Performance Improvement of Fast Handovers for Mobile IPv6

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***Abstract*- Mobile IPv6 (MIPv6) is designed to support IP mobility management in the Internet. The fast handover for Mobile IPv6 (FMIPv6) is an extension of Mobile IPv6. Because FMIPv6 provides the information for layer 2 (L2) handover in advance, the layer 3 handover procedure could start early in order to reduce the handover latency. However, the handover latency of FMIPv6 is still remaining large which is hardly to meet the requirements of real-time applications. To deal with this, we propose a modified fast handover scheme named as Improvement FMIPv6 (called I-FMIPv6) to reduce the overall latency on handover. In I-FMIPv6, when the Mobile Node (MN) receives a Fast Binding Acknowledgment (FBAck) message with the New Care-of Address (NCoA) acceptance, it will send a Binding Update (BU) message to the Correspondent Nodes (CNs) to update the MN's new CoA before the L2 handover occurs. Thus, I-FMIPv6 can avoid circle routing, wrong order and handover latency can be reduce. The obtained simulation results show that by deploying I-FMIPv6 handover latency can be reduces up to 16.79%, the average throughput measured since MN lost connection to Previous Access Router (PAR) till getting stable connection to New Access Router (NAR) can be increases up to 2.57% compared with FMIPv6 at the speed of the moving vehicles in the inner city.**

***Key words:* Mobile IPv6, handover latency, FMIPv6.**

I. INTRODUCTION

Mobile IPv6 (MIPv6) was developed based on the advantages of IPv6 and inherited experience from Mobile IPv4. MIPv6 is the standard of the IETF [11]. A mobile node (MN) is always identified by its home address, regardless of its current point of attachment to the Internet. While a MN is away from its home, it also associates with a Care-of Address (CoA), which provides information about the mobile node's current location. The packets addressed to a MN's home address are routed to its CoA. The protocol enables nodes to cache the binding of a mobile node's home address with its CoA, then sends any packets destined for the MN directly to it at this CoA. In MIPv6, L3 handover is performed after L2 handover is completed. So that, handover latency of MIPv6 includes L2 handover latency, movement detection latency, address configuration latency, and binding update latency [5]. MIPv6 has some limitations, particularly on handover performance when MN moves from one network to another network. The improvement of handover schemes, such as Fast Handovers for Mobile IPv6 (FMIPv6), Hierarchical Mobile IPv6 (HMIPv6), has become standard by the IETF. FMIPv6 is the extension of MIPv6 to reduce latency and packet loss caused by the handover. Many research results have confirmed that the FMIPv6 scheme has some more advantages over MIPv6 scheme [5]. However, the latency and packet loss rate of FMIPv6 still need further improvement, in order to make it be able to meet the requirement of real-time applications. There are also some researches of FMIPv6 improvement with different approaches. NF-MHIPv6 [4] included the concepts of Proxy Mobile IP for creation of CoA and Duplicate Address Detection (DAD). In this protocol, the MN can handover before receiving any information about the new AR (Access Router). Then the handover latency reduced about 0.02 seconds to 0.08 seconds. An integrated mobility scheme [6] combines the procedures of fast handover for Mobile IPv6 (FMIPv6) and Session Initiation Protocol (SIP) mobility for real-time communications. A proposed mobility model [7] is based on statistical analysis of the Received Signal Strength Index (RSSI) datasets measured in various radio propagation environments. They validate that an adaptive autoregressive process can be used as a handover prediction model. FMIP-M [8] designed the new access router to select a suitable multicast service method according to the multicast service-related network conditions and supports a reliable multicast transmission by compensating for data losses from the previous access router.

In this paper, we propose a modified protocol of the FMIPv6 scheme called I-FMIPv6 (Improvement-FMIPv6). I-FMIPv6 adds new features to FMIPv6 in which as soon as MN receives FBAck messages with NCoA, MN send Binding Update (BU) message to CN and Home Agent (HA) before the L2 handover actually takes place. Thus, in L2 handover processing, the CN sends packets directly to the NAR (not via PAR). When the MN is connected with the NAR, it can receive packets NAR's buffer and not a binding update to the CN/HA. Therefore, handover latency is improved.

The paper is organized as follows: Section 1 is an introduction. Section II presents FMIPv6 handover scheme. Section III presents the handover scheme of I-FMIPv6. Section IV evaluates performance of I-FMIPv6 handover scheme. Finally, Section V provides conclusion remarks.

II. HANDOVER SCHEME OF FMIPV6

FMIPv6 allows AR service providers to implement a L3 handover to minimize latency and reduce the number of packets loss during the handover process. Depending on whether an FBAck is received on the previous link; there are two modes of operation: MN sends a Fast Binding Update (FBU) message and receives an FBAck message on PAR's link, this scenario is characterized as "predictive" mode of operation. The scenario, in which the MN sends a FBU message from NAR's link, this scenario is characterized as a "reactive" mode of operation [9]. In the framework of this paper, we show the improvements of handover scheme based on predictive mode - FMIPv6 procedure for predictable manner described in Fig. 1.

In FMIPv6, a handover portion of layer 3 is made before the L2 handover. In other words, MN makes the L2 handover while it is still connecting to the PAR. In this case, PAR should have information about the access router to MN plans to move to. In FMIPv6, the handover is initiated by a trigger L2, and then MN will soon make handover.

When MN receives trigger information from the L2, it will sends a Router Solicitation for Proxy (RtSolPr) to PAR to resolve new Access Point Identifiers to subnet-specific information. In response, PAR sends a Proxy Router Advertisement (PrRtAdv) message containing NCoA proposed and IP address of the NAR. After the PrRtAdv message is processed, MN sends FBU message containing NCoA to PAR. In reply FBU message, PAR sends FBAck message to the MN and establish a link between the PCoA and NCoA. Before answering, PAR sends Handover Initiate (HI) messages containing the PCoA, link layer address and the NCoA of the MN to the NAR. NAR use of DAD to verify the uniqueness of NCoA. If the NCoA is a valid address for use, NAR indicates this in the HAck message. If the NCoA is address collision, NAR can assign a different CoA and MN to use this address.

The purpose of the FBU is to establish tunnel between the PCoA and the NCoA, so that arriving packets can be tunneled to the new location of the MN. If the MN does not receive an FBAck message even after retransmitting the FBU, it must assume that fast handover support is not available and stop the protocol operation [9].

After setting the link to the NAR, MN sends RS messages with FNA option and NAR responds with Router Advertisement (RA) message with NAAck option [11]. After attachment to NAR, MN binding update with CN/HA and delivers data packets from CN for MN. The previously established tunnel is removed.

Handover procedures of ***FMIPv6:***

The handover procedure of FMIPv6 is illustrated in Fig. 1:

Step 1. When MN have trigger L2, MN sends RtSolPr message to PAR.

Step 2. As a response to RtSolPr, PAR sends PrRtAdv message to MN.

Step 3. The MN sends FBU message to PAR.

Step 4. The PAR sends HI message to NAR.

Step 5. As a response to HI, NAR sends HAck messages to PAR.

Step 6. The PAR sends FBAck message to MN.

Step 7. L2 handover is completed, MN send RS message to NAR and receives RA message.

Step 8. The MN sends BU messages to the CN/HA.

Step 9. The CN sends BAck message to MN and direction flow from PAR to NAR.

Step 10. The NAR delivers the data packets to the MN.

III. HANDOVER SCHEME OF I-FMIPV6

The idea is to perform some work of L3 handover, which can be done earlier and not required to perform after L2 handover. Specifically, MN updates NCoA with the CN/HA before leaving the PAR to NAR (before L2 handover). Thus, after link to the NAR, MN must not update NCoA with CN/HA.

Operation of I-FMIPv6:

When MN receives L2 trigger, it will discover the identities and capabilities of candidate of the ARs candidate (CARs). The CARs has two aspects: the IP address and the perceived ability of the CAR. This process called "Discovery CAR" (CARD) [10]. CARD protocol performs reverse address, possible mapping from L2 identifier of an IP address of AP to CAR related connection to AP detection and perform capabilities of CAR, which helps optimizing the decision MN handover.

When MN decision handover to a CAR (NAR), it starts L3 handover from PAR to NAR by sending a RtSoPr message containing link layer address of the new access point or access point identifier to the PAR.

The PAR sends a PrRtAdv message containing the link layer address of the new access point or access

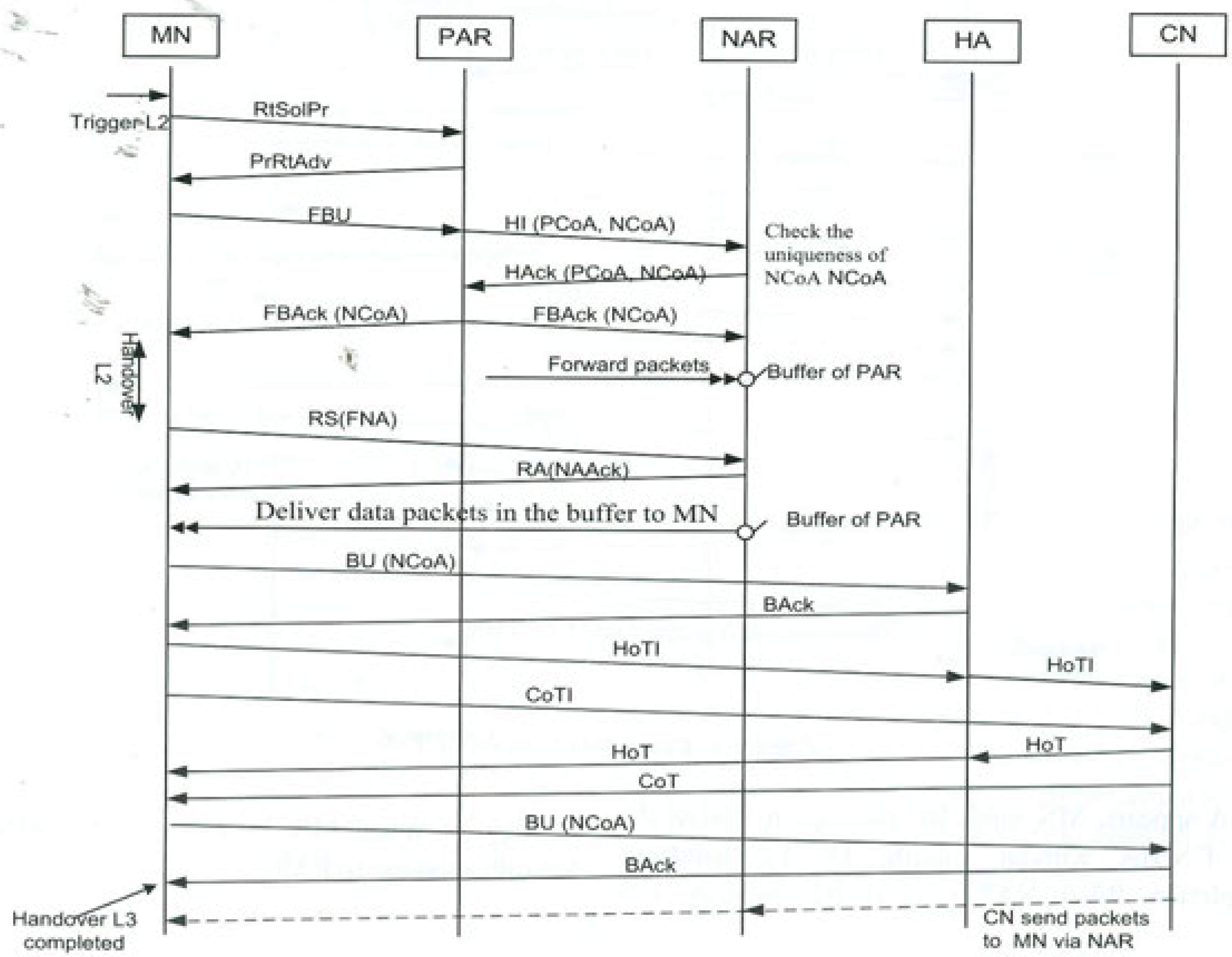

Figure 1. Procedures for FMIPv6

point identifier copied from RtSolPr message, the link layer address and IP address of the NAR.

After the PrRtAdv message is processed, MN obtains NCoA and sends FBU message including NCoA to the PAR. Before answering FBU message, PAR sends a HI message containing the NCoA to NAR. NAR use of DAD to verify the uniqueness of NCoA and respond by sending HAck messages to the MN via PAR. Address validation NCoA is unique or different assigned NCoA. If there is an assigned NCoA returned in the FBack, the MN must use the assigned address upon attaching to NAR. Thus, MN has a valid NCoA address and can use this NCoA after receiving FBAck messages. As soon as valid NCoA appears, MN sends BU message to update the link CN/HA without waiting for L2 handover completion. When NAR receives BU message, CN redirects traffic to NCoA (no via PAR). If the MN does not receive a BAck message from CN before disconnects to PAR then I-FMIPv6 operates same as FMIPv6.

After the L2 handover setting the link to the NAR, MN sends RS messages with FNA option and NAR responds with Router Advertisement (RA) message with NAAck option [11]. Soon after, the NAR delivers data packets from CN for MN without having to binding update to the CN/HA.

*Handover procedures of I-**FMIPv6:***

The handover procedure of I-FMIPv6 is illustrated in Fig. 2:

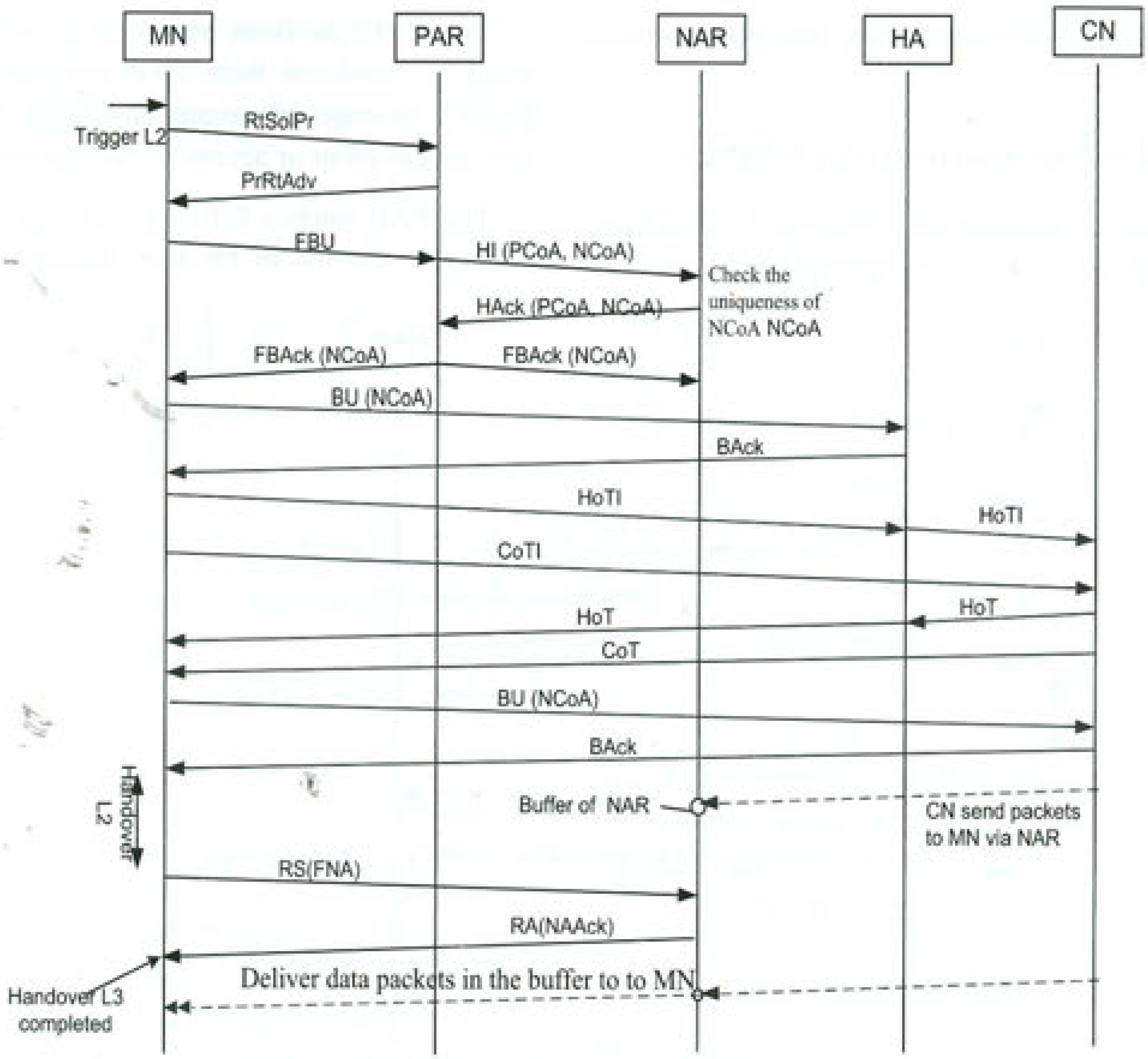

Figure 2. Procedures for I-FMIPv6

Step 1. When MN have trigger L2, MN sends RtSolPr message to PAR.

Step 2. As a response to RtSolPr, PAR sends PrRtAdv message to MN.

Step 3. The MN sends FBU message to PAR.

Step 4. The PAR sends HI message to NAR.

Step 5. As a response to HI, NAR sends HAck messages to PAR.

Step 6. The PAR sends FBAck message to MN.

Step 7. The MN sends BU messages to the CN/HA.

Step 8. The CN sends BAck message to MN and direction flow from PAR to NAR.

Step 9. L2 handover is completed, MN send RS message to NAR and receives RA message.

Step 10. The NAR delivers the data packets to the MN.

In the I-FMIPv6, the binding update with HA/CN (step 8 in FMIPv6) is performed immediately after MN receives FBack messages (after step 6 in FMIPv6). Therefore, the CN sends packets to MN via NAR (not via PAR) before handover L2 so that can be avoid circle routing and wrong order. When MN is connected with NAR, it doesn't have to binding update with HA/CN. Thus overall handover latency can be reduced.

IV. Performance Evaluation of I-FMIPv6

A. *Mathematical analysis*

With fast handover for Mobile IPv6, the ability of sending the packet to the new subnet depends on L2 handover latency, IP connectivity latency and binding update latency. In order to analyze and evaluate this work, we consider mobile systems as described in Fig. 3, (reference models according to the study published in [3]) with the following assumptions:

- $d_{X\text{-}Y}$: Average number of hops between X and Y;
- tX.Y: Transition latency between X and Y;
- t_{BU}: Binding Update latency;
- t_{FNA}: IP connectivity latency;
- t_α: Wireless link transition latency;
- t_β: Wired link transition latency;
- tL2: L2 handover latency;
- R_m: Value of MinRtrAdvInterval configured on an AR.
- R_M: Value of MaxRtrAdvInterval configured on an AR.
- Transition latency both directions between two nodes is the same.
- Transition latency from MN to CN shorter total transition latency from MN to HA and from HA to CN;
- Latency processing in the AR, MN, CN is negligible (and thus can ignore the influence of causes within the process).

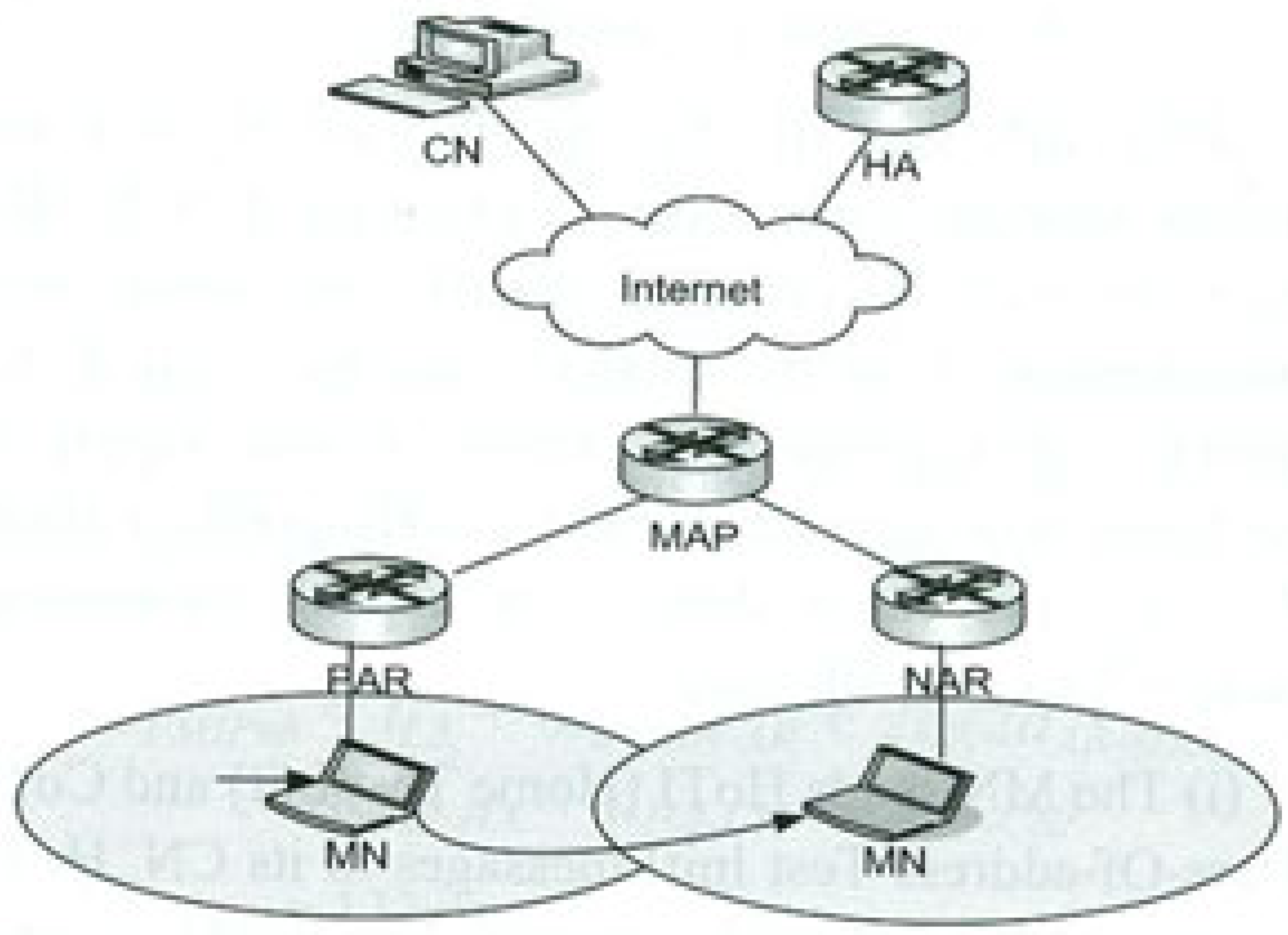

Figure 3. Network model for performance analysis

B. *FMIPv6*

Figure 1 is the handover procedure of FMIPv6 and Fig. 4 shows the sequence of signaling messages for FMIPv6 handover scheme in terms of their request response time intervals. The handover latency of FMIPv6 does not include movement detection latency and duplicate address detection latency. The handover scheme of FMIPv6 includes L2 handover latency, IP connectivity latency and binding update latency. The handover latency of FMIPv6 will be denoted T_{FMIPv6} and calculated by the following formula:

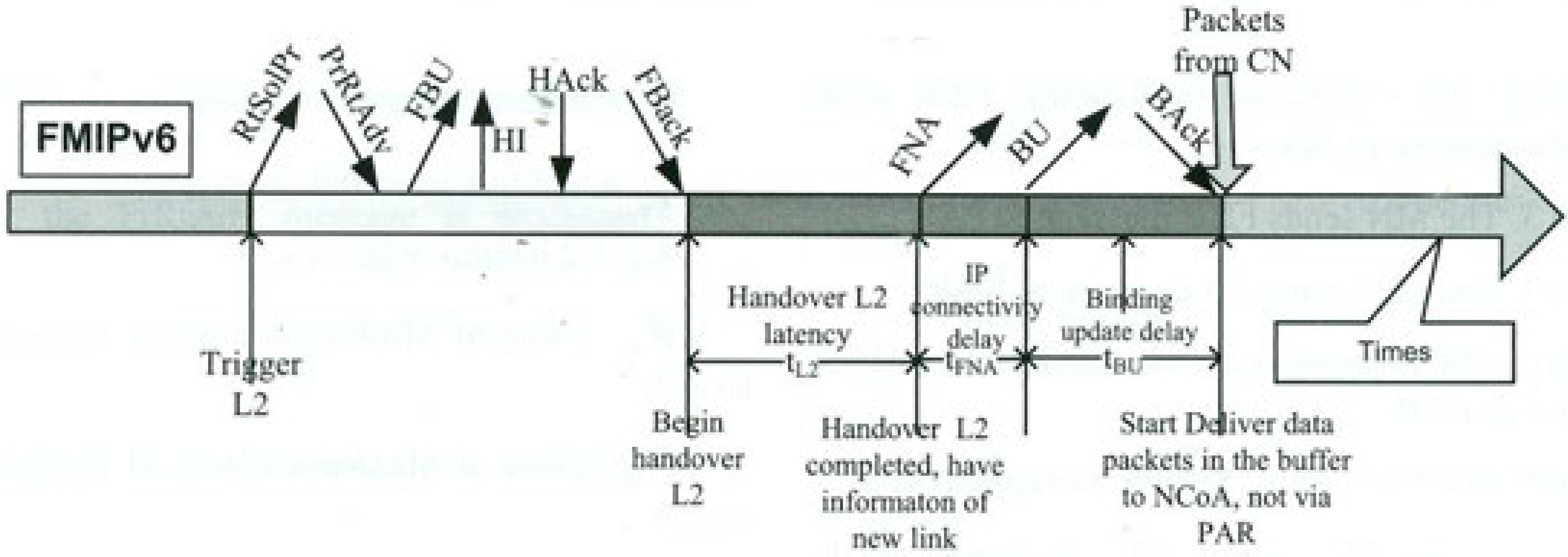

Figure 4. Time diagrams of FMIPv6 handover scheme

$$T_{FMIPv6} = t_{L2} + t_{FNA} + t_{BU} \quad (1)$$

tFNA including sending RS message latency to NAR and receiving RA message latency, calculated as following:

$$t_{FNA} = 2t_{MN\text{-}AR} = 2t_{\alpha}d_{MN\text{-}AR} \quad (2)$$

When MN sent BU message to the CN, to avoid attacks from the error sent BU messages to CN, BU must be authenticated, encrypted link using key management. After the mobile node has created the binding management key (Kbm), it can supply a verifiable binding update to the correspondent node [11]. The process is done to be capable of routing packets back, as following:

(i) The MN sends HoTI (Home Test Init) and CoTI (Care-Of-address Test Init) messages to its CN. HoTI is sent to CN indirectly through HA, CoTI is sent directly.

(ii) In response to these messages, the CN sends HoT (Home Test) message via HA to MN and CoT (Care-of Test) message directly to the MN.

After making back routing procedures, MN can perform the binding update to CN, t_{BU} is calculated using the formula:

$$t_{BU} = \max(2(t_{MN\text{-}HA} + t_{HA\text{-}CN}), 2t_{MN\text{-}CN}) + 2t_{MN\text{-}CN}$$

Because of latency transition between MN and CN shorter, total transition latency between MN and HA, between HA and CN, thus:

$$t_{BU} = 2(t_{MN\text{-}HA} + t_{HA,CN}) + 2t_{MN\text{-}CN}$$

$$= 2(t_{MN\text{-}AR} + t_{AR\text{-}MAP} + t_{MAP\text{-}HA} + t_{HA\text{-}CN}) + 2(t_{MN\text{-}AR} + t_{AR\text{-}MAP} + t_{MAP\text{-}CN})$$

$$= 4t_{\alpha}d_{MN\text{-}AR} + 2t_{\beta}(2d_{AR\text{-}MAP} + d_{MAP\text{-}HA} + d_{HA\text{-}CN} + d_{MAP\text{-}CN}) \quad (3)$$

From (1, 2 and 3), the handover latency of FMIPv6 calculated by the following formula:

$$T_{FMIPv6} = t_{L2} + 2t_{\alpha}d_{MN\text{-}AR} + 4t_{\alpha}d_{MN\text{-}AR} + 2t_{\beta}(2d_{AR\text{-}MAP} + d_{MAP\text{-}HA} + d_{HA\text{-}CN} + d_{MAP\text{-}CN})$$

$$= t_{L2} + 6t_{\alpha}d_{MN\text{-}AR} + 2t_{\beta}(2d_{AR\text{-}MAP} + d_{MAP\text{-}HA} + d_{HA\text{-}CN} + d_{MAP\text{-}CN}) \quad (4)$$

After CN receives the BU message, the CN sends packets directly to MN through NAR and remove the tunnel established previously. Therefore, there is the possibility of incorrect packet order and need to rearrange the order of the packets.

C. I-FMIPv6

Figure 2 is handover procedure of I-FMIPv6 and Fig. 5 shows the sequence of signaling messages for I-FMIPv6 handover scheme in terms of their requested response time intervals. The handover latency of I-FMIPv6 does not include movement detection latency, address configuration latency and binding update latency. Thus, handover latency of I-FMIPv6 only includes L2 handover latency, IP connectivity latency. The handover latency of I-FMIPv6 will be denoted $TI_{\text{-}FMIPv6}$ and calculated by the following formula:

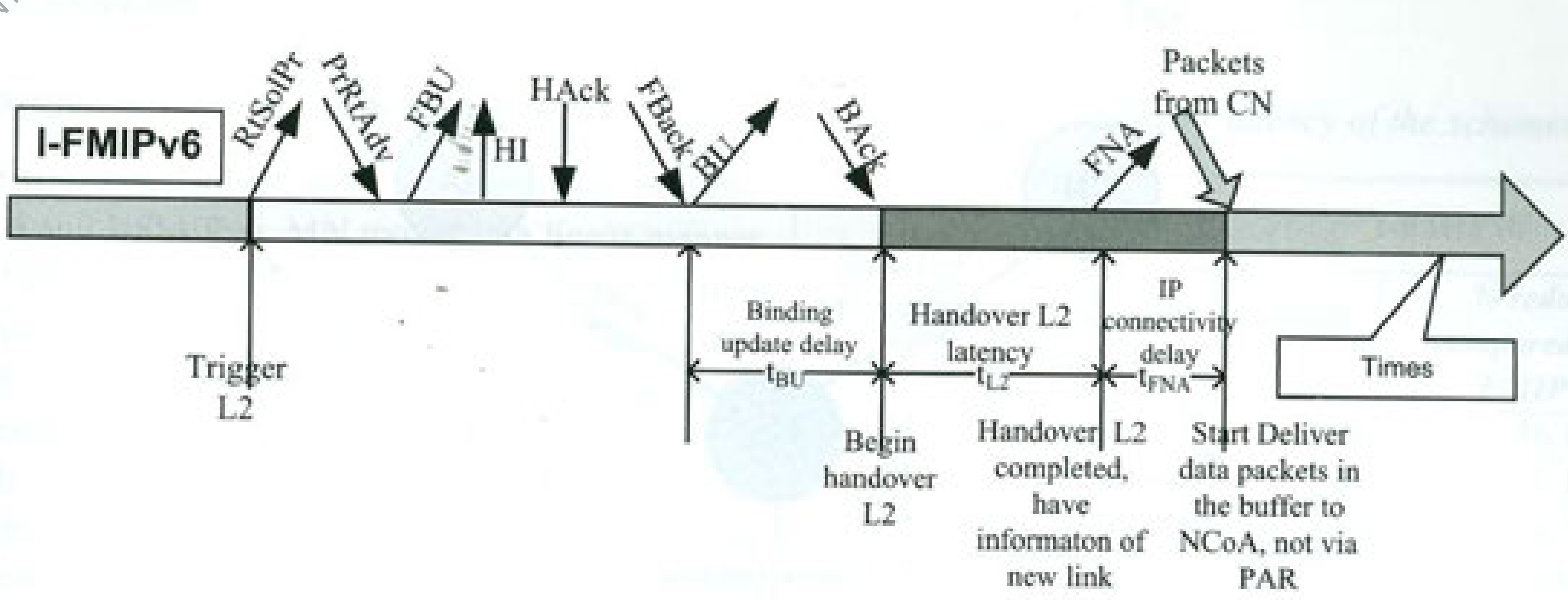

Figure 5. Time diagrams of I-FMIPv6 handover scheme

$$T_{I\text{-}FMIPv6} = t_{L2} + t_{FNA} \quad (5)$$

tFNA including latency send RS message to NAR and receive RA message latency, calculated as follows:

$$t_{FNA} = 2t_{MN\text{-}AR} = 2t_\alpha d_{MN\text{-}AR} \quad (6)$$

From (5, 6), calculate the handover latency of I-FMIPv6 by the following formula:

$$T_{I\text{-}FMIPv6} = t_{L2} + 2t_\alpha d_{MN\text{-}AR} \quad (7)$$

From formula (4 and 7), we calculate the handover latency of I-FMIPv6 reduced compared with handover latency of FMIPv6 is:

$$T_{FMIPv6} - T_{I\text{-}FMIPv6} = 4t_\alpha d_{MN\text{-}AR} + 2t_\beta(2d_{AR\text{-}MAP} + d_{MAP\text{-}HA} + d_{HA\text{-}CN} + d_{MAP\text{-}CN}) \quad (8)$$

D. The calculated figures

It is assumed the transport (core) network is Ethernet - IEEE 802.3, 10BaseT, 100BaseT and the access network is based on IEEE 802.11. The value parameters of the networks are stated in Table 1.

Table 1. Analytical, evaluate model parameters [3, 12]

Parameters	Value	Parameters	Value
$d_{MN\text{-}AR}$	1	t_α	2 ms
$d_{AR\text{-}MAP}$	2	t_β	0.5 ms
$d_{MAP\text{-}HA}$	6	t_{L2}	100 ms
$d_{MAP\text{-}CN}$	4	t_{DAD}	1000 ms
$d_{HA\text{-}CN}$	6	R_m	30 ms
		R_M	70 ms

From the formulas (4 and 7), we calculate the handover latency of FMIPv6 and I-FMIPv6 as following:

$$T_{FMIPv6} = t_{L2} + 6t_\alpha d_{MN\text{-}AR} + 2t_\beta(2d_{AR\text{-}MAP} + d_{MAP\text{-}HA} + d_{HA\text{-}CN} + d_{MAP\text{-}CN})$$

$$= 132\text{ms}$$

$$T_{I\text{-}FMIPv6} = t_{L2} + 2t_\alpha d_{MN\text{-}AR}$$

$$= 104\text{ms}$$

So, the calculation result of handover latency of I-FMIPv6 reduces 28ms compared with FMIPv6.

b. Evaluation by simulation

E. Simulation model

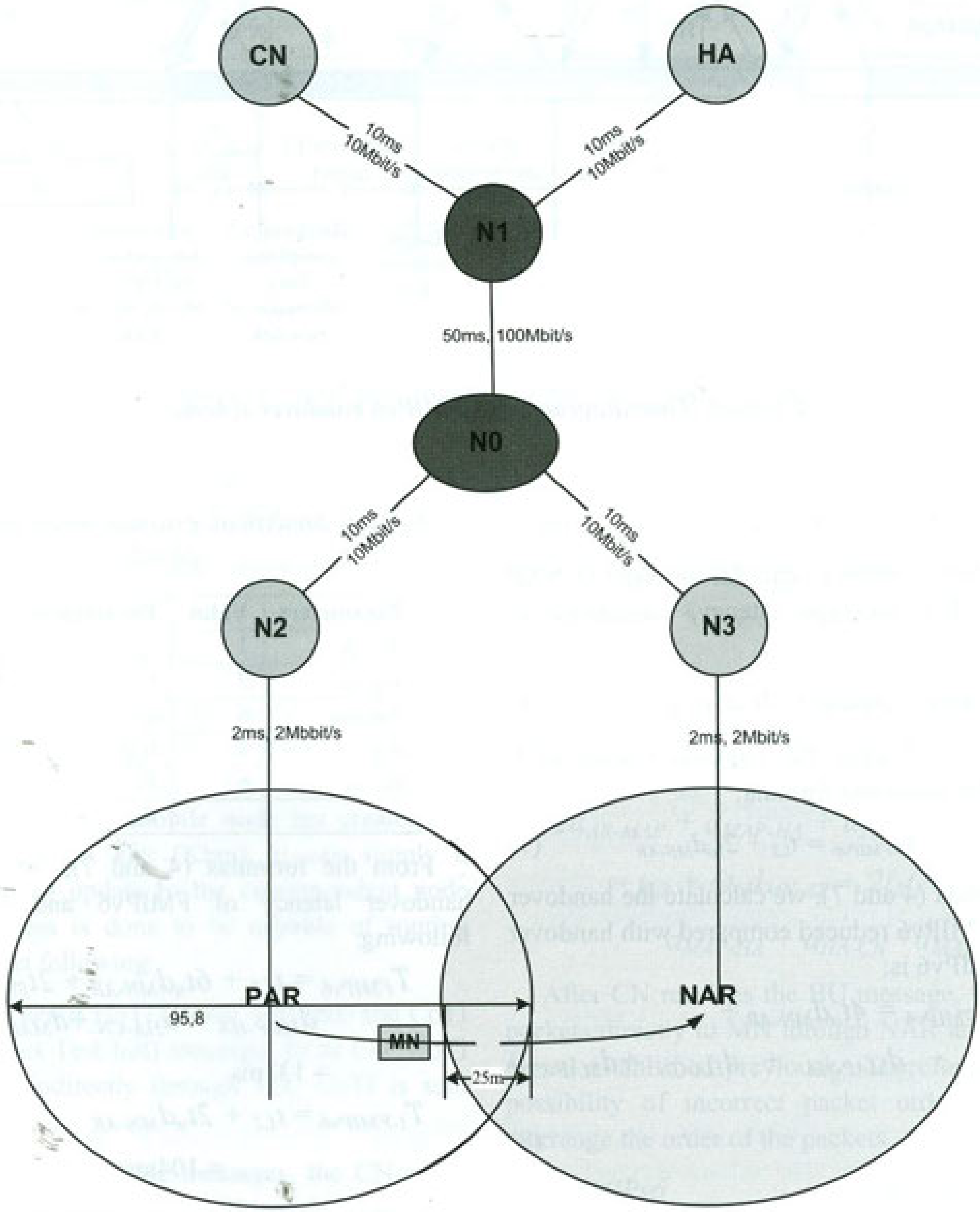

Figure 6. The simulation model

Network model for simulation is shown in Figure 6 [2]. This experiment is configured based on NS-2 allinone-2.31 on Ubuntu 10.04 operating system. Both CN and HA are connected to an intermediate node (N1) with 10ms link delay and 10Mbit/s links. The link between N1 and the N0 is 100Mbit/s link with 50ms link delay. The N0 is further connected to the intermediate nodes N2 and N3 with 10ms link delay over 10Mbit/s links. N1 and N2 are connected to PAR and NAR with 2ms link delay over 2Mbit/s links. The wireless link bandwidth is 2Mbit/s. The type of N2-PAR and N3-NAR link is set to be DropTail queue. The rest of these link use randomly early detection (RED) queue, CN is bound with TCP source agent, while MN associates with receiver agent. It is assumed the transport network is Ethernet – IEEE 802.3, 10BaseT, 100BaseT and the access network is IEEE 802.11, the coverage radius is 47.9 meters, the overlapping region is 25 meters.

F. Performing simulation experiments

We run simulations with the handover schemes FMIPv6 and I-FMIPv6. MN moves in a linear manner from PAR to NAR with 3.6km/h (1m/s) [3], 10km/h (2.78m/s), 30km/h (8.33m/s), 35km/h (9.72m/s) and 60km/h (16.33m/s). CN and MN start communicating with each other after 5 seconds, MN moves at 10 seconds. At each speed, the simulation is carried out five times with plus/minus 1% tolerant of speed and time moves of the MN, simulation time is 100 seconds.

G. Simulation results

The simulation results are averaged from the results of five runs for each handover scheme at a moving speed of MN. Handover latency is calculated with standard deviation is 0.0223 seconds, the average throughput since MN lost connection to PAR till getting stable connection to NAR is calculated with standard deviation is 0.0075 Mbit/s. Regarding to packet loss rate, the simulation results show that packet loss rate of I-FMIPv6 nearly the same with , have reduced but not significantly. This result is consistent with theory that TCP retransmission is used in case of packetloss. Thus we do not show and analyze results of simulation about packet loss.

1) The handover latency:

Table 2 is the handover latency of the schemes and the Fig. 7 shows the handover latency for handover schemes.

I-FMIPv6 has handover latency from 0.5127 seconds to 0.5144 seconds, 16.19% to 16.79% lower than handover latency of FMIPv6 when MN moves at 3.6 km/h, 10 km/h, 30 km/h. When MN moves at 35 km/h handover latency of I-FMIPv6 approximately 0.619 seconds, equivalent of FMIPv6; and when MN moves at 60 km/h handover latency of I-FMIPv6 around 2.249 seconds.

Table 2. Handover latency of the schemes

Speed of MN (km/h)	FMIPv6	I-FMIPv6	
	Latency (sec)	*Latency (sec)*	*% reduce compared with FMIPv6*
3.6	0.6138	0.5144	16.19
10	0.6147	0.5134	16.48
30	0.6162	0.5127	16.79
35	0.6193	0.6192	0.00
60	2.2499	2.2498	0.00

2) The throughput

Table 3 is the throughput average from MN lost connection to PAR till stable connection to NAR and Figure 8 shows the throughput average from MN lost connection to PAR till stable connection to NAR of schemes.

I-FMIPv6 have the throughput average from MN lost connection to PAR till stable connection to NAR ranging from 0.3560 Mbits/s to 0.4841 Mbits/s, 0.19% to 2.57% higher than the throughput average from MN lost connection to PAR till stable connection to NAR of FMIPv6, depending on the speed of MN is 3.6 km/h, 10 km/h or 30 km/h. When MN moves speed at 35 km/h, I-FMIPv6's the throughput average from MN lost connection to PAR till stable connection to NAR is 0.3555 Mbit/s, equivalent with

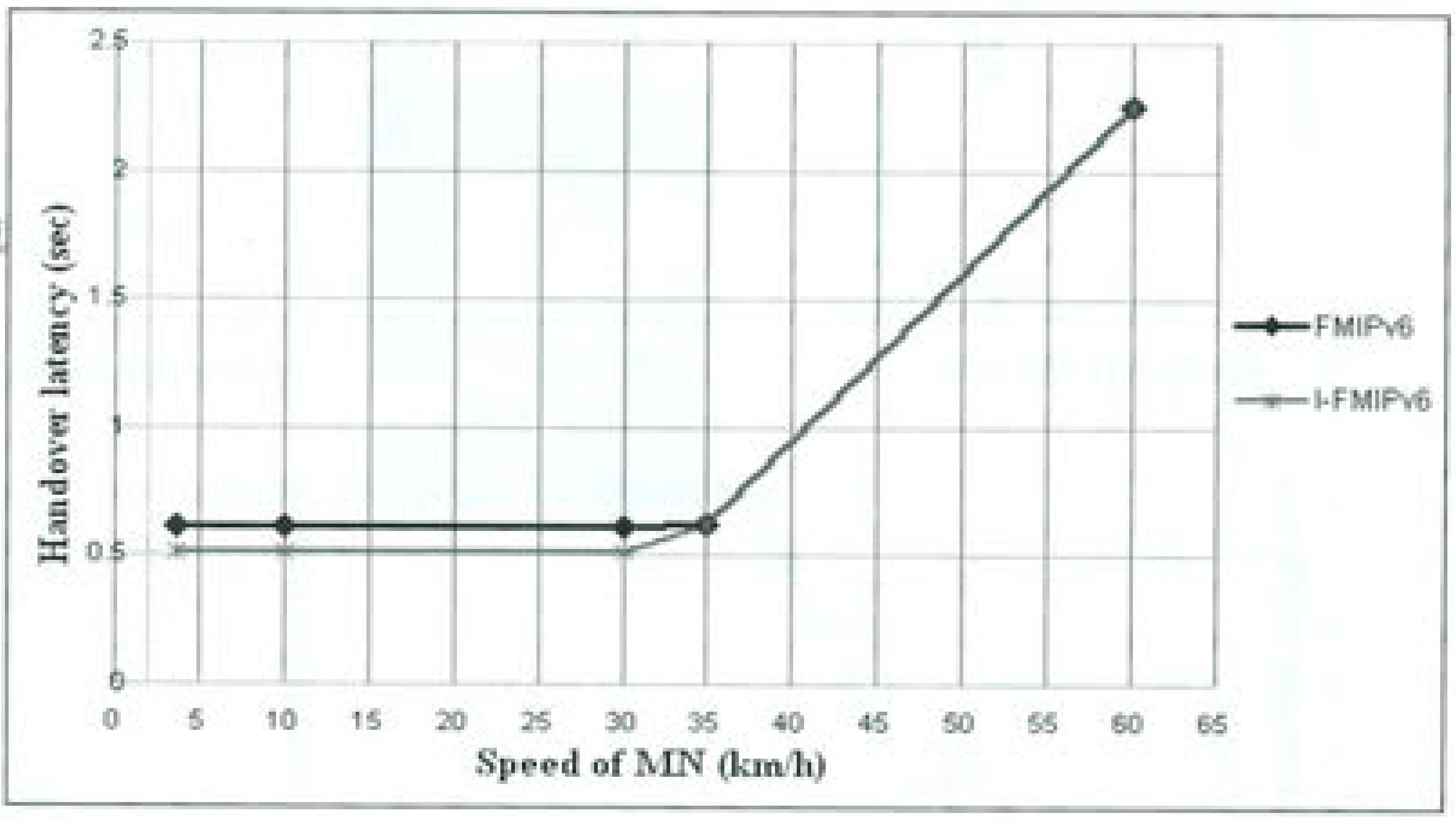

Figure 7. Handover latency of schemes in the process handover

the throughput average from MN lost connection to PAR till stable connection to NAR of FMIPv6. When MN moves at 60 km/h, the throughput average from MN lost connection to PAR till stable connection to NAR of I-FMIPv6 equivalent with the the throughput average from MN lost connection to PAR till stable connection to NAR of FMIPv6, is about 0.1621 Mbit/s.

The simulation results show that when MN moves at slow speed, the I-FMIPv6 has better performance than FMIPv6. Handover latency of the I-FMIPv6 decreases up to 16.79% comparing with FMIPv6. The throughput average from MN lost connection to PAR till stable connection to NAR of the I-FMIPv6 increases up to 2.57% compared with FMIPv6. When MN moves at 35 km/h, I-FMIPv6 has handover performance equivalent to FMIPv6's handover performance. That result is because the MN has not enough time for binding update to HA/CN before L2 handover takes place, should act as FMIPv6. When MN moves at high speed, MN cannot perform any part of the L3 handover before L2 handover takes place, consequently the handover schemes of FMIPv6 and I-FMIPv6 act equivalent handover schemes of MIPv6.

Table 3. The throughput average from MN lost connection to PAR till stable connection to NAR

Speed of MN (km/h)	FMIPv6	I-FMIPv6	
	Throughput (Mbit/s)	*Throughput (Mbit/s)*	*% higher compared with FMIPv6*
3.6	0.4316	0.4406	2.10
10	0.4720	0.4841	2.57
30	0.3554	0.3560	0.19
35	0.3555	0.3555	0.00
60	0.1621	0.1621	0.00

V. CONCLUSION

FMIPv6 is the extension of MIPv6 in order to reduce latency and packet loss caused by the handover. However, the handover latency of FMIPv6 is still quite high. This paper proposed a modified handover scheme of FMIPv6 called I-FMIPv6). In I-FMIPv6, the MN requests prior information about the router that it will move to through PAR. The MN can

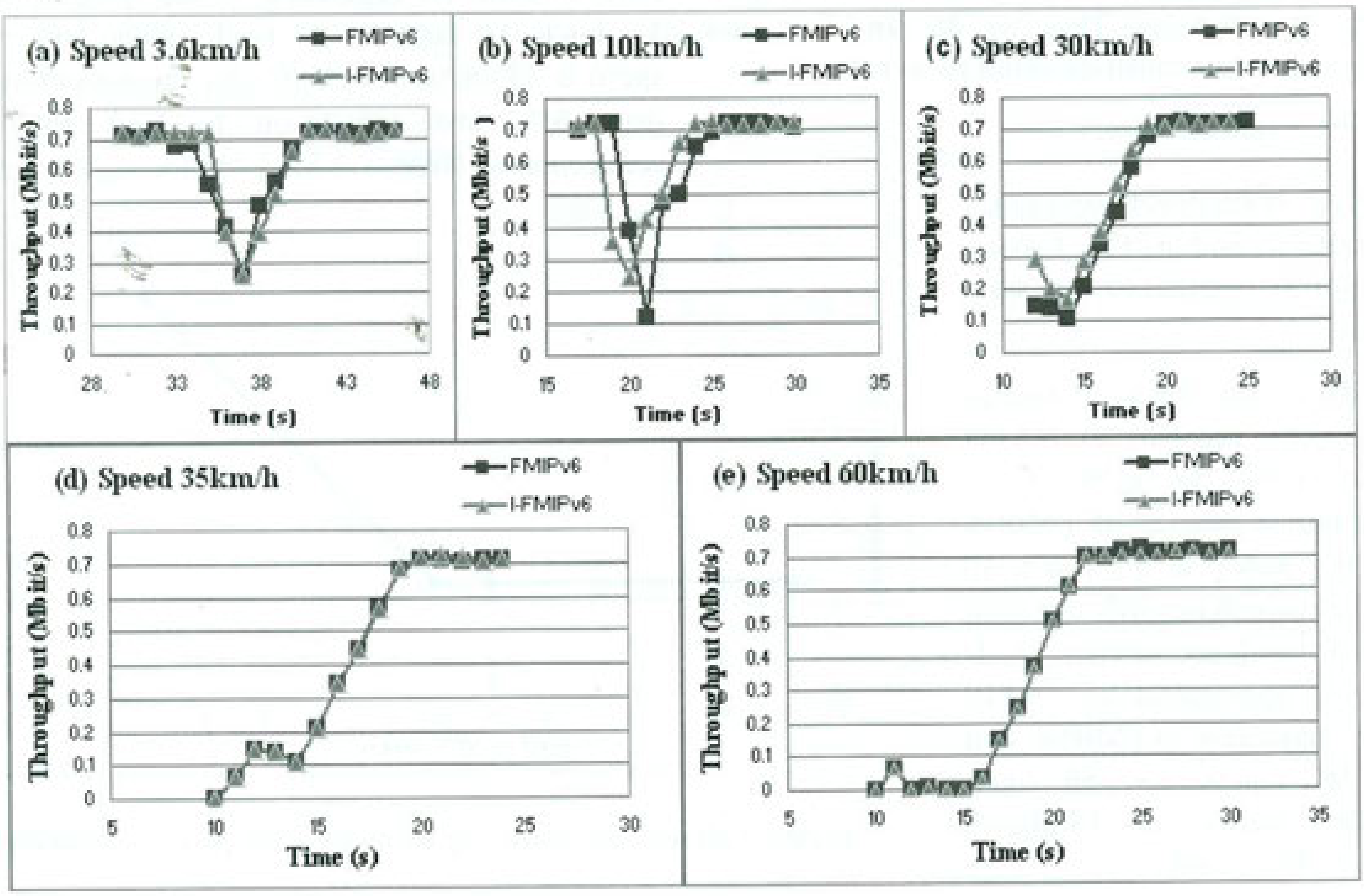

Figure 8. Graphs the throughput average from MN lost connection to PAR till stable connection to NAR

connect to PAR until binding update to CN/HA complete. In I-FMIPv6 handover scheme, MN will perform address configuration and send the BU message to CN/HA when it is still connected to the PAR. When the MN is switched to the NAR, it does not need to perform binding update registration to the CN/HA. The analysis and simulation results show that I-FMIPv6 is able to provide better performance than FMIPv6 when MN moves at low speed (moving speed of vehicles in the inner city) and handover performance is the same when the MN moves at high speed.

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