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NETWORK LAYER MOBILITY MANAGEMENT PROTOCOLS IN HETEROGENEOUS ENVIRONMENT

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Abstract: *In heterogeneous environment, mobility management represents the basis for providing seamless connectivity to users roaming between various access networks. Several network layer mobility management protocols have been and still are being developed. Each solution provides a specific functionality and requires operations of particular network entities. This paper surveys key protocols for providing network layer mobility support, possibilities of their improvements, as well as functionality achieved by combining them.*

Ključne reči: *Handover, HetNets, mobile IP, mobility management, network layer.*

1. Introduction

In order to meet the upcoming exponential growth of mobile data traffic, operators are deploying more network infrastructures to make wireless systems closer to the users, and thus increase spectrum efficiency and spatial reuse. The availability of wireless networks is the result of low-cost local points of attachment (PoA) deployment and the operators' short-term strategies of covering smaller geographic areas (such as relay stations deployment). The advantage of femtocells, for example, will certainly improve indoor coverage and provide reliable connectivity without the need for the cost-inefficient deployment of additional base stations. On the other hand, some dense urban areas will be served by a mix of overlapping access networks (e.g., Wi-Fi, WiMax, LTE, etc.) reaching different coverage. It is clear that mobile terminals (MTs) have been evolving from single interface phones to multitask devices with a number of connectivity capabilities.

In this context, heterogeneous networks (HetNets), which are comprised of coexisting macrocells and low power nodes such as picocells, femtocells, and relay nodes, have been heralded as the most promising solution to provide a major performance leap [1]. However, in order to realize the potential coverage and capacity benefits of HetNets, operators are facing new technical challenges in mobility management, inter-cell interference coordination, backhaul provisioning, etc. Among these challenges, mobility management is of special importance [2].

The next generation in mobility management enables different wireless networks to interoperate with one another to ensure seamless mobility and global portability of multimedia services. Mobility management affects the whole protocol stack, i.e. radio resource reuse at the physical layer, encryption and compression at the link layer, congestion control at the transport layer, and service discovery at the application layer. Because mobility is essentially an address translation problem, it is therefore naturally best resolved at the network layer by changing the routing of datagrams destined to the mobile node (MN) to arrive at the new PoA.

This paper surveys recent researches on network layer mobility management in heterogeneous environment. The rest of this paper is organized as follows. First, traditional and perspective mobility management protocols are presented. Special attention is provided to mobile IP solutions, because they are widely accepted in this research field. Next, protocol improvements possibilities are analyzed. Finally, some hybrid mobility management solutions are briefly presented.

2. Traditional Network Layer Mobility Management Protocols

Various network layer protocols have been proposed as global or local mobility management solutions that are intended to handle the MN's mobility within the same domain or across network domains, respectively. IP mobility can be classified into two main categories: host-based and network-based. In the host-based category, the MN must participate in the mobility related signaling. On the other hand, in the network-based category, the network entities are the only entities that are involved in the mobility related signaling.

It is obvious that **Mobile IPv4** (MIPv4) [3], proposed by the Internet Engineering Task Force (IETF) more than ten years ago, is not the optimal solution to support an increasing number users and real-time services, because it suffers from extra end-to-end (E2E) packet delay due to the routing of each packet through the home agent (HA) (a.k.a. triangular routing), lack of addresses and high signaling load. In addition, all on-the-fly packets, which were already tunneled to the old care-of address (CoA), are lost whenever the MN moves from one to another foreign agent (FA), because the new FA cannot inform the old one about this movement. Furthermore, the mobility signaling delay is very high and may vary significantly when the distance between the home network and the visited network is large.

Mobile IPv6 (MIPv6) [4] is a well-known standard for global mobility support, which overcomes many constraints experienced in MIPv4. MIPv6 enables a MN to move within the Internet domain without losing current data connection directly with its corresponding node (CN), while in MIPv4 the CN sends a packet to the MN through the HA and FA by a longer route. MIPv6 supports node mobility in order to be reachable at anytime and anywhere by its CN. This is done by providing the MN with a fixed home address through HA. Furthermore, if the MN is in the home network all packets destined to it will not have to be altered and can reach through the normal routing process. Moreover, when the MN moves to a new visited network it is assigned a temporary CoA provided by the visited network and the MN will not be reachable through its home address. Therefore, the HA is now responsible to receive packets that are destined for the MN. Whenever HA receives such packets, it will tunnel it to the MN's current CoA.

Therefore, MN has to update its HA on its current CoA, consequently, HA will forward all packets through a tunnel destined to the MN's home address to its current CoA at the visited network. Therefore, the data transfer between HA and MN uses the tunnel ends at the MN directly (not to the FA as in the MIPv4). Furthermore, MIPv6 introduces a route optimization in order to solve the triangular routing problem and improve network performance. The basic idea is to provide efficient routing between the MN and its CN, through exchange query-response messages between the MN and CN to establish a direct and secure route. Hence, all packets can travel between the CN and MN without being intercepted by the HA. This optimization improves network reliability, security and reduces network load.

However, despite the good standing of this protocol, it has been slow to deploy in real implementations due to some drawbacks, such as high handover latency, high packet losses and signaling overheads [5]. In addition, the local mobility of MN is handled in the same way as global mobility, i.e., when the MN moves to a new subnet, it will update its new PoA each time to HA and CN, without any locality consideration, thereby causing perceptible degradation of real-time traffic performance. All these weaknesses led to various researches and developments of other mobility enhancements that focused on MIPv6 performance improvements.

Fast MIPv6 (FMIPv6) [6] was proposed to reduce latency and minimize service disruption during handover related to the MIPv6. It uses link layer events (triggers) in order to improve the handover performance in terms of packet loss by anticipating the handover and tunneling the packets to the new access router (AR) until the binding update is received by the HA and CN. At the same time the MN will advertise its presence and availability to the new AR and will start receiving data to the new CoA. This solution provides a substantial improvement of handover latency and packet loss. On the other hand, the main drawback of this solution is the precise coordination required between the MN, previous AR and new AR and high unpredictability of packets arriving at the PoA.

In general, FMIPv6 optimization is based on a reliable handover prediction that enables predictive configuration of the MN involved in the mobility signaling. However, this prediction relies on the link layer trigger availability and the appropriate triggering time, which affects the beginning of the handover and will determine whether fast handover optimizations will take place. Accordingly, the absence of an accurate prediction such as erroneous handover detection, and, hence, early triggers, may negatively affect the seamlessness of this protocol.

Hierarchical MIPv6 (HMIPv6) [7] is a local mobility management protocol designed to reduce handover latency and signaling overheads that occur when MN frequently change PoA. It adds an indirection for locating the MN independent of where the CN and HA are located in the network topology. It tunnels packets to a mobility anchor point (MAP), which is addressed by a regional CoA. The MAP in turn, tunnels these packets to the MN addressed by an on-link (local) CoA. Therefore, the MN's local handover mobility information only needs to be signaled to the MAP, hence, avoiding high handover latency and binding updates overheads.

In general, all the host-based mobility management protocols require a protocol stack modification of the MN and change its IP addresses in order to support its mobility within or across network domains. Consequently, it may increase the MN complexity and waste of radio resources. Furthermore, some drawbacks still remain in the host-based mobility protocols (e.g., long handover latency, high packet loss, signaling overhead, etc.), which, put together, indicate the inappropriateness of these protocols to satisfy the quality of service (QoS) requirements for multimedia services.

Proxy MIPv6 (PMIPv6) [8] has been standardized by the IETF Network-based Localized Mobility Management (NETLMM) working group as a fundamental protocol of the homonymous category. It is based on MIPv6 and reuses some of its signaling concepts and functions. In particular, user terminals are provided with mobility support without their involvement in mobility management and signaling, as the required functionality is relocated from the MN to the network. Movement detection and signaling operations are performed by a new functional entity called the mobile access gateway (MAG), which usually resides on the access router. Through standard terminal operation, including router and neighbor discovery or using link layer support, the MAG learns about MN movement and coordinates routing state updates without any mobility-specific support from the terminal. IP addresses used by nodes within localized mobility domain (LMD) are anchored at an entity called the local mobility anchor (LMA), which plays the role of local HA for the corresponding domain. Bidirectional tunnels between the LMA and MAG are set up so that the MN can keep the originally assigned address despite its location within the LMD. Through the intervention of the LMA, packets addressed to the MN are tunneled to the appropriate gateway within the domain. Upon arrival, packets are locally forwarded to the MN, which is therefore oblivious to its own mobility.

As illustrated in Fig. 1, the overall PMIPv6 signaling flow includes initial attachment phase and handover procedure phase. Once a MN attaches to a MAG module and sends router solicitation (RtrSol) message for the first time, the MAG and the LMA exchange proxy binding update (PBU) and proxy binding acknowledgement (PBA) messages. The LMA sends an address assigned to a MN via a PBA message, and also sets up a bidirectional tunnel with the MAG for the MN to be able to communicate with a CN.

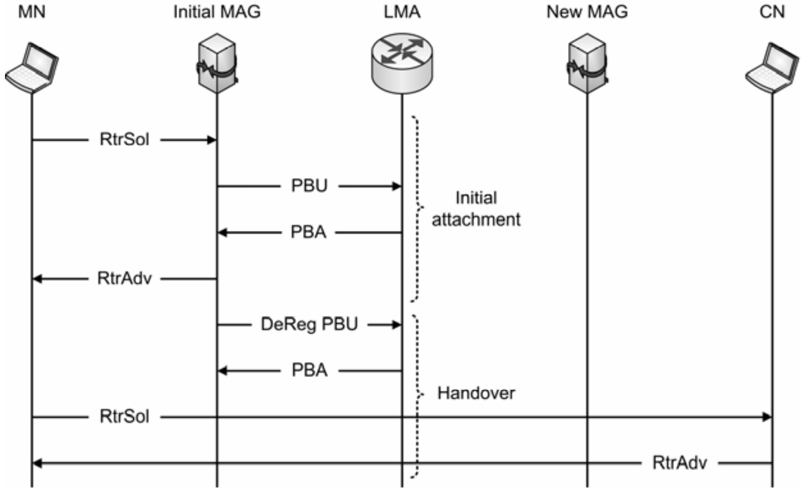

Figure 1. Proxy MIPv6 operations.

The second phase describes the MN movement from initial MAG to new MAG until it can resume send/receive data packets to/from its CN. When initial MAG detects the MN movement away from its access link to the new MAG, it sends a Deregistration PBU (DeReg PBU) message to the LMA with the zero value for PBU lifetime. Upon receiving this request, the LMA will identify the corresponding mobility session for which the request was received, and accepts the request after which it waits for a certain amount of time to allow the MAG on the new link to update the binding. However, if it does not receive any PBU message within the given amount of time, it will delete the binding cache entry. Upon detecting the MN on its access link, the new MAG will signal the LMA to update the binding state. Finally, the serving MAG will send the router advertisements (RtrAdv) containing the MN's home network prefixes.

In PMIPv6, all the data traffic sent from the MN gets routed to the LMA through a tunnel between the MAG and the LMA. The LMA forwards the received data packets from the CN to the MAG through a tunnel. After receiving the packets the MAG at the other end of the tunnel will remove the outer header and forward the data traffic to the MN. Furthermore, PMIPv6 is a localized mobility management protocol which shortens the signaling update time and reduce the disruption period. Therefore, the PMIPv6 handover can be relatively faster than the MIPv6 by using the link layer attachment information. However, PMIPv6 still suffers from communication interruptions due to the link layer handover, which basically, depending on the underlying technology used, needs some time to complete [5]. Consequently, all data packets sent during this handover period are lost. Moreover, enhancing the seamlessness of the PMIPv6 handover is still needed in order to support the QoS of real-time sensitive services and multimedia applications as well as the interaction with MIPv6 in order to support global mobility. Recently, the 3GPP and WiMAX forum have envisaged employing PMIPv6 for interworking with heterogeneous wireless access networks [9].

In the case when MN connects to the PMIPv6 domain through multiple interfaces and over multiple access networks, the network will allocate a unique set of home network prefixes for each of the connected interfaces. However, if a handover is performed by moving its address configuration from one interface to another, and if the LMA receives a handover hint from the serving MAG about the same, the LMA will assign the same home network prefixes that it previously assigned prior to the handover. The MN will also be able to perform a handover by changing its PoA from previous MAG to a new one using the same interface and will be able to retain the address configuration on the attached interface. In Table 1, a summary comparison is provided for the main characteristics of various network layer mobility management protocols.

Table 1. Characteristics of traditional network layer mobility management protocols.

Protocol	MIPv6	FMIPv6	HMIPv6	PMIPv6
Mobility scope	Global	Global/local	Local	Local
Management	Host-based	Host-based	Host-based	Network-based
Required entities	HA	HA, AR	HA, MAP	LMA, MAG
Route optimization	Supported	Not supported	Supported	Supported
Handover latency	High	Low	Moderate	Low
Packet loss	High	Less/high	Less	Less
Multihoming	Not supported	Not supported	Not supported	Supported

The **Network Mobility (NEMO) Basic Support** protocol [10] extends MIPv6 to support the movement of a whole network (mobile network), by the mobile router taking care of the mobility management (i.e., mobility signaling and tunnel setup) on behalf of the nodes of the network, called mobile network nodes (MNNs). The IP addresses of these nodes belong to the mobile network prefix (MNP) that is anchored at the HA of the mobile router. Regarding mobility, the NEMO is a client-based solution, because it is also based on mobility functionality in the MN, a router in this case. The main purpose of this protocol is to address the requirement of transparent Internet access from vehicles.

NEMO inherits the limitations of MIPv6 as well as having its own drawbacks. Although NEMO seems to fit well in the context of terrestrial transport systems, it has not been designed to support the dynamics and special characteristics of vehicular communication networks (VCNs) [11]. The current version, as defined by the standard, does not incorporate a route optimization mechanism, and that affects its performance in vehicular scenarios.

Because packets sent by CNs reach the mobile network through one or more bi-directional tunnels between the HA and the mobile router, route traversed by packets may be suboptimal when the mobile network and CN are in the same network (or topologically close) that is far away from the HA. Suboptimal route results in inefficiencies such as higher E2E delay, additional infrastructure load, susceptibility to link failures, etc. [12]. Moreover, requirement of all packets from or to the mobile network to pass through HA creates bottleneck. Header overhead is another issue associated to the problems of suboptimal route. As a packet passes through each tunnel, it is encapsulated resulting in increased packet size. Encapsulation results in header overhead that decreases bandwidth efficiency, and increases the chance of fragmentation. Moreover, encapsulated packets are also decapsulated as many times as the number of encapsulations. Encapsulation and decapsulation require additional processing at HA and mobile router. Handover of a mobile router is similar to that of a MIPv6 node. When a mobile router moves from one network to another, it has to discover an access router to obtain a CoA, and perform registration with the HA. This procedure results in delay that interrupts ongoing connections. The problem of handover delay reduction is not unique to NEMO, and has been adequately addressed for MIPv6.

An interesting extension to PMIPv6, specially designed for public transport system communications, is proposed in [13]. **NEMO-enabled PMIPv6** (N-PMIPv6) fully integrates access networks in localized mobility domains. Concerning this approach, users can obtain connectivity either from fixed locations or mobile platforms (e.g., vehicles) and can move between them while keeping their ongoing sessions. N-PMIPv6 architecture exhibits two remarkable characteristics:

- It is totally network-based solution, therefore no mobility support is required in the terminals.
- The handover performance is improved, both in terms of latency and signaling overhead.

A MN is not only able to roam between fixed gateways (i.e., MAGs as in conventional PMIPv6), but also between moving gateways (called mMAGs, which are also able to roam within the domain), without changing the IPv6 addresses they are using. A mMAG behaves as a mobile node from the viewpoint of fixed gateways, since moving gateways roam between different fixed gateways while keeping the same IP address. Moreover, a mMAG behaves as a regular gateway from the MN's perspective, and extends the localized domain by providing attached terminals with IPv6 prefixes of the domain, and by forwarding their packets through the LMA. An additional bi-directional tunnel between the moving gateway and the LMA is used to hide the network topology, and avoid changing the particular prefix assigned to the terminal while roaming within the same domain.

3. Possibilities of Network Layer Mobility Protocols Enhancement

Considering reduction of handover latency and data loss in PMIPv6, the **Fast Handovers for PMIPv6** (FPMIPv6) procedure is proposed [14]. This standard specifies some necessary extensions for FMIPv6 to support the scenario when the MN does not have IP mobility functionality and hence is not involved with either MIPv6 or FMIPv6 operations. Moreover, FPMIPv6 does not require any additional IP-level functionality on the LMA and the MN running in the PMIPv6 domain.

FPMIPv6 can operate in predictive and reactive modes. In predictive mode (if the MN detects a need for handover), the MN initiates handover procedures by transmitting an indication message to the previous MAG. In reactive mode, when the MN requires handover, the MN executes network re-entry to the new MAG. Then new MAG initiates handover procedures before the MN informs the necessity of handover to the previous MAG. Predictive (initiated over previous MAG) and reactive (initiated by new MAG) FPMIPv6 operations are presented in Fig. 2.

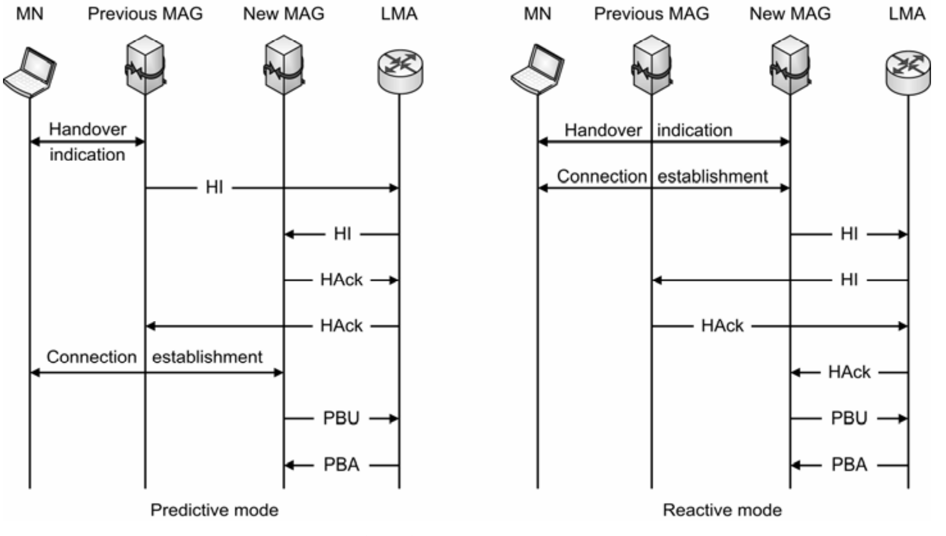

Figure 2. Fast handovers operations for PMIPv6.

FPMIPv6 can reduce the PMIPv6 handover delay by allowing the MN to begin forwarding packets as soon as it detects a new link. FPMIPv6 operates on the assumption that each of the MAGs has a database that has information (e.g., PoA identification, proxy CoA, etc.) of all the other MAGs that exist in the same network. However, if the new MAG is located in a heterogeneous network then there may be no way to obtain the proxy CoA of the new MAG in advance, which is a problem that was occurred when conducting handover between heterogeneous access networks. Especially when a real-time multimedia packet stream needs handover management support, information of the new MAG that is located in the heterogeneous network needs to be known in advance as the QoS parameters on the target network side may need to be negotiated. Due to these reasons, even with FPMIPv6 implemented, it may be difficult to conduct seamless handover to the new MAG. Therefore, an enhanced FPMIPv6 scheme is proposed to reduce the packet-forwarding delay and E2E data transmission delay by eliminating traffic aggregation problems through improved coordinated data-path switching and also by using shorter data-paths instead of longer IP-tunneled data-paths [15].

Commonly, signaling packets are small and approximately the same size. Therefore, compared to packet transmission time, the propagation delay becomes an important criteria in mobility protocols performance analysis. In order to present performance analysis of FPMIPv6 and enhanced FPMIPv6, it can be assumed that the previous and new PMAG are at equal distance with the LMA. Therefore, the message propagation delay of PBU (T_{PBU}), PBA (T_{PBA}), fast PBU (T_{FPBU}), fast PBA (T_{FPBA}), handover packet-forwarding address request (T_{HPAR}), and corresponding response (T_{HPAP}) can all be set equal to the propagation delay between the LMA and MAG ($T_{LMA\text{-}MAG}$) since these messages are exchanged between the previous MAG and LMA or the new MAG and LMA. Since, signaling packets exchanged between MAGs need to be routed through the LMA, the propagation delay for HI (T_{HI}), HAck (T_{HAck}), and $T_{MAG\text{-}MAG}$ are all equal to $2T_{LMA\text{-}MAG}$. The connection establishment time (T_{conn}) can be set to $2T_{MAG\text{-}MN}$, where $T_{MAG\text{-}MN}$ is the propagation delay between the MAG and MN, and the transmission delay of forwarded data packets (T_{df}) is set to 10 ms. $T_{MAG\text{-}MN}$ is set to 0.5 ms and $T_{LMA\text{-}MAG}$ is set as a variable where various values were tested during the simulation. The handover indication message propagation delay ($T_{h.ind}$) is equal to $T_{MAG\text{-}MN}$.

For the predictive mode, the handover signaling delay ($T_{HO,pre}$) and data packet-forwarding delay ($T_{DF,pre}$) of FPMIPv6 are expressed respectively as

$$T_{HO,pre} = T_{h.ind} + T_{HI} + T_{HAck} + T_{conn} + T_{PBU} + T_{PBA}, \tag{1}$$

$$T_{DF,pre} = 2T_{df} + T_{MAG-MAG} + T_{MAG-MN}. \tag{2}$$

On the other hand, handover signaling delay ($T_{E\text{-}HO,pre}$) and data forwarding delay ($T_{E\text{-}DF,pre}$) for enhanced FPMIPv6 are expressed respectively as

$$T_{E-HO,pre} = T_{h.ind} + 2T_{FPBU} + 2T_{FPBA} + 2T_{conn} + (T_{HPAR} + T_{HPAP}), \tag{3}$$

$$T_{E-DF,pre} = 2T_{df} + T_{LMA-MAG} + T_{MAG-MN}. \tag{4}$$

In the reactive mode, the handover signaling delay ($T_{HO,rea}$) and data packet-forwarding delay ($T_{DF,rea}$) of FPMIPv6 are expressed respectively as

$$T_{HO,rea} = T_{conn} + T_{HI} + T_{HAck} + T_{PBU} + T_{PBA}, \tag{5}$$

$$T_{DF,rea} = 2T_{df} + T_{MAG-MAG} + T_{MAG-MN}. \tag{6}$$

Signaling delay ($T_{E\text{-}HO,rea}$) and data packet-forwarding delay ($T_{E\text{-}DF,rea}$) for reactive mode of enhanced FPMIPv6 are expressed respectively as

$$T_{E-HO,rea} = T_{conn} + 2T_{FPBU} + 2T_{FPBA} \,, \tag{7}$$

$$T_{E-DF,rea} = 2T_{df} + T_{LMA-MAG} + T_{MAG-MN} \,. \tag{8}$$

The total time-delay of the FPMIPv6 procedure is defined as $T_{FPMIPv6,x} = T_{HO,x+TDF,x}$ and the total time-delay of the enhanced FPMIPv6 procedure is defined as $T_{E\text{-}FPMIPv6,x} = T_{E\text{-}HO,x+TE\text{-}DF,x}$, where *x=pre* or *x=rea* when representing predictive or reactive mode, respectively. Based on the above assumptions and relations, it can be concluded that $T_{FPMIPv6,x}$ = ($T_{EFPMIPv6,x}$ + $3T_{LMA\text{-}MAG}$), therefore $T_{FPMIPv6,x} > T_{E\text{-}FPMIPv6,x}$. Fig. 3 shows the results obtained through simulation of total handover delay for predictive and reactive modes with varying $T_{LMA\text{-}MAG}$ [15].

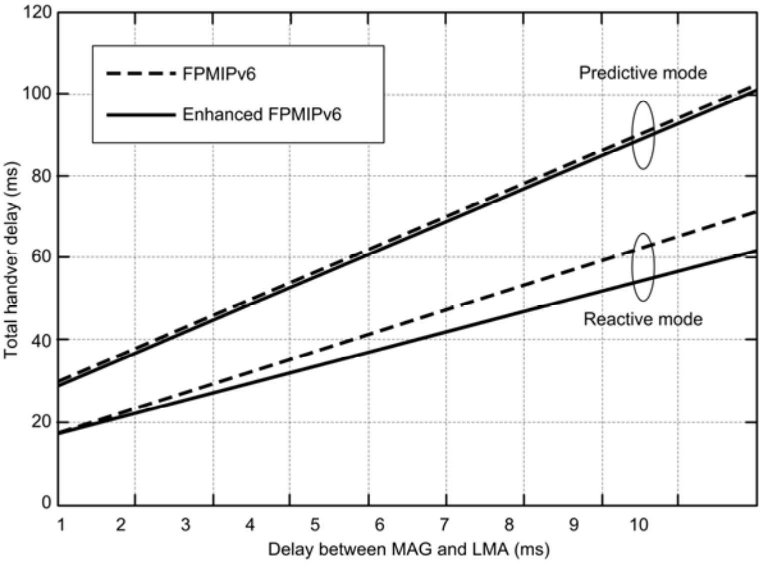

Figure 3. Total handover delay for FPMIPv6 and enhanced FPMIPv6.

Obvious delay reductions, particularly in reactive mode, can be regarded as a consequence of reduction in the data forwarding and the handover delay of the enhanced FPMIPv6 scheme. Since data packets are buffered at the LMA in the enhanced FPMIPv6, no IP-tunneling is required between the previous and new MAG. These advantageous properties make the enhanced FPMIPv6 scheme more suitable for heterogeneous mobility compared to FPMIPv6 operations.

4. Hybrid Network Layer Mobility Management Solutions

Although each of the network layer mobility management protocols is designed to be used independently, there are circumstances in which two or more of them can be combined. In most cases the combination is the result of individual actions of the different actors involved in scenario (e.g., users, operators) with each of them deploying a solution to fulfill its own requirements [16]. For example, a client-based solution can be set up by a user requiring global mobility, but then the MN could visit a network where the operator has deployed a network-based solution to provide mobility support to its visiting nodes. On the other hand, the combination can also be planned to get together different functionalities, for example, network mobility and host mobility.

The basic combinations do not require modifying the individual protocols. Although they are used together, they are not aware of each other and they do not have explicit mechanisms to cooperate, so there is no increased complexity because new functionality implemented in the involved nodes does not exist. In what follows some representative hybrid solutions are presented.

MIPv6+PMIPv6. A MN uses MIPv6 to obtain global mobility support (i.e., it can roam to any visited network while keeping global reachability and session continuity). On the other hand, an operator deploys PMIPv6 in order to offer local mobility support (within the domain) without requiring any support from the MNs. In this scenario, a MIPv6 node may visit the PMIPv6 domain. The operation of MIPv6 in the MN, when visiting a PMIPv6 access network, is the same as when visiting any other foreign network. Initially, after attaching to the domain, the MN obtains an IP address (to be used as its CoA), and registers it in its global mobility agent (i.e., the HA). Since the address used in the PMIPv6 domain remains the same while roaming within this domain, movements are transparent to the mobility management software in the user terminal (i.e., MIPv6). Furthermore, the terminal can also move to an access network outside the domain while keeping ongoing sessions. This is done by the terminal getting another temporal address from the new access network and using MIPv6 to keep its global mobility agent (i.e., the HA) updated with its new location.

In this case, 24 bytes of additional overhead are added in the entire path between the MN and the CN, due to the use of MIPv6, plus an IPv6 tunnel (40 bytes) between the LMA and the MAG where the MN is attached (due to the use of PMIPv6). It is important to note that, out of the overall overhead, only the 24 bytes added by MIPv6 are present in the wireless access.

NEMO+PMIPv6 (+MIPv6). A mobile router uses NEMO protocol in order to acquire global mobility support for itself and the corresponding network. A node inside the mobile network can be a standard IP node without mobility support, if it is not going to move away from the mobile network. It can also be a node with MIPv6-based global mobility support, able to roam to other networks. In addition, an operator deploys PMIPv6 to offer local mobility support without requiring any support from visiting nodes (hosts/routers).

Concerning this scenario, two different tunnels are involved to enable the communications of the mobile network: one between the mobile router and its HA (due to the use of NEMO), and another between the LMA and the MAG serving the mobile router (due to the use of PMIPv6). Consequently, there are up to 80 additional bytes of overhead in some wired segments of the path (when both tunnels are present), and up to 40 bytes in the wireless access (due to the use of NEMO), though not in the last wireless hop between the user terminal (i.e., the MNN) and its access router. A third overhead component (24 bytes in route optimized mode) is required if the terminal attached to the mobile network is itself a MIPv6 node outside its home network.

A particularly relevant example of this scenario is the provision of Internet connectivity in public transportation systems where users benefit from seamless access using mobility unaware devices, while the network mobility support (i.e., the mobile router) takes care of managing the mobility on behalf of the terminals. Some of the access networks can also provide PMIPv6 support. In this situation, where NEMO and PMIPv6 protocols are combined, when the mobile router enters the localized domain, it gets a temporal address (to be used as its CoA) from the domain and registers this address in its global mobility agent (i.e., HA), binding the mobile network prefixes managed by the mobile router to its current location (i.e., CoA). Since this new acquired IPv6 address is provided by the PMIPv6 domain, it does not change while the mobile network roams within the localized domain, and therefore its movements are transparent to the NEMO protocol. Moreover, the mobile network is able to roam not only within the localized domain but also outside the domain, thanks to the NEMO operation that provides global mobility support. A user terminal will not be able to leave the mobile network without breaking its ongoing sessions unless this terminal has MIPv6 support.

MIPv6+N-PMIPv6. This scenario is very similar to the MIPv6+PMIPv6 combination. A MN uses MIPv6 to obtain global mobility support (i.e., it can roam to any visited network while keeping global reachability and session continuity). In addition, an operator deploys N-PMIPv6 to offer local mobility support enabling local roaming without requiring any support from user terminals. With N-PMIPv6 this local mobility domain is composed of fixed and moving MAGs. In this scenario, a MIPv6 terminal may visit the N-PMIPv6 domain. A user terminal can both move within a localized domain without changing its IP address and can also leave the domain without breaking any ongoing communications, by acquiring a new temporal address from the new access network and using MIPv6 to register this temporal address in its global mobility agent. The difference with the MIPv6+PMIPv6 combination is that here the localized domain integrates both fixed and moving MAGs, so that a user terminal is able to roam between fixed and mobile access infrastructure within the domain without involving/requiring any IP mobility support in the terminal (thanks to the use of N-PMIPv6 protocol). Whenever the terminal changes its location within the domain, the new access gateway (fixed or mobile) will update the terminal's location in the LMA. In this hybrid solution, three overhead components are required: one (24 bytes) between MN and CN (due to the use of MIPv6 in route optimized mode), an IPv6 tunnel (40 bytes) between the LMA and the fixed MAG, and a second tunnel between the LMA and the mMAG.

An example of this scenario can also be a public transportation system, where mobility unaware devices would not only get Internet access while moving or while waiting at the station platforms, but also while roaming between fixed and mobile access infrastructure. Additionally, the use of MIPv6 would also enable a MN to roam outside the localized domain, for example, when leaving the public transportation environment.

NEMO+N-PMIPv6 (+MIPv6). In this combination, as in the previous one, an operator deploys N-PMIPv6 in order to support local mobility enabling local roaming (within the domain) without requiring any support from the user terminals. However, the operator also deploys NEMO mobile router capabilities in the mMAGs, which enable the corresponding mobile networks to be able to move outside the localized domain while keeping ongoing sessions. This can be a common configuration if the mobile network needs to move out of a domain (e.g., a vehicle leaves the N-PMIPv6 localized domain deployed in a city and connects to another network operator). Using the N-PMIPv6 protocol, the localized domain integrates both fixed and moving MAGs, so that a user terminal is able to roam between fixed and mobile access infrastructure within the domain without changing IP address. The terminal can also be connected to a mMAG that moves outside the localized domain, and thanks to the use of NEMO functionality, this movement will be transparent to terminals in the mobile network, i.e., they will not need to change their IP addresses. The terminal can also use MIPv6 to obtain global mobility, i.e., to be able to roam outside the access infrastructure over N-PMIPv6 and the mobile networks created by using NEMO.

The most effective way of deploying this scenario is by co-locating the global mobility agent of the mobile router functionality (i.e., the HA) and the LMA in the same node, so they can share the same range of addresses. With this configuration, the localized domain becomes also the home network (domain) of the global mobility support. Therefore, when the mobile network is at the home domain, packets addressed to a MN attached to this network are forwarded through the LMA, as in the N-PMIPv6 simple case. This means that when the mobile network is away from its home domain, a bi-directional tunnel is created between the mobile router and HA, used to forward all the traffic from or to terminals connected to the mobile network. In case the mobile network moves out of its home domain, the mobile router cannot act anymore as a mMAG, either because the visited domain is not an N-PMIPv6 localized domain or because the mMAG lacks the appropriate security associations with the LMA of the visited domain. When the mobile network is not at its home domain, a user terminal moving away from the mobile network would need to change its IP address, thus breaking ongoing sessions unless the MN has its own MIPv6 support. In this combination a node in the network has to combine LMA (N-PMIPv6) and HA (NEMO) functionality.

When a mobile network is attached to a mMAG (located in home N-PMIPv6 domain), and assuming a deployment scenario in which the LMA and the HA are co-located, two IPv6 tunnels are required. First one is between the LMA and the fixed MAG, and a second one is between the LMA and the mMAG. If the user terminal is a MN running MIPv6 (which is outside its home network), an additional overhead component (24 bytes) is required due to the use of MIPv6 in route optimized mode.

Considering presented hybrid solutions, it can be concluded that they can have an important impact on the overhead and handover delay, leading to performance penalties which can be significant in certain cases. Comprehensive experimental evaluation of hybrid mobility management solutions regarding handover delay is conducted in [16].

5. Concluding Remarks

Many network layer mobility protocols have been and still are being developed by several standardization bodies, in particular by the IETF. Each protocol provides a different functionality (e.g., terminal mobility or network mobility) and requires operations in different network entities. The evaluation of traditional mobility management schemes clearly shows that the network-based mobility protocol, proxy MIPv6, is the most promising solution to improve the mobile communications performance on localized networks and it is expected to fulfill most of the services requirements in the heterogeneous wireless environments (e.g., vehicular and aeronautical communication systems, etc.).

The current trend in the evolution of mobile communication networks is towards terminals with several network interfaces that get ubiquitous Internet access by dynamically changing access network to the most appropriate one. Handovers between different access networks are going to be usual. In this situation the different solutions are going to co-exist in order to provide seamless mobility. There is no general solution because each of them addresses different requirements. Motivated by the limitations of centralized solutions, in terms of poor scalability, inefficient usage of network resources, and high packet delay, future researches could be oriented to the newly paradigm of distributed mobility management.

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Sadržaj: *Upravljanje mobilnošću predstavlja osnovni mehanizam za obezbeđivanje besprekidne konektivnosti korisnika u heterogenim bežičnim mrežama. Do sada je predloženo nekoliko protokola mobilnosti na mrežnom sloju. Svako od ovih rešenja ima svoje prednosti i nedostatke u pogledu funkcionalnosti i mogućnosti implementacije. U ovom radu analizirani su karakteristični protokoli mobilnosti mrežnog sloja, mogućnosti njihovog unapređenja, kao i poboljšanja funkcionalnih karakteristika njihovim kombinovanjem.*

Ključne reči: *Hendover, heterogene mreže, mobilni IP, mobilnost, mrežni sloj.*

PROTOKOLI MOBILNOSTI MREŽNOG SLOJA U HETEROGENOM OKRUŽENJU

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