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RESEARCH ARTICLE

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Performance analysis of proxy mobile IPv6 based on IEEE802.16e

Abstract Proxy mobile Internet protocol version 6 (PMIPv6) is a network-based mobility management protocol proposed by Internet Engineering Task Force (IETF), which allows nodes to remain service connectivity while moving around in the IPv6 Internet. PMIPv6 is different from the host-based mobility management protocols (mobile Internet protocol version (MIPv6), hierarchical mobile IPv6 (HMIPv6), fast handover for mobile IPv6 (FMIPv6), and fast handover in hierarchical mobile IPv6 (F-HMIPv6)), whose signaling are transferred among some network entities except mobile node (MN). This paper focuses on the analytical modeling of performance analysis for PMIPv6 and other protocols using IEEE802.16-based wireless metropolitan area networks as the wireless access network. The performances of these protocols are evaluated by some metrics like handover latency, service disruption time, and binding update cost. Numerical results show that PMIPv6 has better performance.

Keywords PMIPv6, mobility management protocols, IEEE802.16e, analytical modeling, performance analysis

1 Introduction

Internet Engineering Task Force (IETF) proposed a network-based mobility management protocol, proxy mobile Internet protocol version 6 (PMIPv6), in August 2008. PMIPv6 is a new method to solve IP mobility challenge. It is possible to support mobility for IPv6 nodes without host involvement by exchanging mobile IPv6 signaling message between a network node and a home agent. PMIPv6 is based on the mobile Internet protocol version (MIPv6) that has some advantages [1].

1) Reuse of home agent functionality and the message/format used in mobility signaling. MIPv6 is a mature protocol with several implementations that have undergone interoperability testing.

2) A common home agent would serve as the mobility agent for all types of IPv6 nodes.

Hierarchical mobile IPv6 (HMIPv6), fast handover for mobile IPv6 (FMIPv6), and fast handover in hierarchical mobile IPv6 (F-HMIPv6) are the extensions of MIPv6 that solve the problems of MIPv6 in different sides. MIPv6, HMIPv6, FMIPv6, and F-HMIPv6 are mobility management protocols that are based on the host.

Through the comparison of PMIPv6 and other protocols, we can see that the network-based protocol has advantage over other host-based protocols. The rest of this paper is organized as follows. Section 2 introduces PMIPv6 protocol and other protocols. Section 3 gives the mobility model and discusses the performance metrics of different protocols based on the mobility model. Section 4 analyzes the influence of parameters on performance of protocols. We finally conclude the paper in Sect. 5.

2 Mobility management protocols

2.1 PMIPv6

In PMIPv6 protocol, some new terms are given, which are to be interpreted as follows [1]:

1) PMIPv6 domain

PMIPv6 domain refers to a network where the mobility management of a mobile node (MN) is handled using the PMIPv6 protocol. There are two entities that are involved in PMIPv6 domain: local mobility anchor (LMA) and mobile access gateway (MAG).

2) LMA

LMA is the home agent for the mobile node in a PMIPv6 domain that is the entity to manage the mobile node's binding state.

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3) MAG

MAG is an entity in PMIPv6 domain that is responsible for tracking the mobile node's movement. It has a function on an access router that manages the mobility-related signaling for a mobile node that is attached to its access link.

4) Proxy care-of address (PCoA)

PCoA is a globe address configured on the interface of MAG and is the endpoint of the tunnel between LMA and MAG. LMA registers it in the binding cache entry for the mobile node.

5) Proxy binding update (PBU)

PBU is a request message sent by MAG to finish the binding update process.

6) Proxy binding acknowledgment (PBA)

PBA is a response message sent by LMA to finish the binding update process.

Figure 1 gives the handover process of PMIPv6. PMIPv6's IP layer handover is carried out after media access control (MAC) layer handover. First, MAG and LMA exchange PBU message and PBA message to establish a bi-directional tunnel. Then, MN sends a router solicitation (RS) message to the base station (BS), and BS replies a router advertisement (RA) message to MN. After that, the handover process is finished. MN uses the tunnel to deliver the data.

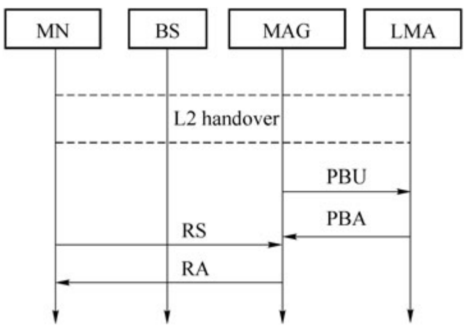

Fig. 1 PMIPv6 handover process

2.2 Other protocols

Figure 2 gives the handover process of different mobility management protocols, including MIPv6 [2], HMIPv6 [3], FMIPv6 [4], and F-HMIPv6 [5], and it also gives MAC layer handover process of IEEE802.16e [6].

3 Performance analysis

3.1 Network model

Figure 3 shows the network model, which includes MN, BS, access router (AR), mobility anchor point (MAP), home agent (HA), and correspondent node (CN). There are four MAPs, and each MAP has n ARs [7]. The coverage of MAP is called domain, and the coverage of AR is called cell. In other words, each domain has n cells. A BS connected to an AR has a wireless access interface for connecting MNs. HA and CN are connected to different MAPs. In this paper, we suppose MN is located in another MAP different from HA's and CN's MAPs. In Fig. 3, a, b, c, d, e, and f denote the hop counts between different entities.

We adopt fluid flow (FF) model in where the direction of an MN's movement in an MAP domain is distributed uniformly in the range of (0, 2π). V is the average speed of MN. Let μ_c, μ_d be cell crossing rate and domain crossing rate, respectively. Furthermore, let μ_l be the cell crossing rate for that MN still stays in the same MAP domain. If we assume that each AR coverage area is S_{AR}, the border crossing rate is given by [8]

$$\mu_c = \frac{2v}{\sqrt{\pi S_{AR}}},$$

$$\mu_d = \frac{\mu_c}{\sqrt{n}},$$

$$\mu_l = \mu_c - \mu_d = \frac{\sqrt{n}-1}{\sqrt{n}}\mu_c.$$

In this paper, we suppose that residence time in a cell and in a domain follow exponential distribution with parameters μ_c and μ_d, while session arrival process follows a Poisson distribution with rate λ_S. Hence, the average number of cell crossing and domain crossing can be obtained as follows:

$$E(N_c) = \frac{\mu_c}{\lambda_S},$$

$$E(N_d) = \frac{\mu_d}{\lambda_S}.$$

Let $E(N_l)$ be the average number of cell crossing rate of an MN, which is in the same domain. We can get the expression [9]

$$E(N_l) = \frac{\mu_l}{\lambda_S}.$$

3.2 Parameter analysis

Using the network model and mobility model, we analysis the important performance metrics, such as handover latency, service disruption time, and binding update cost. Let t_1, t_2 denote the unit transmission delay of a control packet in a wired, wireless link, respectively; c_1, c_2 the unit transmission cost of a control packet in a wired, wireless link, respectively; $T_{X,Y}$ the transmission time of a control packet between entities X and Y; $C_{X,Y}$ the transmission cost

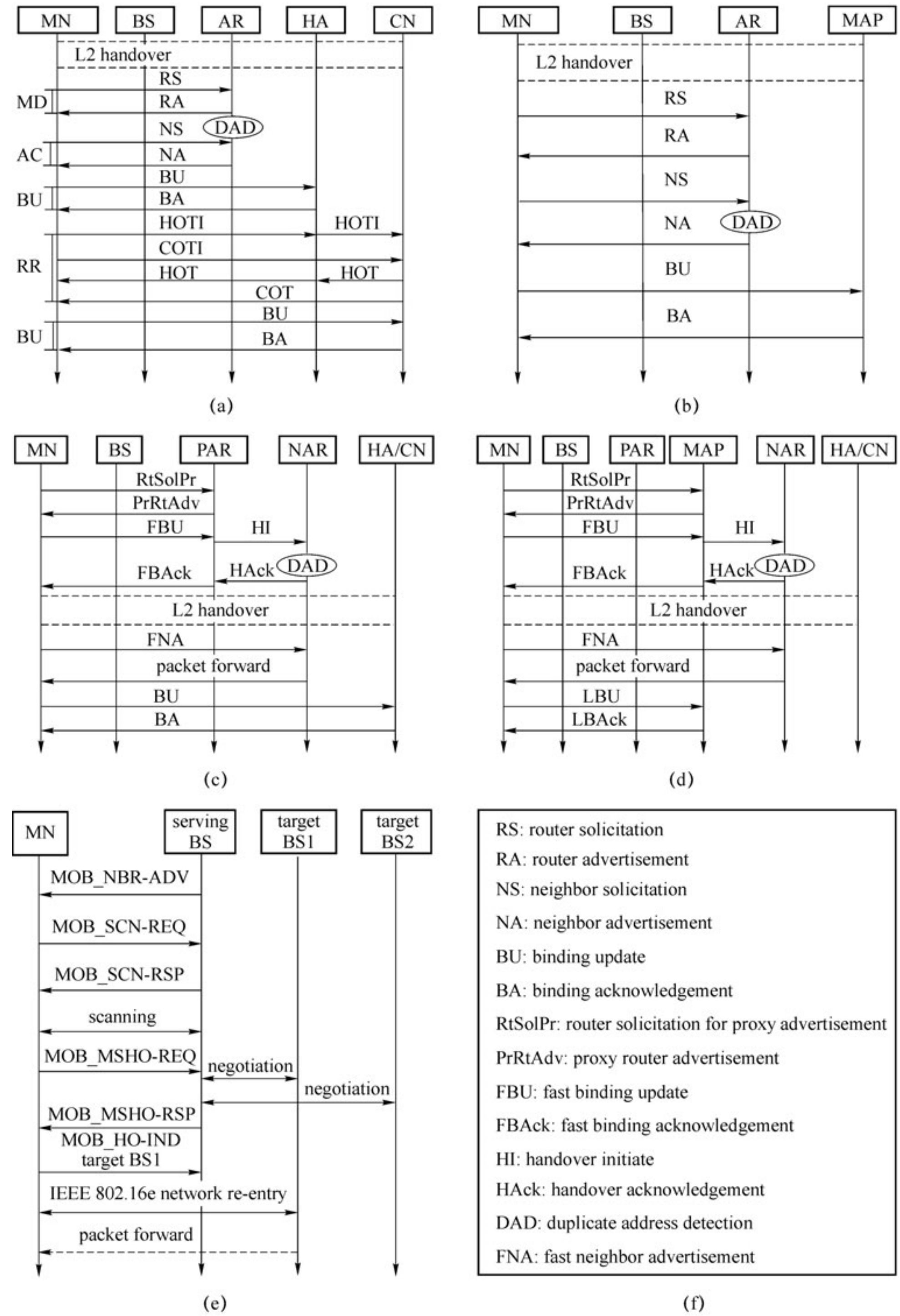

Fig. 2 Handover process of different protocols. (a) MIPv6; (b) HMIPv6; (c) FMIPv6; (d) F-HMIPv6; (e) IEEE802.16e MAC layer handover; (f) abbreviations

of a control packet between entities X and Y; and $d_{X,Y}$ the hop distance between X and Y. Although different control packets have different size, we assume that they have the same size for simplicity. Therefore, the transmission delay and transmission cost are proportional to the hop distance.

We can get the following equations:

$$T_{X,Y} = t_1 d_{X,Z} + t_2 d_{Z,Y},$$

$$C_{X,Y} = c_1 d_{X,Z} + c_2 d_{Z,Y},$$

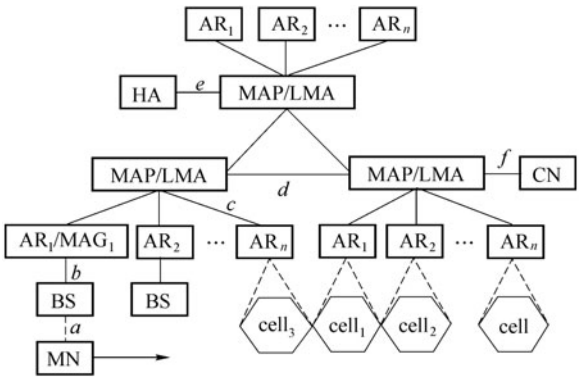

Fig. 3 Network model

where $d_{X,Z}$ is the hop distance of wired link, and $d_{Z,Y}$ is the hop distance of wireless link. We assume that S_c and S_d are the size of a control packet and a data packet. The relationship of S_c and S_d is that

$$k = \frac{S_d}{S_c}.$$

Therefore, the transmission delay and cost of a data packet is k greater than a control packet.

3.2.1 Handover latency

Handover latency is defined here as the interval between the time MN sends mobile station handover request (MOB_MSHO-REQ) message and the time MN can send or receive data packets. We assume that the propagation time (10^{-3} ms), processing, and queuing delays are much smaller than the transmission time, so they are negligible.

For PMIPv6, MN starts IP layer handover after MAC layer handover. The handover latency can be expressed as follows:

$$T_{\text{handover}}^{\text{PMIPv6}} = 3T_{\text{MS,BS}} + T_{\text{nego}} + T_{\text{re-entry}} + 2T_{\text{MAG,LMA}} + 2T_{\text{MAG,MS}}. \quad (1)$$

3.2.2 Service disruption time

Service disruption time is defined as the period when MN cannot send or receive data packets. It usually lasts from when MN disconnects from the serving BS until it can send or receive the data packet in the new link. MN cannot receive data packets when it sends a mobile handover indication (MOB_HO-IND) message to the serving BS. Then, MN performs the IEEE802.16e network re-entry procedure and sends a fast neighbor advertisement (FNA) message. The service disruption time of PMIPv6 is given by the following equation:

$$T_{\text{service}}^{\text{PMIPv6}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + 2T_{\text{MAG,LMA}} + 2T_{\text{MAG,MS}}. \quad (2)$$

3.2.3 Binding update cost

Depending on the type of movement and mobility management protocol, two kinds of binding updates can be performed: local binding update (C_l) and globe binding update (C_g) [10]. For MIPv6 and FMIPv6, globe binding update is performed regardless of movement type. For HMIPv6, F-HMIPv6, and PMIPv6, globe binding update is performed when MN moves out an MAP domain. The binding update cost is expressed as follows:

$$C_{\text{BU}} = E(N_l)C_l + E(N_d)C_g. \quad (3)$$

Supposing that $\text{SMR} = \lambda_S/\mu_c$, the binding update cost becomes

$$\begin{aligned} C_{\text{BU}} &= \frac{\mu_l}{\lambda_S}C_l + \frac{\mu_d}{\lambda_S}C_g \\ &= \frac{\mu_c}{\lambda_S\sqrt{n}}[(\sqrt{n}-1)C_l + C_g] \\ &= \frac{1}{\text{SMR}\sqrt{n}}[(\sqrt{n}-1)C_l + C_g]. \quad (4) \end{aligned}$$

For PMIPv6, the binding update cost is computed as follows:

$$C_l^{\text{PMIPv6}} = 2C_{\text{MAG,LMA}}, \quad (5)$$

$$C_g^{\text{PMIPv6}} = 2C_{\text{MAG,LMA}} + 2C_{\text{MS,HA}} + 2C_{\text{MS,CN}}. \quad (6)$$

For other protocols, the handover latency, service disruption time, and binding update cost can be obtained as follows:

$$T_{\text{handover}}^{\text{MIPv6}} = 3T_{\text{MS,BS}} + T_{\text{nego}} + T_{\text{re-entry}} + 4T_{\text{MS,NAR}} + T_{\text{DAD}} + 4T_{\text{MS,HA}} + 2T_{\text{MS,CN}} + 2T_{\text{HA,CN}},$$

$$T_{\text{handover}}^{\text{HMIPv6}} = 3T_{\text{MS,BS}} + T_{\text{nego}} + T_{\text{re-entry}} + 4T_{\text{MS,NAR}} + T_{\text{DAD}} + 2T_{\text{MS,MAP}},$$

$$T_{\text{handover}}^{\text{FMIPv6(pre)}} = 2T_{\text{MS,BS}} + T_{\text{nego}} + 2T_{\text{MS,PAR}} + 2T_{\text{PAR,NAR}} + T_{\text{DAD}} + T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{handover}}^{\text{FMIPv6(rec)}} = 2T_{\text{MS,BS}} + T_{\text{nego}} + T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + 3T_{\text{PAR,NAR}} + T_{\text{DAD}} + kT_{\text{PAR,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{handover}}^{\text{FMIPv6}} = P_{\text{s}}T_{\text{handover}}^{\text{FMIPv6(pre)}} + (1-P_{\text{s}})T_{\text{handover}}^{\text{FMIPv6(rec)}},$$

$$T_{\text{handover}}^{\text{F-HMIPv6(pre)}} = 2T_{\text{MS,BS}} + T_{\text{nego}} + 2T_{\text{MS,MAP}} + 2T_{\text{MAP,NAR}} + T_{\text{DAD}} + T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{handover}}^{\text{F-HMIPv6(rec)}} = 2T_{\text{MS,BS}} + T_{\text{nego}} + T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + 3T_{\text{MAP,NAR}} + T_{\text{DAD}} + kT_{\text{MAP,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{handover}}^{\text{F-HMIPv6}} = P_{\text{s}}T_{\text{handover}}^{\text{F-HMIPv6(pre)}} + (1-P_{\text{s}})T_{\text{handover}}^{\text{F-HMIPv6(rec)}},$$

$$T_{\text{service}}^{\text{MIPv6}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + 4T_{\text{MS,NAR}} + T_{\text{DAD}} + 4T_{\text{MS,HA}} + 2T_{\text{MS,CN}} + 2T_{\text{HA,CN}},$$

$$T_{\text{service}}^{\text{HMIPv6}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + 4T_{\text{MS,NAR}} + T_{\text{DAD}} + 2T_{\text{MS,MAP}},$$

$$T_{\text{service}}^{\text{FMIPv6}} = P_{\text{s}}T_{\text{service}}^{\text{FMIPv6(pre)}} + (1-P_{\text{s}})T_{\text{service}}^{\text{FMIPv6(rec)}},$$

$$T_{\text{service}}^{\text{F-HMIPv6}} = P_{\text{s}}T_{\text{service}}^{\text{F-HMIPv6(pre)}} + (1-P_{\text{s}})T_{\text{service}}^{\text{F-HMIPv6(rec)}},$$

$$T_{\text{service}}^{\text{FMIPv6(pre)}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{service}}^{\text{FMIPv6(rec)}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + 3T_{\text{PAR,NAR}} + T_{\text{DAD}} + kT_{\text{PAR,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{service}}^{\text{F-HMIPv6(pre)}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + kT_{\text{MS,NAR}},$$

$$T_{\text{service}}^{\text{F-HMIPv6(rec)}} = T_{\text{MS,BS}} + T_{\text{re-entry}} + T_{\text{MS,NAR}} + 3T_{\text{MAP,NAR}} + T_{\text{DAD}} + kT_{\text{MAP,NAR}} + kT_{\text{MS,NAR}},$$

$$C_{\text{l}}^{\text{MIPv6}} = C_{\text{g}}^{\text{MIPv6}} = 2(C_{\text{MS,HA}} + C_{\text{MS,CN}}),$$

$$C_{\text{l}}^{\text{HMIPv6}} = 2C_{\text{MS,MAP}},$$

$$C_{\text{g}}^{\text{HMIPv6}} = 2(C_{\text{MS,MAP}} + C_{\text{MS,HA}} + C_{\text{MS,CN}}),$$

$$C_{\text{l}}^{\text{FMIPv6}} = C_{\text{g}}^{\text{FMIPv6}} = P_{\text{s}}C_{\text{pre}}^{\text{FMIPv6}} + (1-P_{\text{s}})C_{\text{rec}}^{\text{FMIPv6}},$$

$$C_{\text{l}}^{\text{F-HMIPv6}} = P_{\text{s}}C_{\text{pre(l)}}^{\text{F-HMIPv6}} + (1-P_{\text{s}})C_{\text{rec(l)}}^{\text{F-HMIPv6}},$$

$$C_{\text{g}}^{\text{F-HMIPv6}} = P_{\text{s}}C_{\text{pre(g)}}^{\text{F-HMIPv6}} + (1-P_{\text{s}})C_{\text{rec(g)}}^{\text{F-HMIPv6}},$$

$$C_{\text{pre}}^{\text{FMIPv6}} = 2C_{\text{MS,PAR}} + 2C_{\text{MS,HA}} + 2C_{\text{MS,CN}},$$

$$C_{\text{rec}}^{\text{FMIPv6}} = C_{\text{MS,NAR}} + 2C_{\text{PAR,NAR}} + 2C_{\text{MS,HA}} + 2C_{\text{MS,CN}},$$

$$C_{\text{pre(l)}}^{\text{F-HMIPv6}} = 2C_{\text{MS,MAP}},$$

$$C_{\text{rec(l)}}^{\text{F-HMIPv6}} = C_{\text{MS,NAR}} + 2C_{\text{PAR,MAP}},$$

$$C_{\text{pre(g)}}^{\text{F-HMIPv6}} = 2(C_{\text{MS,MAP}} + C_{\text{MS,HA}} + C_{\text{MS,CN}}),$$

$$C_{\text{rec(g)}}^{\text{F-HMIPv6}} = C_{\text{MS,NAR}} + 2C_{\text{PAR,MAP}} + 2(C_{\text{MS,HA}} + C_{\text{MS,CN}}).$$

4 Numerical results

In this section, we use the parameters in Table 1 to calculate the performance metrics.

Table 1 Parameters to calculate performance metrics

parameters	values	parameters	values
a	1	t_1/ms	5
b	2	t_2/ms	2
c	2	c_1	10
d	4	c_2	2
e	6	λ_S	0.1
f	6	P_s	0.9
n	5	T_{nego}/ms	20
$v/(\text{m}\cdot\text{s}^{-1})$	20	T_{DAD}/ms	500
r/m	100	$T_{\text{re-entry}}$/ms	50
k	5		

Figures 4 and 5 show the variation of handover latency and service disruption time as the wireless link latency changes. Handover latency and service disruption time increase linearly as the wireless link latency changes. In Fig. 4, when MN moves in an MAP domain, the relationship of different protocols' handover latency are

$$\text{MIPv6} > \text{FMIPv6} > \text{F-HMIPv6} > \text{HMIPv6} > \text{PMIPv6}.$$

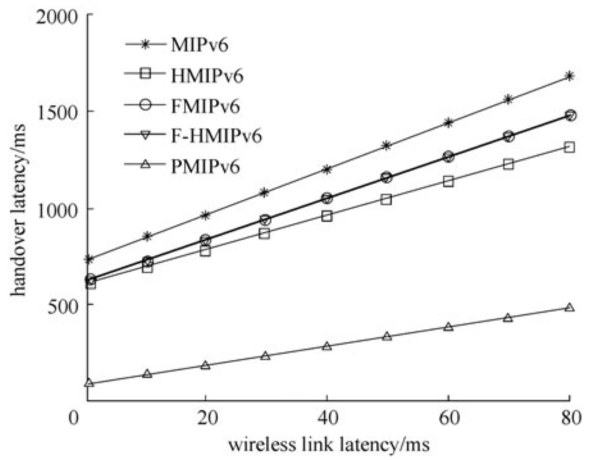

Fig. 4 Handover latency versus wireless link latency

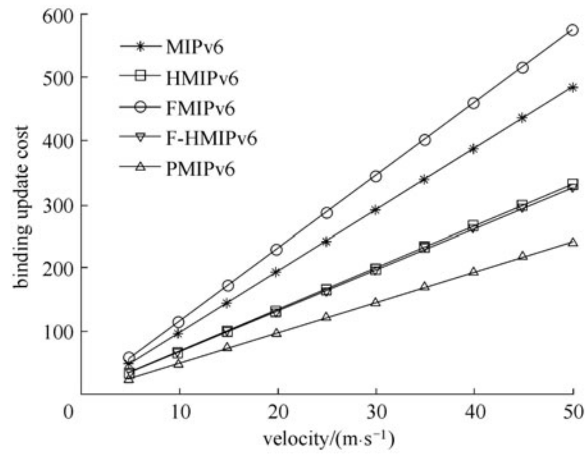

Fig. 6 Binding update cost versus MN's velocity

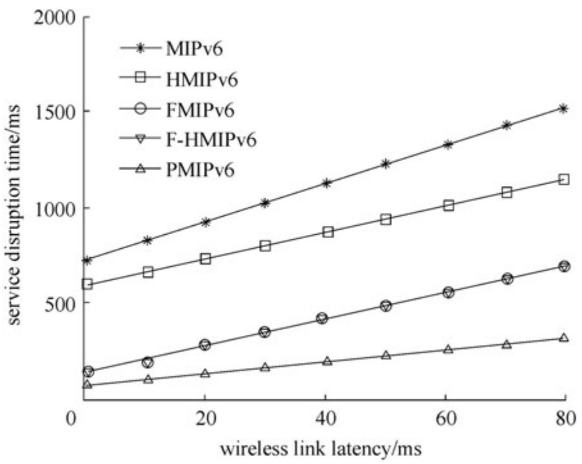

Fig. 5 Service disruption time versus wireless link latency

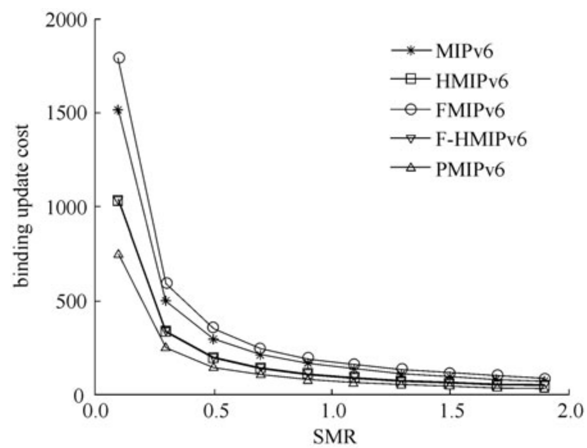

Fig. 7 Binding update cost versus SMR

We can see that the duplicate address detection (DAD) process takes a long time in the whole handover process. PMIPv6 has the least handover latency because it has omitted the DAD process. In Fig. 5, when MN moves in a MAP domain, the relationships of different protocols' service disruption time are

$$\text{MIPv6} > \text{HMIPv6} > \text{FMIPv6} > \text{F-HMIPv6} > \text{PMIPv6}.$$

MIPv6 and HMIPv6 take IP layer handover after MAC layer handover has finished, so the service disruption time is large.

Figure 6 demonstrates binding update cost as a function of MN's velocity. The lower the MN's velocity is, the less the binding update cost is. Figure 7 illustrates the variation of binding update cost as the SMR changes. When SMR is small, λ_S is less than μ_c. The larger μ_c causes frequent cell crossing, so the binding update is large. The relationships of different protocols' binding update cost are

$$\text{FMIPv6} > \text{MIPv6} > \text{HMIPv6} > \text{F-HMIPv6} > \text{PMIPv6}.$$

5 Conclusion

In this paper, we give the performance analysis of different mobility protocols (MIPv6, HMIPv6, FMIPv6, F-HMIPv6, and PMIPv6) in terms of handover latency, service disruption time, and binding update cost. Numerical results show that the PMIPv6 has least handover latency, service disruption time, and binding update cost.

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