMAP) for Micro-mobility Management

Yingying Chen
The University of Hong Kong
yychen@eee.hku.hk

Victor O.K. Li
The University of Hong Kong
vli@eee.hku.hk

Abstract

The Internet is evolving into a hybrid network, which consists of a core wired network, and various wireless access networks. To ensure continuous and seamless communications in this hybrid network, mobility management protocols are required. In the context of the macro-/micro-mobility management infrastructure, numerous micro-mobility protocols have been proposed. These protocols can be divided into two categories, namely, HSR (host-specific routing) protocols, and ABT (agent-based tunneling) protocols. In this paper, we present generic models for the two categories and compare them. We also propose dynamic mobility agent protocol (DMAP) -- a novel IP-based ABT protocol for micro-mobility management. Our analysis shows that DMAP gains enhanced properties over existing ABT protocols.

1. Introduction

The technical advances of mobile terminals, and the desire of consumers to have ubiquitous access to distributed information have fueled the development of the wireless Internet, which consists of a core wired network, and various wireless access networks with different topologies and capacities. To ensure seamless connection in the heterogeneous network, mobility management protocols are required to bridge the various network entities and mobile terminals.

It is generally accepted that the mobility management infrastructure is split into macro-mobility management and micro-mobility management. Mobile IP [1][2][3] is proposed as a macro-mobility solution for the large-scale network. Micro-mobility protocols fall into two major categories: those employing host-specific routing (HSR), and those employing agent-based tunneling (ABT). Due to the omnipresent Internet, we believe providing mobility support in the network layer is the most efficient way for ubiquitous wireless communications. The following discussion and our proposed protocol are therefore IP-based.

In this paper we propose DMAP (dynamic mobility agent protocol). Unlike the majority of previous work, where users are assigned one or more fixed regional mobility agents (MAs), DMAP selects and dynamically changes the MAs for each user, according to its mobility level and possible roaming range.

The rest of the paper is organized as follows. Section 2 briefly describes the current solutions for mobility support, with emphasis on micro-mobility protocols. Based on a comparison between the two categories of micro-mobility protocols, we propose the IP-based ABT infrastructure of DMAP and present the enhanced properties in Section 3. Finally we conclude and discuss our future work in Section 4.

2. Background

In this section we will introduce Mobile IP and its variants, which are suitable for macro-mobility management. Then the two categories of micro-mobility management protocols will be presented.

2.1 Macro-mobility management protocols -- Mobile IP and its variants

Mobile IPv4 [1] is the current standard for mobility management. Mobile IPv4 succeeds in separating the dual-function of the IP address, i.e., identity declaration and routing guidance, thus maintaining an ongoing communications between MN and its correspondent nodes that may be unaware of its roaming status and location changes.

MIP-RO [2] is proposed to solve the problem of triangular delivery path for packets destined to MN. However, the implementation of MIP-RO requires such security mechanisms as key distribution and authentication between the MN and its CNs. Only when the MN is roaming far from its home agent and near its correspondent node can MIP-RO obtain significant efficiency in terms of delay and resource consumption.

Mobile IPv6 [3] benefits from the advances of IPv6 over IPv4 and remedies some deficiencies in Mobile IPv4. For example, the abundance of IP addresses and simplicity of address auto-configuration allow MN to easily acquire a collocated CoA on any foreign network, which renders the function of foreign agent obsolete. The IP Authentication Header makes it convenient to implement wide-scale security mechanisms, provides integrated support for route optimization.

Despite these improvements, some of the inherent weaknesses of Mobile IP are unavoidably inherited. Each time an MN changes its point of attachment to the Internet, it has to propagate a binding update to its home agent or CNs, which may induce heavy global signaling overhead and long update latency, especially when the MN has traveled far from its home network or is changing its point of attachment frequently. This is why micro-mobility management is proposed to limit the location update engendered by small-scale movement, so as to reduce the frequency of triggering global signaling, update latency and packet losses.

2.2 Micro-mobility management protocols

Host-Specific Routing (HSR) protocols

Cellular IP [4], HAWAII [5], and MMP [6] are representative HSR micro-mobility protocols. The structure of the generic HSR model is shown in Fig. 1. On the edge of a local domain, one gateway works at the intersection of macro- and micro-mobility management, serving as foreign agent for the macro-mobility framework. Within the local domain, MAs (i.e., the gateway, routers and/or base stations) construct a *tree* structure. Specifically, the gateway serves as the root of the tree, while other MAs serve as intermediate nodes or leaf nodes. Each intermediate node has exactly one upstream parent node and at least one downstream child node. MNs roaming within the domain may register with the gateway via the leaf node whose coverage area contains the current geographical location of the MN. When an MN arrives at a foreign domain, it obtains a CoA, either a foreign agent CoA (i.e., the gateway's IP address) or a co-located CoA. It then registers the CoA with its home agent via the gateway.

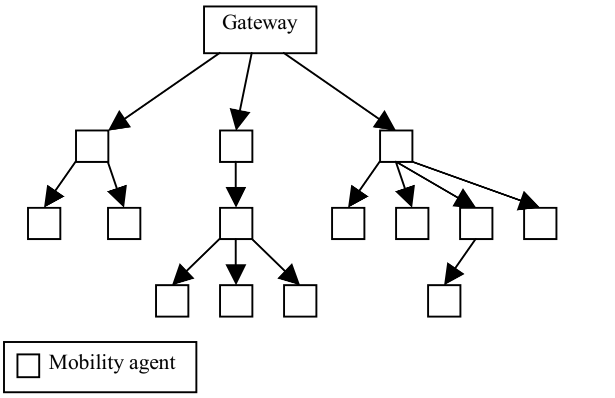

Figure 1. The structure of the generic HSR model

HSR protocols are characterized by the host-specific routing tables maintained by the MAs. According to information extracted from data packets or registration packets sent by an MN, local MAs update the host-based routing entry for the specific MN, which is used to deliver downstream packets destined to the MN. According to the beacons or agent advertisements sent by the gateway, MAs update the routing entry for the gateway, which is used to deliver outgoing packets towards the gateway.

When an MN roams to the coverage area of a new leaf MA, the path update procedure needs to propagate up to the crossover MA located at the intersection of the old delivery path and the new path. Only the involved agents on the way from the crossover MA to the new MA need to update their host-specific routing entry for the MN. Various handoff schemes are designed. For example, semi-soft handoff in Cellular IP and Multicast Non-Forwarding scheme in HAWAII, are designed to limit packet losses. The Single-Stream Forwarding scheme in HAWAII is proposed to ensure in-order arrival of the packets destined to the MN.

Paging support is also proposed in HSR protocols. Idle MNs send empty packets or registration update packets in longer time interval than active MNs do. The paging caches maintained by MAs have longer validity period. Paging cache entries only record approximate location information for MNs.

Agent-Based Tunneling (ABT) protocols

In ABT protocols, MIP-RR [7] and HMIPv6 [8] are multi-layer Mobile IP. Routing is based on the tunneling processed by hierarchical MAs. TeleMIP/IDMP [9][10] proposes a fixed hierarchical structure, i.e., exactly two-hierarchy of foreign agents and one-hierarchy of base stations. MPLS-based MM [11] takes advantage of the faster operation of label lookup and forwarding in MPLS. In all ABT protocols, packets are encapsulated and routed through the tunnels built up among MAs.

The structure of the generic ABT protocols is shown in Fig.2. In ABT, there may be multiple gateways, and, there may even be several gateways for one MN. All the MAs and the tunnels between them within a domain form a *directed graph*, with each edge (i.e., tunnel) connecting its first vertex (the edge's source, i.e., the tunnel's source MA) to its second vertex (the edge's target, i.e., the tunnel's target MA).

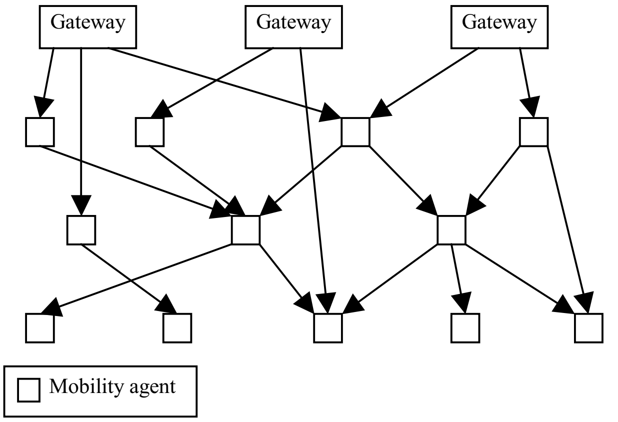

Figure 2. The structure of the generic ABT model

In ABT protocols, an MN visiting a foreign network needs to register with one or a series of hierarchical local MAs, from the closest MA to its gateway(s). The primary gateway then relays home registration to the MN's home agent. The home agent records the gateway's publicly routable address as the CoA for the MN. Each MA on different hierarchies also records a specific CoA for a visiting MN. Most frequently, they record the next lower-level MA's IP address as the CoA for an MN. The MN's home address is used as its identifier in the visiting domain.

Routing in ABT protocols is enabled via the technology of encapsulation and tunneling. When packets destined to an MN arrive at its gateway in the foreign domain, the gateway searches its visitor list entry for the MN, extracts the CoA for it, then encapsulates the packets by using the CoA as destination address. Fig.2 illustrates the process of encapsulation. The encapsulated packets are thus tunneled to the next lower-level MA, which either repeat encapsulation as the gateway, or replaces the destination address of the received packets' encapsulating IP header with the CoA of the MN newly extracted from its visitor list entry, and tunnels the re-encapsulated packets to the next lower-level MA. Until the MN itself receives the packets, the delivery along the hierarchies ends. Packets sent from the MN are delivered as in Mobile IP or via reverse tunneling along hierarchical MAs.

3. IP-based ABT infrastructure of DMAP

3.1 Comparison between HSR and ABT

Table 1 compares the two categories of micro-mobility management. Based on our analysis, ABT infrastructure is a more evolutionary and scalable choice.

	HSR	ABT
Structure	Tree	Directed graph
gateway(s) per domain	One only	Multiple
Identifier for MN in domain	Home address or co-located CoA	Home address
Routing tables at MAs	Host-specific routing entries	Traditional IP routing entries
Methods of packet delivery	Host-specific routing	Tunneling
Delivery path when both source and destination in same domain	Source→MAs in between→ gateway→ MAs in between→ destination	Source→ involved MAs in between→ destination
Location update	Integrated with routing; propagated to crossover MA	Separate from routing; propagated to gateway

Table 1. Comparison between HSR and ABT

Firstly, the tree structure of HSR makes the only gateway a bottleneck between macro- and micro-mobility management. Potential failure of the bottleneck may induce dysfunction of the whole domain. However, the multiple gateways of ABT not only provide backup for each other, but also balance the load within the local domain.

Secondly, HSR requires new construction of routing signaling, routing scheme, and/or address structure within a local domain, which adds considerable load on configuring the entities (i.e., the gateway, MAs) of a domain. By comparison, the traditional IP routing employed by ABT can avoid this problem.

Thirdly, the MAs in HSR protocols build up host-specific routing entries for each visiting MN. With the expeditious growth of MNs, host-specific routing will create a considerable burden for the database of MAs. In addition, it is time-consuming to search for one routing entry in the large database. The host-specific routing scheme is not scalable. By comparison, ABT protocols employ traditional Internet addressing scheme; therefore, MAs only need to maintain network information at the individual networks. The sacrifice ABT protocols have to make is the signaling overhead for encapsulation and tunneling. However, the added overhead involved is acceptable due to its scalability and adaptability to the speedy growth of the system.

Fourthly, in HSR protocols, when both the source node and the destination node stay in the same domain, the packets are routed from the source node towards the gateway, then from the gateway to the destination node. The delivery path is not optimal. However, in ABT protocols, the packets need not go through the gateway; instead, they can be tunneled to the destination node only via involved MAs.

One shortcoming of ABT is the signaling overhead and handoff latency induced by the location update propagated to the gateway. HSR succeeds in integrating the location management and routing table; the location update is therefore associated with the routing table update, and only propagated to the crossover MA.

3.2 Details of DMAP

We propose DMAP (dynamic mobility agent protocol) based on the ABT infrastructure, so as to achieve better latency performance in both location management and handoff management, at the cost of moderate signaling overhead. As in other ABT protocols, DMAP delivers packets along the tunnels constructed among MAs.

In DMAP, there will be a chain of MAs for each MN. The MAs of one chain may lie on different hierarchies. They maintain a record of CoA for the MNs at different distances. The MA on the highest level (HMA) controls the largest range for handoff and paging. The MA on the lowest level (LMA) controls the smallest range for handoff. Both HMA and LMA are decided and adjusted according to the mobility level and roaming range of the MN.

Originally, when an MN roams to a new foreign domain, it registers with the access point of the wireless access network, reporting its speed and estimated roaming range. The access point decides the number of hierarchies needed to construct the chain of MAs for the MN, and the hierarchies of LMA and HMA. The access point then begins to construct the chain of MAs via registration with selected MAs step by step. In particular, the hierarchy level of HMA and LMA depends on the MN's mobility level and its potential roaming range. Qualitatively, the wider the potential roaming range, the higher the HMA hierarchy . The higher the mobility level and the more frequently the MN traverses the boundary of a cell, the lower the LMA hierarchy. The chain of MAs is also in charge of location management for the MN. The LMA periodically reports location update information of the MN to the chain of MAs. The HMA registers with the MN's home agent for the sake of home registration. The update interval is the validity period of the CoA record.

Later on, when the MN roams to the coverage of another LMA, the process of handoff is triggered. The MN registers with a new access point. Meanwhile, it reports its old CoA and obtains a new CoA from the access point. Update of the CoA is propagated up the hierarchy beginning from the new access point. The access point searches all of its upstream MAs for a lowest-level crossover MA, which is located at the intersection between the old chain and the new chain. The crossover MA is the endpoint of the CoA update for the MN. At the crossover MA, packets destined to the MN are diverted, along the new chain of MAs. The crossover MA also sends an up-direct message to the MN's old CoA, which requests the old LMA to redirect those packets that failed to be forwarded to the MN and are currently buffered at the LMA, along the old chain upwards to the crossover MA, then delivered to their destinations. The record of CoA information for the MN on the old chain of MA will expire after its validity period. If there is no intersection between the old chain and the new chain, which indicates that the hierarchy of the HMA is not high enough to cover the MN's possible roaming range, the HMA is raised one level higher. If the MN traverses the boundary of LMA more frequently than its allowed handoff limit (AHL), the LMA will be raised one level higher so as to decrease the handoff frequency. On the other hand, if the MN stays within the coverage of an LMA for a period longer than the CoA update time (CUT), the LMA should be decreased one level.

3.3 Enhanced properties

Our proposal introduces HMA and LMA for each MN, in response to the MN's potential roaming area and mobility level individually. The dynamic chain of MAs for one MN ensures that the most appropriate set of agents are tailored for the MN's movement.

In terms of location management, the distributed HMAs, instead of gateways, may lie at a low hierarchy quite near the MN if limited roaming area is involved, so that the location update only need to traverse limited number of hierarchies, which may eliminate the latency problem for location update in ABT protocols. Similarly, for MNs with high mobility level, its LMA may be located at a high hierarchy quite near its HMA; the location update may also traverse limited hierarchies of MAs.

In terms of seamless handoff, DMAP addresses the three major issues, namely, handoff latency, packet losses, and signaling overhead. Firstly, DMAP jointly considers the roaming range and mobility level of an MN. HMA handles the former factor, while LMA handles the latter one. HMA and LMA facilitate fast handoff, i.e., handoffs are completed as soon as possible and as effective as possible. Secondly, the up-direct message requires the LMA to redirect packets in transit to the MN, which facilitates seamless handoff by significantly reducing packet losses. Thirdly, as long as an MN stays within the coverage of its HMA, there is no need to register with its home agent. Therefore, the signaling overhead is eliminated for within-HMA movement.

In addition, the distributed liaison between MNs and their selected chains of MAs balances the load on the network, allowing for incremental deployment of MAs and scalable increase of MNs.

4. Conclusion and future work

In this paper, we summarize the generic models of the two categories of micro-mobility management protocols. Based on a comparison between them, we propose a novel ABT protocol named DMAP which gives optimized performance in location management and handoff management. One key feature of DMAP is the dynamic design of HMA and LMA.

We note that ABT is in a nascent stage of research. We will perform computer simulation and analysis to verify our design. We will also compare the performance of DMAP and existing fixed mobility agent protocols.

References

[1] C. Perkins, "IP mobility support for IPv4," RFC3344, Aug 2002.

[2] C. Perkins et al., "Route Optimization in Mobile IP," Internet-Draft, IETF, Sep 2001.

[3] D. Johnson et al., "Mobility Support for IPv6," Internet-Draft, IETF, Feb 2003.

[4] A. Campell et al., "Design, implementation and evaluation of Cellular IP," *IEEE Personal Communications*, Aug 2000, 34-41.

[5] R. Ramjee et al., "HAWAII: a domain-based approach for supporting mobility in wide area wireless networks," *Proc. IEEE Int'l Conf. Network Protocols*, Nov 1999.

[6] A. Dutta et al., "Multilayered Mobility Management for Survivable Network," *Proc. Milcom*, Oct 2001.

[7] E. Gustaffon et al., "Mobile IP Regional Registration," Internet-Draft, IETF, Mar 2002.

[8] H. Soliman et al., "Hierarchical Mobile IPv6 mobility management (HMIPv6)," Internet-Draft, IETF, Oct 2002.

[9] S. Das et al., "TeleMIP: Telecommunications Enhanced Mobile IP Architecture for Fast Intra-domain Mobility," *IEEE Personal Communications Magazine,* vol. 7, no. 4, Aug 2000, 50-58.

[10] A. Misra et al., "IDMP-Based Fast Handoffs and Paging in IP-Based 4G Mobile Networks," *IEEE Communications Magazine*, Mar 2002, 138-145.

[11] F. Chiussi et al., "Mobility Management in Third-Generation All-IP Networks," *IEEE Communications Magazine*, Sep 2002, 124-135.