Comparative Analysis of IPv6 Mobility Management Protocols

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Abstract: The advancement of wireless and mobile communication technologies and the proliferation of mobile devices have made inroads into all aspects of day-to-day life due to their computing and communicating abilities. This amplified the number of mobile users using the Internet for e-business, online payments, shopping, file sharing etc. Providing a seamless and pervasive mobility is the most challenging and essential task to support global roaming. Internet Engineering Task Force [IETF] developed and standardized Mobile IPv6 (MIPv6) and its enhancements such as Hierarchical Mobile IPv6 (HMIPv6), Fast Handovers for Mobile IPv6 (FMIPv6) as Host-based mobility management protocols where the mobile node initiates the mobility related signaling. These protocols suffer from high handover latency, signaling overhead and packet loss. Recently IETF has standardized Network-based mobility management protocols such as Proxy Mobile IPv6 (PMIPv6) and Fast Proxy Mobile IPv6 (FPMIPv6) where the mobility signaling is controlled by network entities. This paper explores a detailed survey of various IPv6 mobility management protocol characteristics and techniques, by examining their performance parameters and elaborates the comparison of various mobility management protocols. Furthermore issues and challenges of each protocol are also discussed.

Keywords: mobility management, IPv6, handover management, location management, handover latency, binding update

1. Introduction

Internet has evolved into an important medium for all types of data sharing and connectivity which imposes the requirement of unique IP address from every host. Due to the high computing power of mobile devices at affordable price the number of mobile users is increasing rapidly. According to a study by Google and AT Kearney, world will see a major mobile explosion as the Internet user base will swell to several billions by 2017 [1]. This paved the way for the evolution of IPv6, one of the most significant technology changes in the history of the Internet. As IP addresses are assigned in a topological manner each subnet will have different IP address prefixes. The movement of MN between Access Points belonging to a common subnet is managed by L2 handover. But when a mobile node changes its point of attachment from one subnet to another it cannot retain its previous link IP address. This breaks the IP session continuity since TCP connections are configured by IP address [2]. Mobility support and management in IPv6 is gaining the attention of researchers to support global roaming.

Mobility Management

The process that a mobile node changes its point of attachment from one network to another is called Handover or Handoff. Managing this handover at L3 is called mobility management [3]. Mobility management is one of the most challenging and demanding research areas for fulfilling the requirements of future generation. It provides location management service and handover management service. Location management tracks the current location of the MN for delivering data packets. Handover management allows the network entities to maintain the on-going sessions of the MN while it is moving and changing its point of attachment [3]. Handover procedure is done in three phases i) handover initiation phase ii) handover decision phase iii) Handover execution phase [4].

Internet Engineering Task Force (IETF) working group has developed various mobility management protocols. These IP mobility management protocols are classified into host-based and network-based mobility protocols [5]. Among them Mobile IPv6 a host-based protocol

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is the most representative and standardized protocol which allows a mobile node to stay reachable while moving across the network domains [6]. Since the mobile node is involved in the mobility related signaling which requires protocol stack modification it coerces the mobile node for modifications which is expensive and complex. This lacuna finds the protocol unable to support the real-time applications. Various enhancements of MIPv6 such as hierarchical MIPv6 (HMIPv6) [7], Fast handovers for MIPv6 (FMIPv6) [8] were also proposed by IETF working group. But these protocols still suffer from the signaling overhead. Recently IETF-NETLMM (2008) has proposed network-based protocols such as Proxy Mobile IPv6 (PMIPv6) [9] and Fast PMIPv6 which reuses the basic functionalities of MIPv6 and supports local roaming. PMIPv6 does not require the involvement of the mobile node in any mobility related signaling instead the network devices take over the responsibility of signaling with the Home agent. However PMIPv6 still suffers from handover latency. This paper elaborates the essential features and potencies of various mobility management protocols in terms of techniques, characteristics and performance. Furthermore issues and challenges of each protocol are discussed.

2. Mobility Management Protocols

Terminologies:

Mobile Node (MN): A node that often changes its point of attachment in the internet, while still reachable via its home address

Home Agent (HA): A router on a mobile node's home network with which the MN has registered its HoA.

Foreign Agent (FA): A router in the visited network with which the MN has obtained its CoA.

Home Address (HoA): The permanent IP address registered with the HA

Care-of-Address (CoA): The temporary IP address valid in the visited network

MAP: Mobility Anchor Point

2.1 Host-based mobility management

Host-based mobility management protocols such as MIPv6, HMIPv6, and FMIPv6 support mobility management at the network layer (L3). In Host-based approach the MN initiates the handover and all the mobility related signaling. These protocols use shared-prefix addressing model in which multiple MN's in the same subnet configures their address with the regular IPv6 network prefix [10]. The network prefix is obtained from the router advertisement message which is broadcast. The configured address is verified for uniqueness at every subnet. In general all these protocols deploy AAA for authentication. These protocols do not support multi-homing [5]. Some of the Host based mobility management protocols are discussed.

2.1.1 Mobile IPv6

Characteristics: MIPv6 [11] is a Host-based global mobility management protocol which allows mobile nodes to remain reachable while moving around the network domains. It is a reactive protocol which supports both location management and handover management. The mobile node holds two types of address: HoA and CoA. A MN is always identified by its HoA which is a permanent IP address valid in its home network. A MN is always reachable at this HoA. While away from its home network, an MN is also associated with a care-of address (CoA), which provides information about the MN's current location. Thus the HoA always identifies the MN and the CoA always locates the MN on the network.

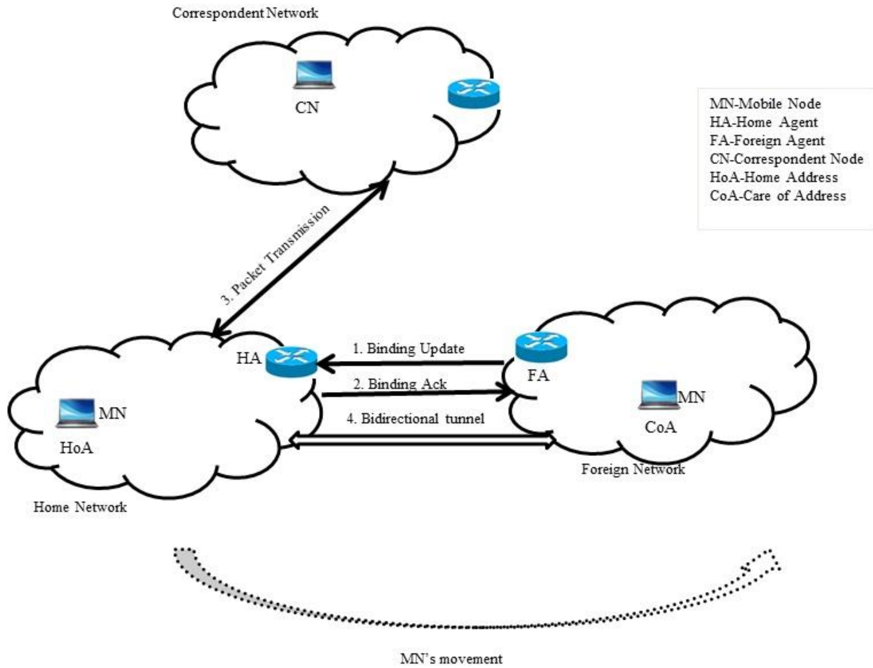

Figure 1 Signal flow of MIPv6

Technique: When an MN moves to a new location it exchanges Router Solicitation/Advertisement (RS/RA) messages to discover a new access router and configures the CoA. Furthermore, to ensure the uniqueness of the configured CoA (through stateless or stateful mode) the Duplicate Address Detection (DAD) procedure is performed by exchanging Neighbor Solicitation/ Advertisement (NS/NA) messages. The association made between the HoA and current CoA is known as binding. After acquiring a CoA, an MN updates its current location to the HA by exchanging binding update (BU) and binding acknowledgment (BAck) messages. This transparent routing imposes non-optimal routing path causing a communication delay if the MN and its CN are located on topologically closer networks or on the same network and the HA is far away. To enable route optimization, the MN updates its current location to CN by sending BU message. It also performs Return Routability (RR) procedure to secure the binding update with the CN. To optimize the route MN initiates a Home Test Init message via HA and Care-of Test Init message directly to CN. When a CN receives a Home Test Init or a Care-of Test Init message from a MN, it replies to the MN with a Home Test message and a Care-of Test message.

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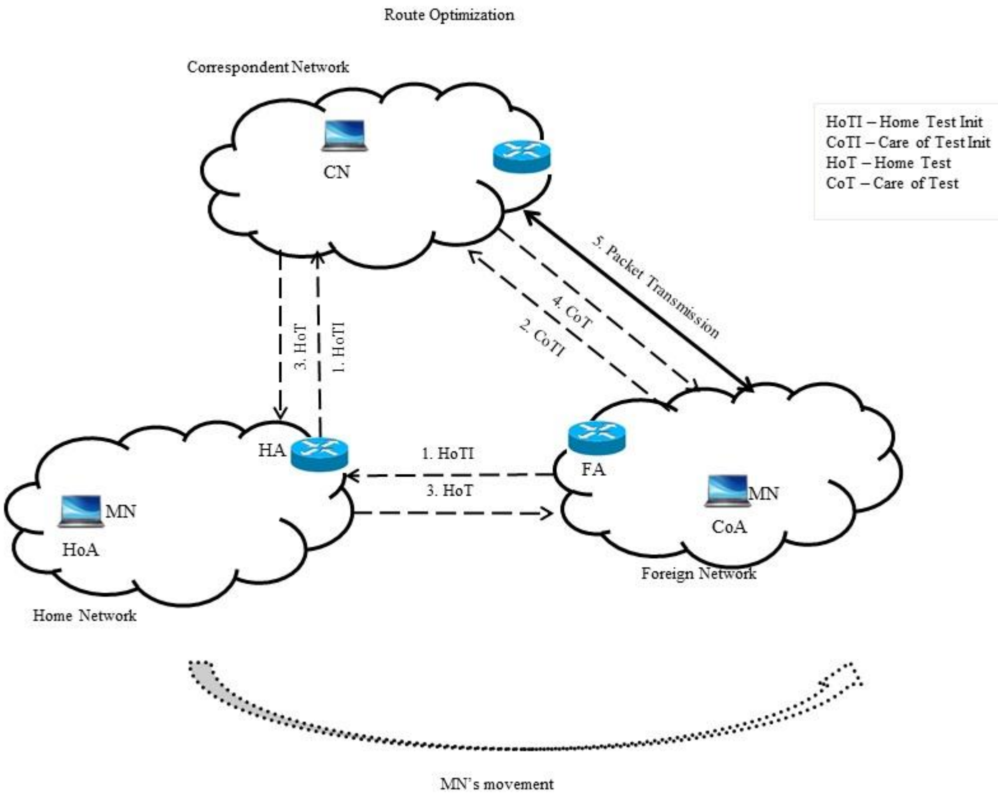

Figure 2 Route optimization

Issues: However MIPv6 suffers high handover latency, packet loss and signaling overhead. The performance of DAD takes quite a long time for exchanging NS/NA. The exchange of binding updates incurs round trip delay in handover and disrupts the active connections which lead to loss of packets [12]. Although the return routability procedure protects the sessions it also increases the signaling traffic. All these drawbacks make MIPv6 inappropriate for real-time applications such as video streaming and voice over IP service with QoS requirements.

2.1.2 HierarchicalMIPv6 protocol

Characteristics: Hierarchical MIPv6 [7] was developed to overcome the shortcomings of MIPv6. It is a local mobility management protocol because it handles the IP registration locally, which reduces the signaling overhead between MN, it's CN and HA. It is a reactive protocol. The HO latency is moderate and the packet loss is less in this protocol.

Technique: The global internet is divided in regions defining local area mobility. These domains are independent from subnets and are generally managed by a unique administrative authority. A new entity called Mobility Anchor Point (MAP) is introduced which can be located at any level in a

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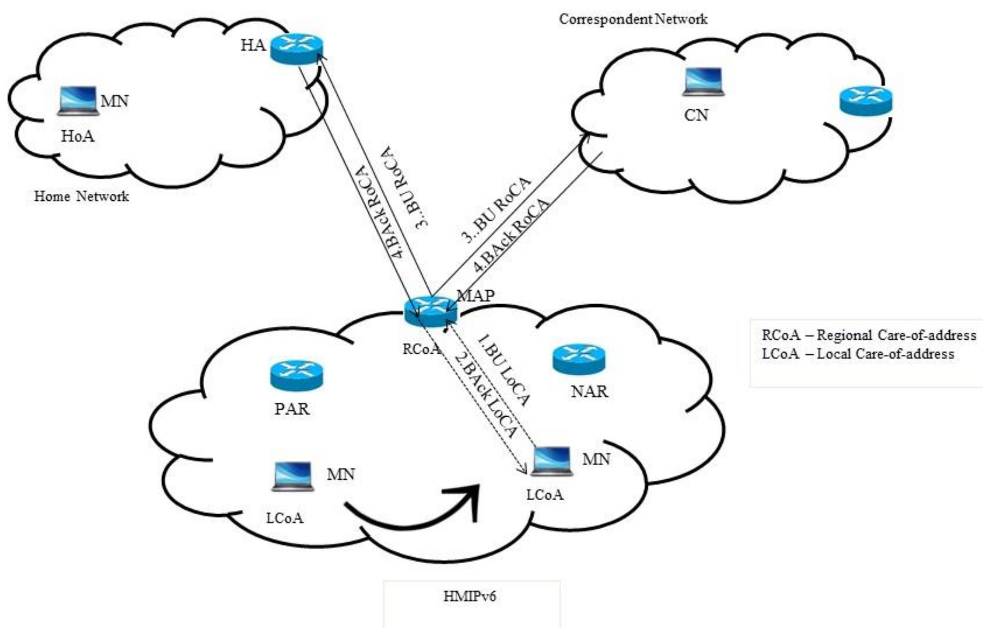

Figure 3 HMPv6

hierarchical network of routers. Each domain is connected to the rest of the internet by MAP. The MAP acts as a local HA in the visited network. The mobility anchor point is announced in the agent advertisement message. When the MN enters the foreign domain for the first time it must perform a home registration. The MN is assigned two temporary IP addresses: a regional care-of address (RCoA) which is configured by MAP's subnet prefix and an on-link care-of address (LCoA) that corresponds to the current location of the MN. When the MN roams from one access router to another within MAP's domain it updates the MAP with its LCoA but it does not need to update the HA or CN with its current location. Thus the local movement of an MN within MAP domain is hidden from HA and CNs. When the MN roams across the MAP domain it uses the MIPv6 and updates it's HA and CNs with its current location. Thus it reduces the signaling traffic

Technique: The protocol enables an MN to quickly detect that it has moved to a new subnet outside its domain and the delay incurred in location update.

Issues: Although it reduces the HO latency, packet loss and mobility signaling in intra-map handover compared to MIPv6 the inter-map handover may take a long time if the MAPs are topologically far away from HA. This protocol partially supports QoS.

2.1.3 Fast MIPv6 protocol

Characteristics: The FMIPv6 [8] protocol uses L2 triggers to anticipate the handoff before it actually occurs. This handoff anticipation helps to reduce the overall handoff delay. Compared to MIPv6 and HMIPv6, FMIPv6 reduces handover latency in both global and local roaming. The FMIPv6 can be either proactive or reactive. It does not support the location management.

by providing the new access point and the associated subnet prefix information when the

MN is still connected to its current subnet. The reactive FMIPv6 is based on break-before-make approach in which initiates the L3 handover procedure after the L2 handover is completed. The basic operation of proactive FMIPv6 is based on make-before-break approach in which an MN can anticipate the handover process and inform the new access router (NAR) about the handover by utilizing the L2 trigger to initiate the L3 handover procedure while the MN is still in the old access router (PAR) before the L2 handover is completed. This reduces the movement detection time. The MN anticipates the handover and sends the RtSolPr message to the PAR requesting the newCoA or by listening to the periodic PrRtAdv message. The PAR constructs the new CoA based on MN's interface ID and NAR's subnet prefix and replies MN by sending the PrRtAdv message which contains a new CoA, NAR's IP address and link layer address to be used by MN on NAR's link. The MN initiates the L3 handover by sending a FBU message with the new CoA to request the PAR to forward the packets to NAR. A tunnel is established between the PAR and the NAR to forward the packets. The PAR sends a Handover Initiate (HI) message to the NAR for checking the uniqueness of the address on the new link. Through the temporary tunnel established it redirects packets to the NAR. The NAR responds with a HAck message. On receiving the HAck message, it sends FBack message to the MN through both PAR and NAR access links. After the NAR receives both FBU and HAck messages it starts forward- ing the MN packets using the tunnel to the MN's old CoA. This tunnel starts at the PAR and ends at the NAR, not to the MN. This allows the MN to use its old CoA while verifying the new one. Moreover, the data packets sent by the MN from its old CoA will also be tunneled back from the NAR to the PAR till the MN verifies its new CoA and updates the HA and the CN. After that, the MN will update the NAR about its movements to its link and the NAR will forward all data packets that are buffered during the MN's handover. In general, FMIPv6 optimization [5] is based on a reliable hand-over prediction that enables predictive configuration of the MN involved in the mobility signaling. However, the handover prediction relies on the L2 trigger availability and the appropriate triggering time, which affects the beginning of the handover and will determine whether proactive or reactive fast handover optimizations will take place.

Issues: Since the FMIPv6 uses L2 triggers for fast handovers the delay of wireless link greatly influences the potency of the protocol. However, when mobility speed of an MN increases it has most significant effect on FMIPv6 since FMIPv6 relies on the assumption that detection of the new agent is well in advance of the actual handover. When the moving speed is higher, the assumption can break down more easily [13]. According to [14] lot of packets are dropped when the MN needs to scan for neighbouring AP's, but adding an additional wireless card to the MN resolves this problem. The tunnel between PAR and NAR is fairly long.

2.2 Network based mobility management protocols

Network based mobility management protocols was developed by IETF to address the problems encountered in host based protocols. In network based approach all the mobility related signaling is taken care by the serving network on behalf of MN [15]. The address model employed in network-based protocol is per-MN-prefix. A unique home network prefix (HNP) is assigned to each MN by unicast router advertisement. The uniqueness of the obtained address is verified at initial domain attachment only. The movement of MN is detected by L2 protocol. These protocols do not support route optimization. Network based protocols outperforms host-based protocols in terms of HO latency and packet loss. These protocols support multi-homing.

2.2.1 Proxy MIPv6:

Characteristics: PMIPv6 [9] is an extension of MIPv6 which uses many concepts and functionalities of MIPv6. It is a reactive protocol. It supports the mobility of MN in a topologically localized domain by assigning a unique HNP and reduces the signaling update time. It requires additional infrastructure for mobility management.

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Technique: The essential components of PMIPv6 are Policy Store (PS), Local Mobility Anchor (LMA) and Mobile Access Gateway (MAG). The PS is responsible for authenticating MN and maintaining MN's profile. The LMA is similar to the HA in functionality and maintains a binding cache entry for each registering MN. The MAG is similar to Access Router and handles all the mobility related signaling of MN as soon as it detects the movement of MN and establishes a tunnel with LMA for packet transmission. The mobile node is exempted from any mobility related signaling. In PMIPv6 when the previously attached MAG (PMAG) detects the movement of MN by examining its signal strength it signals LMA to update its binding cache entry table. The LMA upon receiving the update request sent from the authenticated PMAG waits for a certain amount of time to receive the update request from newly attached MAG (NMAG). The LMA will flush the new binding cache entry if it does not receive the binding update request from NMAG within a certain amount of time. When the mobile node enters the NMAG domain the NMAG detects the presence of new MN on its link and sends the PBU message to the MN's LMA. Upon receiving the PBU message, the LMA updates the binding cache entry table and binds the MN's home network prefix to a Proxy Care-Of Address (proxy-CoA), which is the NMAG address. The LMA then replies the NMAG with a Proxy Binding Acknowledgement (PBAck) message which contains the MN's home network prefix. When the NMAG receives the PBAck message it constructs the bidirectional tunnel with LMA after exchanging Router Solicitation (RS) or Router Advertisement with MN. When the MN receives the RA which contains the Proxy CoA sent by the NMAG, it configures the new CoA address by using either stateful or stateless address auto-configuration procedures. Since the LMA always provides the same home network prefix for a given MN during its movements, the MN obtains the same proxy CoA within the PMIPv6 domain which makes the MN to feel the entire PMIPv6 domain as a single link. After the successful configuration of the new CoA the packet transmission will be started.

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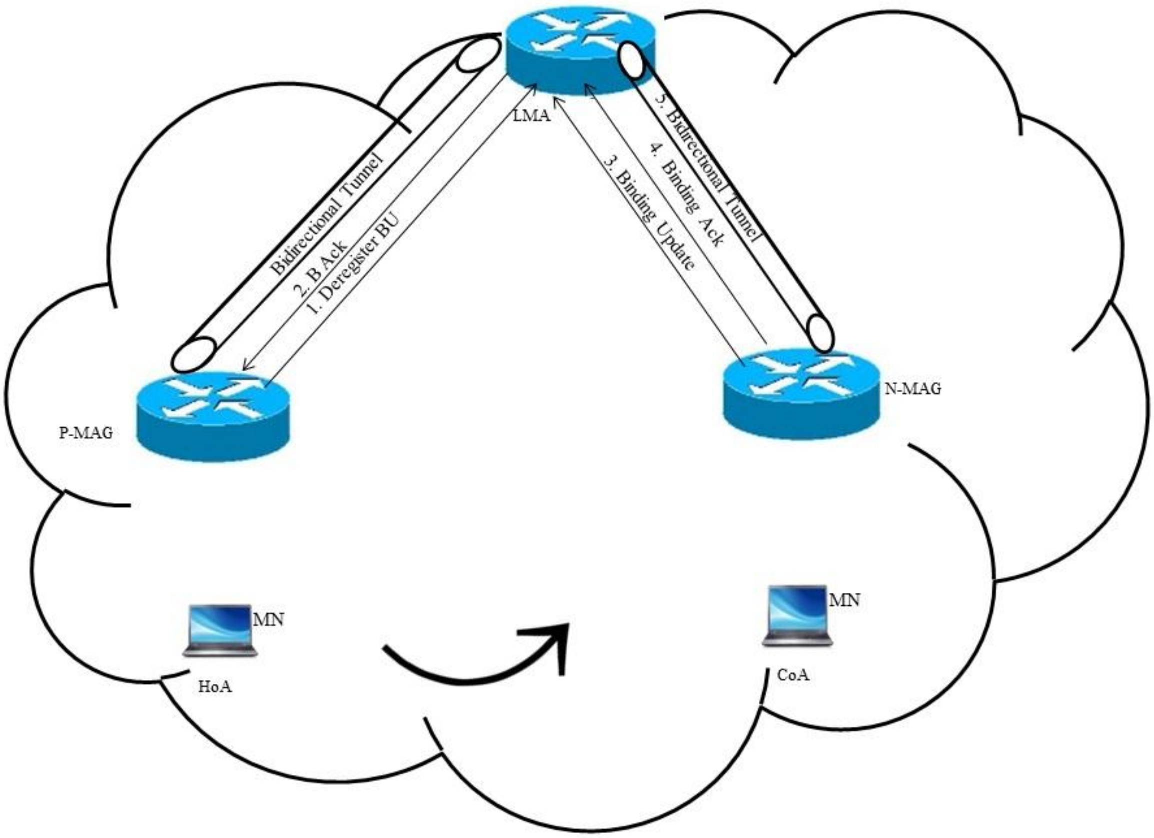

Figure 4 Signal flow of PMIPv6

Issues: Although all the mobility related signaling is controlled by the network entities in PMIPv6 it still suffers from high HO latency and packet loss due to connection disruption [16]. When an MN moves to NMAG domain it has to wait for a quite long time to receive the proxy CoA from NMAG which forces the MN to experience high handover latency and packet loss. Therefore, several fast HO mechanisms have recently been introduced to reduce the HO latency and packet loss. Since the PMIPv6 employs PS for validating and authenticating MN it incurs high packet loss and ineffective authentication problems which owe to high HO. Moreover PMIPv6 enabled network entities are expensive and consumes large amount of bandwidth in the network.

3 Analysis of various mobility management protocols

Handover latency is one of the most important parameter for analyzing the performance of the mobility management protocol. In this section we analyze the various mobility management protocols. The network model for analysis is taken from [17]. To simplify the analysis the intra-domain movement is taken into consideration. The notations used for analysis are taken from [18].

Handover latency of MIPv6:

In [11], it is specified that the routers for supporting mobility should be able to be configured with a smaller *MinRtrAdvInterval* value (= *MinInt*) and *MaxRtrAdvInterval* value (= *MaxInt*) to allow sending the unsolicited RA messages more often. Thus, the mean time between unsolicited RA messages can be expressed as (*MinInt*+*MaxInt*)/2. Therefore, for simplicity, it can be assumed that the mean value of the movement detection delay in MIPv6 and

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HMIPv6 is the half of the mean time between unsolicited RA messages, and thus $T(MD) = (MinInt+MaxInt)/4$ .The handover latency can be expressed as the sum of the delay in movement detection, duplicate address detection and binding update. If L(HO) denotes the handover latency in exchanging mobility signaling then,

$$L(HO)_{MIPv6} = T(L2)+T(MD)+T(DAD)+T(REG)$$
$$T(REG) = T_{(MN,HA)}+T_{(HA,CN)}+T_{(MN,CN)}$$

Where T(L2) is the link layer latency. T(MD) is the delay in movement detection caused by the exchange of RA and RS packets between MN and AR. T(DAD) is the delay in duplicate address detection caused by the exchanging of NS and NA between MN and AR. T(REG) is the delay incurred in binding update with HA and CN with RO. $T_{(MN,HA)}$ is the delay in exchanging BU, BAck, HoTI and CoTI. $T_{(HA,CN)}$ is the delay in sending HoTI and CoTI. $T_{(MN,CN)}$ is the delay in sending HoT, CoT, BU and BAck.

Handover latency of HMIPv6

Let $L(HO)_{HMIPv6}$ be handover latency of HMIPv6 [7] in the administrative domain. Then,

$$L(HO)_{HMIPv6} = T(L2)+T(MD)+T(DAD)+T(REG)_{MAP}$$
$$T(REG)_{MAP} = T(BU)+T(BAck)$$

Where $T(REG)_{MAP}$ is the delay caused in binding update between MN and MAP. As MN roams within same MAP administrative domain, binding update and return routability between MN and HA/CN is not required to be performed.

Handover Latency of FMIPv6

Let $L(HO)_{FMIPv6\text{-}P}$ be handover latency of FMIPv6 [8] Predictive Mode. Then

$$L(HO)_{FMIPv6\text{-}P} = T(L2) + T(FNA)+T(BU)$$

Where T(FNA) is latency caused in sending Fast Neighbor Advertisement message by MN. Only after receiving FNA message NAR forwards buffered packets to MN. In FMIPv6 predictive mode DAD process is performed before L2 handoff. Moreover, Proxy Router Solicitation / Advertisement messages with the previous access router (PAR) are also exchanged before L2 handoff. So it reduces HO latency.

Let $L(HO)_{FMIPv6\text{-}R}$ be handover latency of FMIPv6 Predictive Mode. Then

$$L(HO)_{FMIPv6\text{-}R} = T(L2) + T(FNA)+T(DAD)+T(BU)$$

After receiving FNA message NAR performs DAD process and send New CoA to MN. Hence T(DAD) latency between PAR and NAR is also considered in FMIPv6 Reactive Mode.

Handover latency of PMIPv6:

Let $L(HO)_{PMIPv6}$ be handover latency of PMIPv6 [9]. Then

$$L(HO)_{PMIPv6} = T(L2) + T(BU)_{(MAG\text{-}LMA)} + T(RA)_{(MAG\text{-}MN)}$$

Where $T(BU)_{(MAG\text{-}LMA)}$ is the delay caused in exchanging PBU/PBack messages between MAG and LMA, and $T(RA)_{(MN\text{-}MAG)}$ is delay caused in sending RA message from MAG to MN. In PMIPv6 HO latency is reduced as handover process is controlled by MAG and LMA. Authentication of MN by AAA server incurs additional delay.

The analysis shows that performance of DAD and binding updates increases the HO latency [16]. It is very high in MIPv6 due to the duplicate address detection because until the DAD process is over the MN cannot use the CoA for communication. The HO latency is less in HMIPv6 Intra-domain, as the MN need not update its local movement to HA/CN but the latency increases due to binding updates inter-domain movement. FMIPv6 in predictive mode substantially reduces the latency as MD and DAD are performed before handover but additional signaling is incurred between PAR and NAR [5]. PMIPv6 reduces the HO latency as the handover does not require MN's involvement and binding updates are eliminated. PMIPv6 and FMIPv6 outperform the other protocols because of utilizing L2 trigger [19].

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4 Conclusions

In this paper, various network layer mobility management protocols developed by IETF have been surveyed in detail. The characteristics, techniques have been elaborated and performance of each protocol in terms of handover latency is investigated. From the conducted analysis it is confirmed that binding updates and DAD process consumes a large amount of time during handover which degrades the performance of MIPv6 and HMIPv6 inter-domain roaming. The wireless link delay highly impacts the handover latency. Utilizing L2 information and employing some buffer management reduces HO latency considerably in PMIPv6 and FMIPv6. The HO latency is greatly influenced by network topology which makes these protocols inefficient in current content delivery networks and flat network architectures opening a new platform of research in distributed mobility management.

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