Comparative Analysis of Network Layer and Application Layer IP Mobility Protocols for IPv6 Networks

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***Abstract*:**

In order to provide seamless connectivity to the roaming users several mobility protocols have been developed at different layers. All of these mobility protocols exhibit certain common properties and demonstrate abstract mobility functions. But in order to achieve the desired functions, these implement signaling in different ways. In this paper we analyze two different mobility protocols that operate at different layers such as network layer and application layer. We describe each of the atomic operations and describe how these functional properties are carried out with some experimental results. We also illustrate the applicability of these two mobility protocols for IP Multimedia Subsystem (IMS) architecture.

Keywords: Mobility, IPv6, SIP, MIP, IMS

1 Introduction

With the advent of IPv6 deployment, mobility management to support these IPv6 end hosts are becoming more necessary. A mobility protocol can be defined at different layers, such as layer 2, network layer, transport layer and application layer. Authors in reference [3] have provided comparative performance analysis between few network layer mobility protocols, but have not considered application layer mobility protocol such as SIP. Authors in [4] have compared MIPv4 [5] with SIP-based mobility protocol [2] but have not addressed MIPv6 [1]. In this paper, we provide a comparative analysis between two candidate mobility protocols for IPv6 networks; network layer MIPv6 and application layer SIP-based mobility. Mobile IPv6 is a network layer mobility protocol that has tried to address the drawbacks associated with Mobile IPv4, such as triangular routing and route optimization in addition to providing inbuilt security support. SIP-based mobility management provides an application layer technique to take care of mobility using SIP signaling.

Figures 1a and 1b show two types of mobility protocols and the basic network entities associated with these protocols. These illustrate basic networks such as home network and foreign networks and include several network entities such as SIP proxy, home agent, correspondent node, mobile node that are involved in both application layer and network layer mobility management respectively. These show the basic signaling exchange as the mobile moves from one visited network to another visited network. The functional characteristics between SIP and MIPv6 exhibit certain similarities and differences in many cases. For example there are some basic differences regarding how binding update is sent to the correspondent host, number of signal exchanges during the binding update. For example, in case of MIPv6, a binding update is sent both to the correspondent host and the home agent. Whereas in case of SIP-based mobility, there are three signaling messages sent to the correspondent host and there is no home agent present in the network. For operational details of MIP and SIP readers are referred to the reference articles [1] and [2] for further details.

Rest of the paper is organized as follows. We describe the related work in Section 2. Section 3 describes the basic network operations that are part of a mobility protocol. Section 4 illustrates how these operations are carried out for two different mobility protocols. Section 5 shows the applicability of these two protocols for IMS network and some performance results. Finally Section 6 concludes the paper.

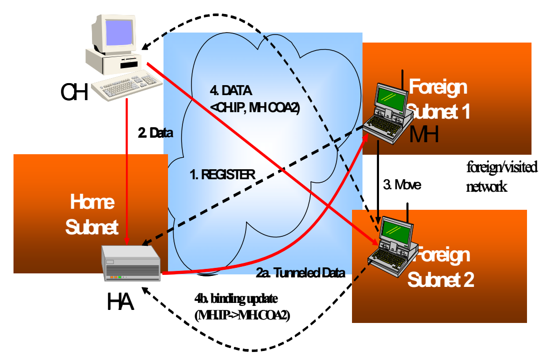

Figure 1a. Network layer mobility protocol - Mobile IPv6

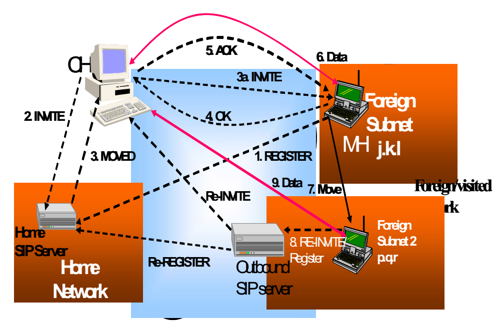

Figure 1b. Application layer mobility protocol -SIP

2 Related Work

There have been few related work that provide comparative analysis between several mobility protocols quantitatively. But these only provide cost comparison between the candidate mobility protocols. Galli et al [3] provide a quantitative analysis between two mobility protocols such as MIPv4 and MIPv6. However, there has not been any work that compares the detailed functional components of the related mobility protocols or how these work in an IMS (IP Multimedia Subsystem) environment.

3 Mobility Functional Properties

A careful study of several cellular and IP-based mobility management techniques provide us some insight into certain basic functions or systems properties that are needed during a mobility event. Optimization of these functions can provide overall mobility systems optimization. We categorize some of these functions below

Discovery: Discovery is the initial phase of any mobility event. A discovery process can consist of several sub-processes such as neighborhood network discovery, resource discovery in the neighboring networks where a mobile may move in.

Network Discovery: Network discovery is part of handoff preparation stage. Before handoff takes place a communicating mobile needs to discover the neighboring networks and the associated network elements around current point of attachment. Based on the type of the networks it plans to connect to (e.g., 802.11, CDMA, GSM) discovery of the appropriate network takes certain amount of time. For example, in an 802.1 1b-based net-work the mobile performs scanning to determine the neighboring networks. How-ever during this scanning process mobile's communication is interrupted briefly. Thus optimization of network discovery process contributes to the optimization of overall mobility event.

Resource discovery: Once the target network is discovered, there are several resource parameters within the target network that need to be discovered as well. These include channel number, frequency, bandwidth, encryption algorithm, authentication server, configuration server etc. Resource discovery process helps to configure the mobile with proper channel number and frequency.

Detection: After a handover decision is made either by the mobile or by the network, the mobile connects to the new point of attachment. Thus an early detection to the new point of attachment helps overall optimization process. Detection phase consists of the following sub-phases

Detection of new point of attachment: Detection of new point of attachment usually follows the discovery process. It could involve the following operation such as detection of new Location Area incase of GSM, detection of new routing Area in case of GPRS, or detection of Subnet, Domain, Cell in case of 802.11-based handoff in an IP-centric network. Each mobility management scheme provides different means of achieving this; such as GSM uses BCCH, CDMA uses pilot channel and 802.11 uses beacon interval to detect new point-of-attachment. In some cases some of the upper layer detection mechanisms such as FA advertisement, ICMP router advertisement, can help provide faster detection in case of movement that involves layer 3 movement.

Detection of loss of old point of attachment: In case of sudden lapse of coverage or disconnection it is important to detect the absence of old connection sooner so that it can start the discovery process of the new point of attachment and prepare for the new connection.

Event Notification: An event notification such as availability of the new point of attachment or lapse of an existing connection is usually provided to the upper layers or policy engine so that any further handoff related upper layer functions can take place to aid the mobility event. These upper layer functions include configuration, registration, binding update and media redirection. Signal-to-Noise ratio threshold or channel strength is one possible event notification technique.

Handoff Triggers: Handoff trigger is the event that follows the handoff decision process. Handoff decision to switch access networks could be mobile controlled, network controlled or mobile assisted. Since layer 2 association takes place before any upper layer association, it helps to provide a layer 2 trigger before the upper layer mobility management functions get executed. Thus an optimized triggering mechanism helps to expedite the handoff process.

Configuration: A configuration process associated with the mobile during its handoff involves the following steps.

1) Configure new temporary connection identifier either at layer 2 or at layer 3 in the new point of attachment of the network, such as Care-of-Address in case of IP environment, TMSI in case of GSM. Configuration process of a new identifier requires a series of signaling handshake between the mobile and the server in the network. It also involves processes such as security bindings, uniqueness checking of the new identifier.

2) Registration is a process of establishing the mapping between permanent identifier and temporary identifier for proper location management functionality. An optimized or hierarchical registration process helps expedited location management and faster de-livery of the new calls.

Security Binding: Before a new communication path is established between the end-points, communicating mobile node needs to authenticate itself and then establish some security association with the network elements those are in the communication path. In many of the mobility management protocols execution of these processes are mandatory and security association may take place at all the layers. Establishing a security association involves exchange of signaling between the mobile and any centralized security server that dispenses the key to the mobile.

Authentication: Authentication process provides a means for the mobile to gain access to the network resources before the communication could start. This process involves handshake between the mobile and the authentication server in the network and can happen at different layer. In case of GSM it uses SRES and A3 algorithm for the authentication. In case of 802.11 environment it uses 802. 1X in layer 2 and other mechanism such as PANA at layer 3.

4 Analysis of Mobility Protocols

We describe below how some of the basic operations such as registration, dynamic binding, configuration, location management, tunneling are taken care of by SIP-based mobility and MIPv6.

Registration: Registration is a process of registering with the home agent or the SIP server as the mobile moves to a new network and obtains a new IP address. In SIP-based mobility management, the mobile updates its IP address with the visited SIP proxy or home proxy. SIP registration helps to expedite the location management functionalities. In case of MIPv6, the mobile sends the binding update to the home agent and corresponding host. Thus binding update to the home agent can be regarded as the registration process for MIPv6.

Configuration: Configuration is a process by which a mobile is configured with a layer 3 identifier by obtaining an IP address from the server. A layer 3 address configuration consists of several sub-processes such as signaling exchanges between the client and the server, duplicate address detection, and actual address assignment. Both MIPv6 and SIP-based mobility management share the common factor that each of these protocols does not require any foreign agent in the network and thus uses co-located care-of-address as the new identifier. SIP-based mobility management in IPv4 networks mostly depends upon DHCP for IP address configuration in a local area environment. There are several proposals that help design an optimized version of DHCP to reduce the time taken by an end client for configuring the IP address and other associated parameters. Both SIP-based mobility management for IPv6 networks and MIPv6 however take advantage of stateless auto-configuration while obtaining an IP address.

Tunneling: Mobile IPv6 tunnels payload packets between the mobile node and the home agent in both directions. This specific tunneling uses IPv6 encapsulation as specified by RFC 2473. In addition to the extra headers assigned to the original packet, there is also some time spent due to processing of encapsulation and de-capsulation. Thus each packet gets loaded with two extra headers one is the source address of the encapsulating agent and the second one is the destination address, where the packet gets de-capsulated. If these tunnels need to be secured then these get replaced by IPSEC tunnels between the mobile and home agent. SIP-based mobility on the other hand does not make use of tunneling as the media travels directly between the CH and MH. Thus processing delay due to encapsulation and tunneling overhead is avoided when SIP-based mobility is used.

Binding Update: Binding update is a process of notifying the correspondent node or other networking node such as home agent about the new layer 3 identifier of the mobile so that the data can get forwarded to the new address of the mobile after the handoff. In case of Mobile IPv6, as the mobile obtains a new care-of-address either via stateful DHCP server or stateless auto-configuration it notifies the correspondent host and the home agent. Since route optimization is an inbuilt mechanism for MIPv6, the new data during mid-session mobility does not need to get rerouted via home agent. On the other hand SIP-based mobility sends the binding update as part of its Re-INVITE signal to the correspondent host only since there is no concept of home agent here.

Fast-Handoff: Mobile IPv6 by itself does not provide fast-handoff methodologies. However there are extensions to Mobile IPv6 such as FMIPv6 and HMIPv6 that provide fast-handoff during mid-session mobility. FMIPv6 provides fast-handoff mechanism by introducing several reactive and proactive mechanisms, whereas HMIPv6 introduces a mobility anchor point such as MPA to take care of intra-domain mobility. Similarly there has been extension to SIP-based mobility to provide fast-handoff by introducing a network entity called B2BUA (Back-to-Back-User Agent) in the middle of the network, forwarding the transient traffic from the previous network or by doing localized multicast.

Security: Both of these mobility management schemes provide security for the signaling and data. MIPv6 takes advantage of network layer security such as IPSec to protect the signaling between the mobile, home agent. It can also use IPSec tunnel instead of MIP tunnel between the mobile and home agent to carry the tunneled data. SIP-based mobility management on the other hand can provide a multilayer security. It can either choose IPSec to provide an overall security layer for both signaling and media (RTP) or it can use S/MIME to secure the SIP signaling and use SRTP to secure the media stream. However SRTP can also be used to protect the data in case of MIPv6, but it will need new key distribution architecture unlike SIP-based mobility where it is done by Invite exchange method.

Session Management: SIP can also help setup and tear down multimedia session for both IPv4 and IPv6 networks. MIPv6 on the other hand cannot set up any session by itself but will depend upon other application layer protocols such as SIP or H.323 to set up the multimedia sessions. In that sense SIP-based mobility management can be a multi-functional mobility protocol that can manage session and take care of mobility as well. Personal and service mobility are supported by SIP signaling only, as it helps to track a mobile user by using the URI (Unique Resource Identifier) scheme. MIPv6 however does not provide personal mobility or service mobility.

Return Routability Support: Mobile IPv6 does provide return routability support by using CTI (Care-of-Test Init) and HTI (Home Test Init) messages. This actually verifies the new care-of-address of the mobile before the binding update is sent out. While it helps to avoid session hijacking etc., it does add delay to the binding update procedure. SIP, on the other hand, does not support inherent return routability testing, but new care-of-address of the mobile can be verified by using cryptographic technique such as SIP identity [5].

4.1 Applicability of Mobility Protocols in IMS

Both 3GPP and 3GPP2 have defined IMS and MMD architecture respectively. These architectures have embraced IPv6 as the underlying networking technology. Although SIP has been adopted as the signaling protocol for session management in

3GPP's IMS architecture, its mobility management can be realized either by SIP or by MIPv6 in 3GPP2 architecture. Both SIP-based mobility management and MIPv6 can provide the desired terminal mobility features by getting rid of some of the inherent inefficiencies associated with Mobile IPv4 such as trombone routing and tunnel overhead. We also describe the applicability of SIP-based mobility management and MIPv6 for this type of network. We illustrate both SIP signaling and data path in figures 3 and 4 respectively with MIPv6 as the underlying mobility protocol.

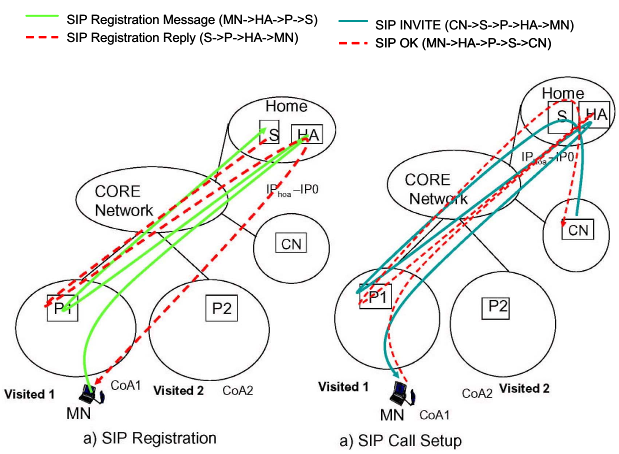

Figure 3. SIP signaling using MIPv6 in IMS/MMD

As shown in figure 3, both SIP registration and SIP Invite messages have to travel via the home agent. As shown in figure 4, new media for an existing session does not need to travel via the home agent but travels direct between CN and MN by way of direct binding update and route optimization.

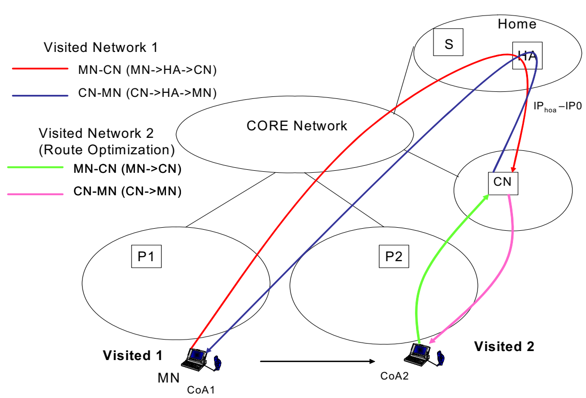

Figure 4. Data path using MIPv6 in IMS/MMD

Figure 5 and 6 show signaling and data path between CN and MN respectively, when SIP is used for mobility binding. Figure 5 shows the path of SIP signaling when underlying mobility protocol is SIP instead of Mobile IP. In this case both registration and call set up messages take a direct path between the mobile and S-CSCF instead of getting routed via any home agent.

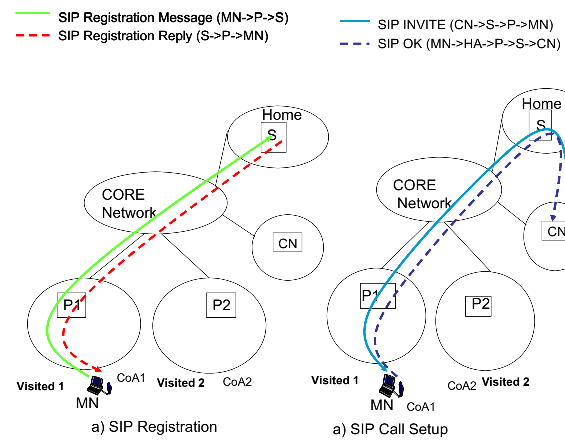

Figure 5. SIP signaling using SIP in IMS/MMD

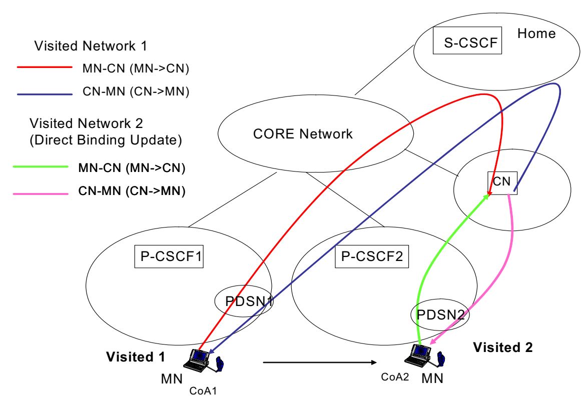

Figure 6. Data path using SIP signaling in IMS/MMD

5 Performance Analysis

There are several factors such as signaling (registration), handoff delay, packet delivery cost that can be analyzed to perform a comparative analysis between two protocols. Registration cost determines the cost between MN and the HA and the home proxy server. Packet delivery cost includes the transmission cost, processing cost that is inclusive of queuing delay etc. As the mobile moves, there is a certain cost associated with the binding update. The binding update cost could take into account few metrics such as distance between the mobile and the correspondent host. There are certain factors that determine the efficiency of these protocols. Mobility rate affects the average number of registrations made per unit time. The visited registrations provide an expedited registration compared to home registrations by limiting the registration messages within a certain limit. Cell residence time, packet mobility ratio, packet arrival rate are some other parameters that determine the efficiency as well. Cell residence time is defined as the average residence time during a call. Packet mobility ratio is defined as the product of call residence time mobility rate and packet arrival time. Thus overall cost is a function of registration cost, packet delivery cost, mobility rate, packet arrival rate, number of sessions. We illustrate call flows associated with two types of mobility protocols. Rebinding associated with layer 2 and layer 3 parameters during the handoff remain the common factors for both of these mobility protocols. However binding update and

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security association part of the protocol component are taken care of differently in each of these protocols. Because of the associated home agent in Mobile IPv6, binding update gets sent to both the home agent and the correspondent host. Binding update to the home agent helps expedite any new incoming session, whereas the binding update to the correspondent host

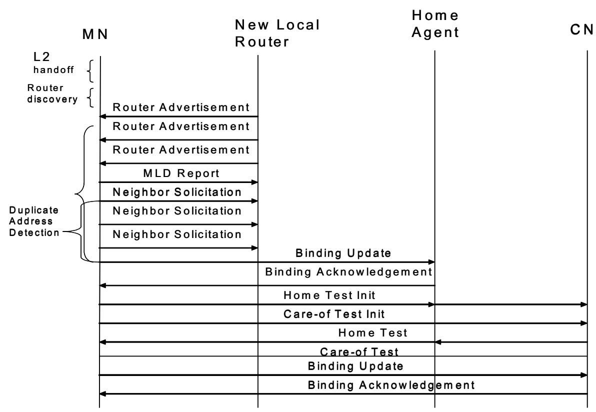

Figure 7 - Signaling flow for MIPv6

helps maintain the existing communication between the communicating nodes. In order to make sure that the binding update is not hijacked or spoofed, a pair of HTI and CTI messages are introduced that cause additional delays to the binding update procedure. As illustrated by Wong et al [6], these delays are compounded when both the hosts are mobile. Handoff delay due to SIP-based mobility does not suffer from any additional delays because of the absence of CTI and HTI messages. But SIP-based binding update involves three messages for the binding update to complete and additional delay is introduced due to application layer processing.

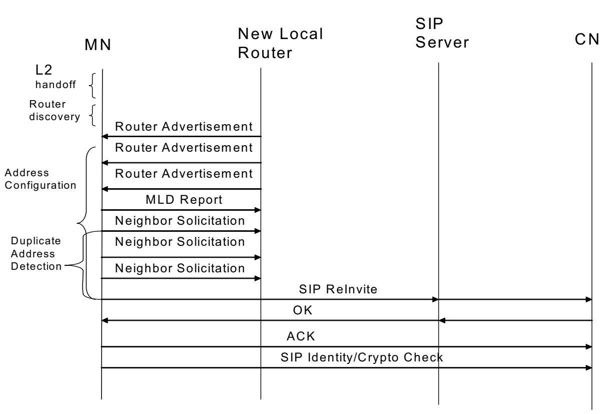

Figure 8: Signaling flow during SIP over IPv6

We present some of the experimental results obtained in a mobility testbed. This mobility testbed has used both SIP and MIPv6 to study the handoff delay. As it appears although SIP-based mobility takes advantage of the application layer signaling to provide terminal mobility functionality, its signaling suffers from additional delays due to processing delay at the application layer during handoff.

Figures 7 and 8 illustrate the associated call flows during a mobile's handoff from one visited network to another. As observed, MIPv6 is subjected to more number of signaling exchanges compared to SIPv6 during the complete handoff process. Table 1 shows the experimental results involving handoff delay for both SIPv6 and MIPv6 as reported in reference [7]. The handoff cases represent the movement from home to visited, and visited to visited network. It shows the delay associated with signaling and media for two cases - with and without duplicate address detection. SIP-based mobility appears to suffer from more delay because of application layer processing. Also these experiments have not taken into consideration the delays that could be contributed due to HTI and CTI for the case of MIPv6.

Table 1: Sample handoff delay SIPv6, MIPv6

Handoff Case	Signaling (ms)			Media (ms)		
	SIP (DAD)	SIP NDAD	MIPv6 NDAD	SIP (DAD)	SIP NDAD	MIPv6 NDAD
H12	3829	171.4	1.5	3854	420.8	21.1
H23	3932	161.6	2.0	4187.7	418.6	30.3
H31	1934.7	161.1	1.0	1949.4	408.4	25.3

6 Conclusions

We have analyzed two mobility protocols such as MIPv6 and SIP that operate in network layer and application layer respectively. We have illustrated how the basic functionalities during a mobility event are taken care of in each of these cases. Since both of these protocols share certain common behavior, we have shown how these two protocols could be useful for IMS/MMD architecture. A preliminary results of performance analysis and experimental results are also provided. This analysis can help derive the overall cost associated with a specific protocol under certain criterion. It is also inferred that this analytical comparison will help determine the scenario when SIP-based mobility is preferred to MIPv6 and vice-versa.

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