CHAPTER V

PERFORMANCE EVALUATION

In this chapter, we present the performance evaluation. Firstly, we describe the simulation environment and performance metrics. The simulation results of Mobile IP, Paging Mobile IP, Paging Mobile IP Post Registration, Paging Mobile IP Regional Registration, Proposed Method 1, and Proposed Method 2 in terms of handoff latency and lost packet are then showed and analyzed individually. We also provide brief comparison among all protocols in this section. We later compare the performance of all protocols as the function of various parameters. Finally, we present the performance comparison between Paging Mobile IP and Proposed Method 2 in non-overlapping cell scenario in terms of handoff latency and lost packet.

5.1 Simulation Environment

In the simulation environment, Constant Bit Rate (CBR) with 10 ms period as the traffic source is sent from Home Agent (HA) to Mobile Node (MN). The size of the CBR traffic is 500 bytes each. Wireless LAN 802.11 is chosen to be the link layer. The period of Agent Advertisement message sent by Foreign Agent (FA) is 1 second. Every FA also broadcasts Link Layer beacon with 100 ms period except for the FA in Paging Mobile IP Post Registration method which broadcasts not periodic Link Layer beacon. There are two paging areas in the simulation environment. Each cell is associated with one FA in an overlapping cell scenario with 122 meters diameter and 1 meter overlapping area. We assumed that all links have 5 Mbps transmission rate and every link has 3 ms transmission delay. The MN's active time percentage is 5 % [4]. Protocol Independent Multicast-Sparse Mode is used as the multicasting protocol. The MN is moving in straight direction from the first FA in the first paging area to second paging area direction. The active timer period is set to be 1495 ms. The MN will change its state to be idle if it has not received any packet during this period of time. We vary the number of FA in a paging area, the speed of the MN, the number of hop from Gateway Foreign Agent (GFA) or router to HA, and the simulation time to check the performances of all protocols in terms of signaling cost, handoff latency, lost packet, and data hop. Figure 5.1 shows the network topology of simulation environment.

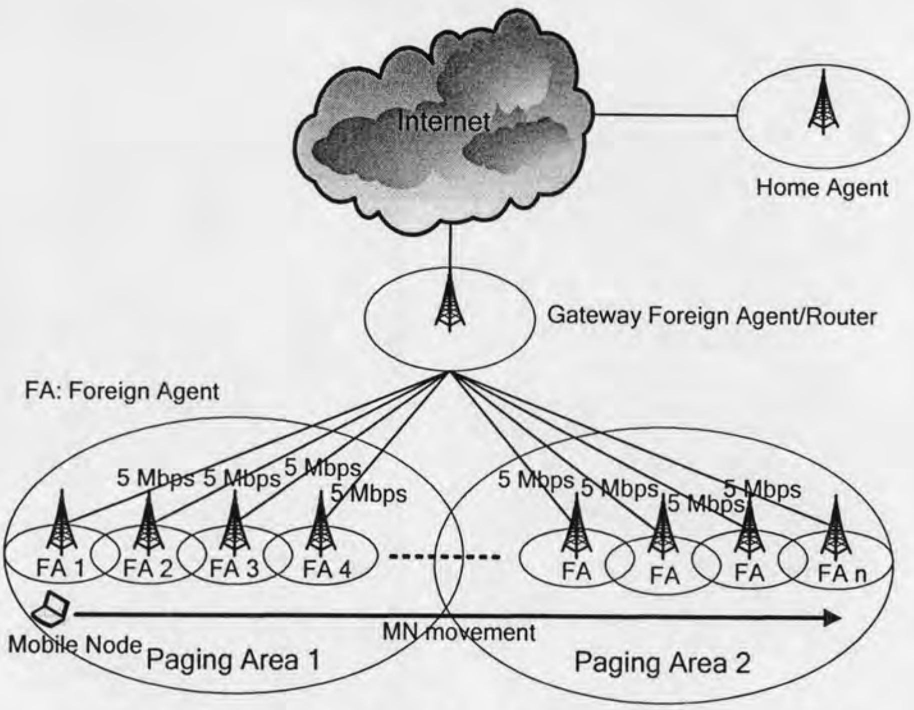

Figure 5.1 Network topology of simulation environment.

5.1.1 Performance Metrics

In this research, we use four performance metrics to check and analyze the performance of each method. These performance metrics are handoff latency, number of lost packet, signaling cost, and number of data hop. Handoff latency is the total time which is measured from the time the MN receives the last packet from the previous FA to the time the MN receives the first packet from the new FA. So, handoff latency is only monitored during active time when the HA is sending packets to the MN. The packets that are missing during handoff time is called lost packets and used as the next performance metric. The third performance metric is signaling cost. Signaling cost is calculated as the total wired hop that the signaling messages of Network Layer travel from one entity to another. We do not consider the wireless messages since it is dominated by Agent Advertisement message. Here, other messages do not give significant amount to total number of signaling cost. The signaling messages may not be the same for every protocol. They depend on the messages used in each protocol. First proposed method, for the example, consists of Regional Registration Request, Regional Registration Reply, Paging Request, Paging Reply, Inter-Agent Advertisement, Protocol Independent Multicast Join, and Protocol Independent Multicast Prune messages. The last performance metrics, data hop, is measured as the total number of hop the packet travels from the sender to receiver. The ordinary packets travel from HA to MN, while the multicast packets in the proposed methods travel from GFA to MN.

5.2 Simulation Results

In this section, we show the simulation results of each protocol. The emphasis is on the handoff process when an active MN moves from one cell to another. The timing of packet sequence received at the MN, handoff latency, lost packets during handoff time, and signaling messages used when the HA sends packets to idle MN are explained. One scenario is simulated for each protocol. We set the speed of the MN to be 20 m/s. There are 10 cells in one paging areas which means there are total 20 cells in the simulation environment. We name the FAs in those cells from FA1 for the first FA in the first paging area to FA20 for the last FA in the second paging area. The number of hop between GFA/router and HA is set to be 40. The MN moves in the straight direction from the center of the first FA in the first paging area to the center of the last FA in the second paging area. Because of MN's speed, the simulation time is also adjusted. The total simulation time is 114.951 s. From this simulation time, the time 100% is set to be 114 s. Time 100% is a period of time where there is only one active interval for data transmission activity of 5 %. It means that, in a certain time period, 95% of this period is continuously idle and there is only one continues data transmission from the HA in the rest of this period [5]. Time 100% is not the same as the total simulation time since we want all packets from the HA arrive at the MN at the end of the simulation. We process all simulation results in this chapter by using Microsoft Excel software.

5.2.1 Simulation Results of Mobile IP

The MN starts to move at the beginning of simulation. In Mobile IP, MN registers to HA by exchanging Registration Request and Reply messages every time the MN reads an Agent Advertisement message from new FA. When HA starts sending data packets to the MN, it sends those packets to FA19 since the MN registered to HA through this FA at the last registration. The registered FA19 then directly forwards the packets to the MN. It is not similar to other protocols where there is paging process to search for MN's precise location. Therefore, the first packet in Mobile IP arrives at the MN faster than other methods. The time when the HA begins to deliver packets to the MN depends on the time 100% of every scenario. The HA starts sending packets at 95% of time 100%. Figure 5.2 shows the packets sequence received at the MN as the function of time and also handoff timing when the MN moves from FA19 to FA20.

Figure 5.2 shows that the MN with 20 m/s speed receives first packet at 108,461 ms. The MN continues receiving packets from FA19 until packet number 349. At time 111,951 ms, when the MN is supposed to receive packet number 350, the packet is lost since the MN has moved out of FA19 cell and enters the coverage area of FA20. The incoming packets from FA19 are then still lost until the MN finishes registration with HA via FA20. The MN starts registration when it receives Agent Advertisement from FA20 which is sent at time 112,001 ms. The MN then sends Registration Request to and receives Registration Reply from HA via FA20. Receiving Registration Request, the HA changes the route of packets to MN from FA19 to FA20. At time 112,301 ms, the MN restarts to receive packets from the HA through FA20. The MN receives packet number 385 until totally there are 571 packets at the end of the simulation via the FA20. It can be seen that during the handoff process, the MN has to wait to Agent Advertisement for about 60 ms to start registration. Moreover, the registration process also takes long signaling delay about 300 ms because the distance between HA and FA20 is quite far. Handoff process results in 360 ms handoff latency in which there are 35 lost packets. The MN's waiting time for Agent Advertisement can be longer than 60 ms in other scenario since that message is broadcast every 1 second by each FA so that there is a possibility that the MN has to wait longer time to conduct registration. Future sections with different simulation scenarios will confirm this analysis.

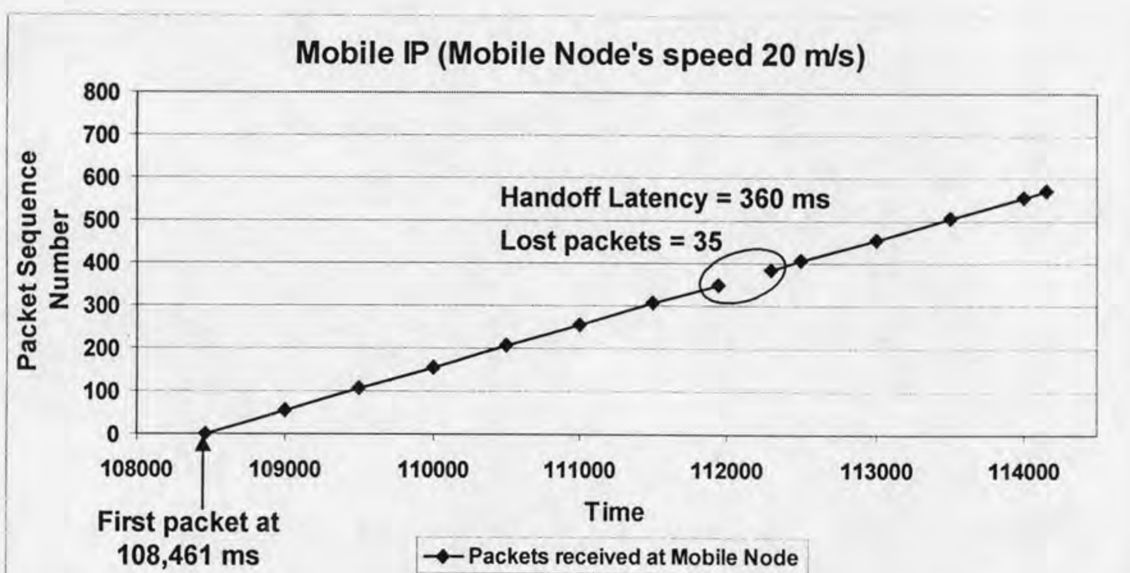

Figure 5.2 Mobile IP packets received timing for the Mobile Node with 20 m/s speed.

5.2.2 Simulation Results of Paging Mobile IP

In the simulation of Paging Mobile IP, an idle MN does not conduct registration when it moves to another cell within the same paging area. The idle MN registers to HA only when it moves to new paging area. In this simulation, idle MN registers when it has leaved FA10 in first paging area and receives Agent Advertisement message from FA11 as the first FA in the second paging area. The HA then records FA11 as the last registered FA. When the active time for the MN comes, HA starts to send data packets to FA11. However, the MN is now located at FA19. Therefore, FA11 buffers incoming packets and transmits Paging Request messages to all FAs in the second paging area via the router as well as broadcasts that message it its own cell. All other FAs in the second paging area then also broadcast Paging Request message in their cells. When the MN receives this message, it registers to HA via FA19. HA then changes the MN's registered FA and starts to send packets to the MN via FA19. Receiving the Registration Reply message, the MN sends Paging Reply message to FA11 through FA19 and router. FA11 then forwards all buffered packets to MN via router and FA19. As can be seen from Figure 5.3, the paging procedure in Paging Mobile let the first packet arrive later than that of Mobile IP in the previous section. The first packet for the MN with 20 m/s speed arrives at 108,745 ms. This time is later 284 ms than the time of first packet in Mobile IP in which the first packet arrives at 108,461 ms. Time of 284 ms is quite significant if the packets sent are real time traffic since the delay of the first packet may degrade the quality of the communication. Sometime in the future, the MN leaves FA19 and enters the coverage area of FA20. The handoff procedure is the same as Mobile IP. Therefore, all timing points such as the time when the MN loses the packet from FA19, the packet number, and the time the MN receives Agent Advertisement from FA20, handoff latency, and number of lost packets during handoff process are the same as Mobile IP as explained in the previous section.

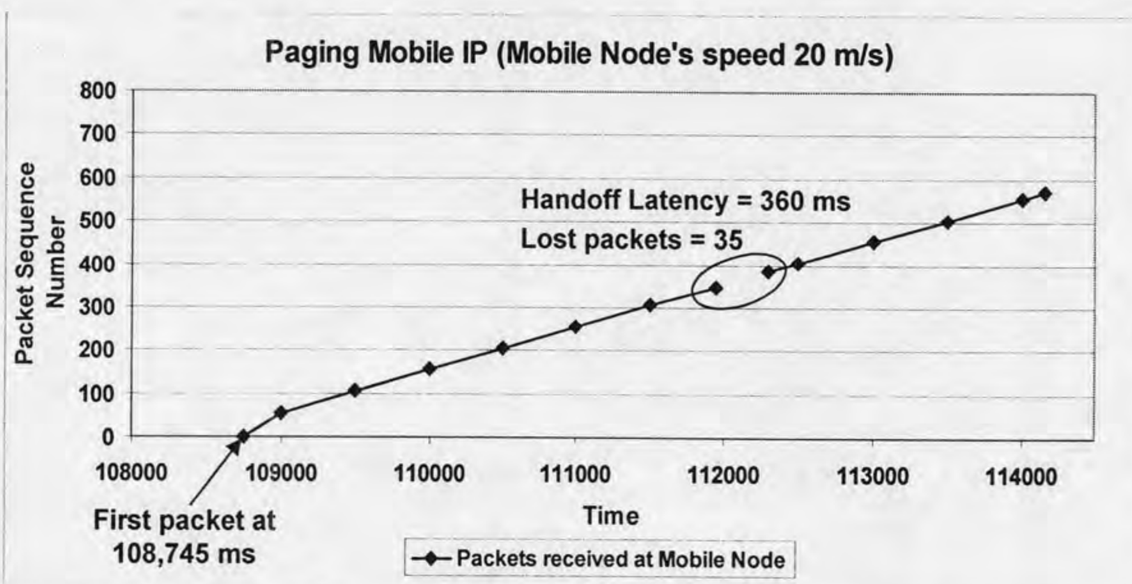

Figure 5.3 Paging Mobile IP packets received timing for the Mobile Node with 20 m/s speed.

5.2.3 Simulation Results of Paging Mobile IP Post Registration

Idle MN in Paging Mobile IP Post Registration acts the same as the MN in Paging Mobile IP. It registers to HA when it leaves first paging area at FA10 and enters FA11 as the first FA in the second paging area. The HA then updates the registered FA of the MN to be FA11. The active MN uses Post Registration scheme for movement detection. The active MN uses Link Layer beacon for movement detection and trigger to the registered FA and present FA to construct Bi-Directional Edge Tunnel (BET) that is used for tunneling of buffered and incoming packets from the registered FA to the MN via the router and present FA before the MN conducts Network Layer registration through the present FA. Simulation results for Paging Mobile IP Regional Registration are demonstrated in Figure 5.4.

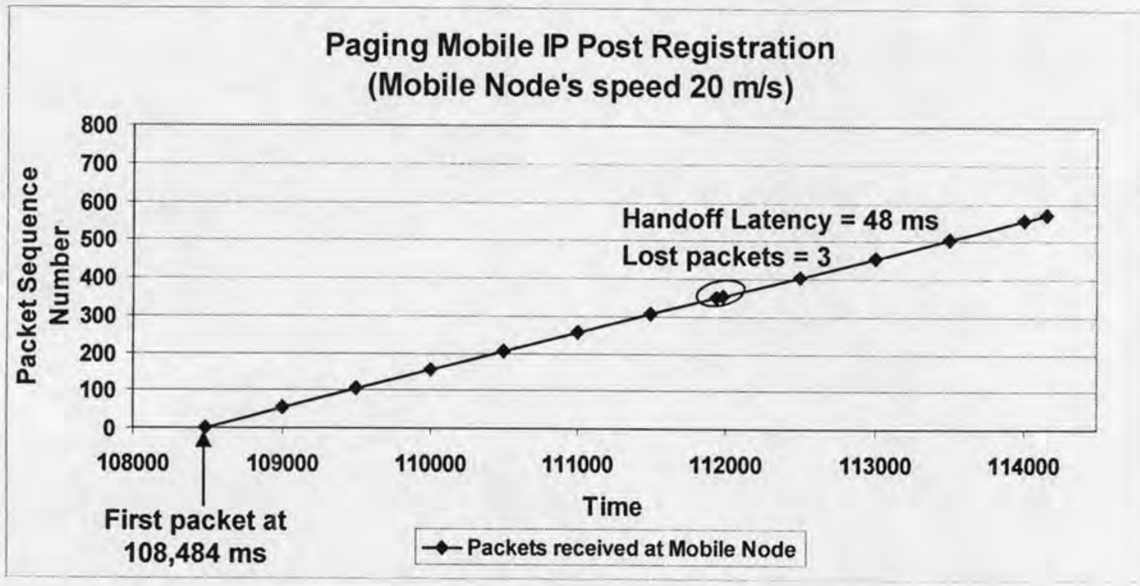

Figure 5.4 Paging Mobile IP Post Registration packets received timing for the Mobile Node with 20 m/s speed.

In this scenario, as in other protocols, the MN is in coverage area of FA19 when the HA starts sending packets to it. HA first delivers the packets to FA11 as the registered FA. FA11 then buffers incoming packets, broadcasts Link Layer beacon in its cell and transmits Paging Request messages to all FAs in the second paging area via the router. All other FAs then also transmit Link Layer beacon in their own cell for searching the MN after they receive Paging Request message. Starting from this time, the Link Layer beacon is not periodic anymore since all FAs in the second paging area reset the starting time for transmitting Link Layer beacon every 100 ms. Receiving the beacon, the MN associates with FA19 by sending Association Request message. This message triggers FA19 to send Handoff Request message to FA11 via router. FA11 then replies with Handoff Reply message back to the FA19. At this point, the BET has been constructed between FA11 and FA19. FA11 then forwards all buffered and incoming packets to the MN through router and FA19. As the results of all processes above, the MN receives the first packet at time 108,484 ms. This point of time is better than that of Paging Mobile IP which is 108,745 and only differs 23 ms from that of Mobile IP which is 108,461 ms. The MN continues to receive packets via the BET until it has finished registration via FA19. At time 109,001 ms, FA19 transmits Agent Advertisement message. Obtaining this message, the MN registers to HA via FA19. HA then deletes the record of FA11 and starts to send packets to MN via FA19.

Since the MN has entered the active state, it uses Post Registration method for movement detection. As can be observed from Figure 5.4, the handoff latency when the MN moves to FA20 cell is 48 ms and the lost packets is 3. The reason behind these results is as follows. The MN is supposed to receive packet number 350 from FA19 at time 111,951 ms, but at that time, the MN has leaved the FA19's cell and entered FA20's cell without receiving Link Layer beacon when it was located within overlapping area between FA19 and FA20. Thus, the BET can not be constructed before the MN leaves FA19's cells and it causes lost packets until the MN has finished Link Layer handoff at FA20. MN can receive Link Layer beacon from FA20 fast since the beacon has 100 ms period. Receiving Link Layer beacon from FA20, the MN conducts Link Layer handoff by exchanging Association Request and Association Response messages. Association Request triggers FA20 to send Handoff Request message to FA19. Receiving this message, FA19 replies with Handoff Reply message. At this point of time, the BET between FA19 and FA20 via the router has been constructed. Therefore, FA19 can forward incoming packets to the MN via router and FA20. At time 111,989 ms, the MN receives packet number 353 via the tunnel and continues to receive the packets through it until the MN has finished Network Later registration via FA20. The MN starts registration after it receives Agent Advertisement transmitted by FA20 at time 112,001 ms.

5.2.4 Simulation Results of Paging Mobile IP Regional Registration

Paging Mobile IP Regional Registration extends Mobile IP Regional Registration to support paging. As in Paging Mobile IP, idle MN does not have to register when it roams to another cell. The idle MN only registers when it changes its paging area. In the simulation, when the MN moves to second paging area from FA10 in the first paging area to second paging area, the MN conducts regional registration to GFA through FA11 when the MN receives Agent Advertisement from that FA11. At the time the GFA receives first packet for the MN from HA, the MN's state record in the GFA is idle. Consequently, the GFA buffers incoming packets and sends

Paging Request messages to all FAs in the second paging area. Those FAs then broadcast that message in their cell to search for the MN. Receiving Paging Request message from FA19, the MN registers to GFA via that FA. Once Regional Registration Reply arrives at MN, it sends Paging Reply message to GFA via FA19. The GFA then starts forwarding all buffered and incoming packets to the MN.

As can be noticed from Figure 5.5, the first packet arrives at time 108,470 for the MN with 20 m/s speed. It only differs 9 ms that of Mobile IP which is 108,461 ms and is much better than original Paging Mobile IP which is 108,745 ms. It is also better than Paging Mobile IP Post Registration, which is 108,484 ms. The reason for the last case is that in Paging Mobile Post Registration, the time of paging process which also includes Link Layer handoff and the construction of BET between FA11 and FA19 takes longer time than the paging process in Paging Mobile IP Regional Registration. Furthermore, packets in the Post Registration method use longer route than that of Paging Mobile IP Regional Registration as packets are sent from last registered FA to present FA via the router.

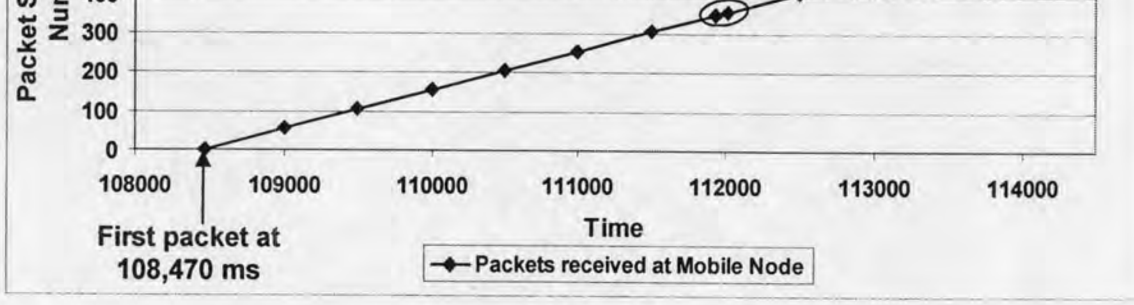

Figure 5.5 Paging Mobile IP Regional Registration packets received timing for the Mobile Node with 20 m/s speed.

As the MN moves to FA20 direction, the MN passes the overlapping area between FA19 and FA20. The MN loses the packets sent from FA19 after the MN leaves FA19's cell. The first lost packet that is packet number 350 at time 111,950 ms. Packets sent from FA19 remain lost until the MN conducts regional registration at FA20. The MN starts regional registration process when it receives Agent Advertisement from FA20 sent at time 112,001 ms. Once the regional registration process is completed, the GFA forwards incoming packets to the MN via FA20. The

MN then restarts to receive the packets. The first packet from FA20 arrives at time 112,020 ms. Handoff process results in 80 ms handoff latency and 7 lost packets. These numbers are much better than those of Mobile IP and Paging Mobile IP, where the handoff latency and lost packets are 360 ms and 35 packets respectively. The reason is that the signaling delay that occurs when the MN has to registers to far away HA in Mobile IP and Paging Mobile IP can be reduced by only conducting regional registration to GFA. For the scenario used in the simulation, where the number of hop between GFA/router and HA is 40 hops, the handoff latency can be reduced up to 280 ms. The amount of this time gets higher as the number of hops between GFA/routers increases. Therefore, it is effective to use regional registration if the visited domain of MN is far from HA.

The last analysis is that the handoff latency and number of lost packets in Paging Mobile IP Regional Registration is higher than that of Paging Mobile IP Post Registration. The reason behind this result is that the MN in Paging Mobile IP Regional Registration relies on Agent Advertisement sent every 1 second by every FA, while the MN in Paging Mobile IP Post Registration depends on Link Layer beacon sent every 100 ms by each FA. Therefore, the MN in Paging Mobile IP Post Registration can detect that it has moved to another cell faster than the MN in Paging Mobile IP Regional Registration.

5.25 Simulation Results of First Proposed Method

MN moves in idle state at the beginning of simulation. It does not register when it roams in the same paging area. When MN leaves the first paging area and receives Agent Advertisement from FA11 as the first FA in the second paging area, the MN registers to GFA by exchanging Regional Registration Request and Reply messages. As in the previous methods, the MN is located at FA19's cell when the first packet from HA arrives at GFA. The GFA then buffers incoming packets and transmits Paging Request messages to all FAs in the second paging area. All FAs then broadcast these messages in their cell. Obtaining Paging Request message, the MN conducts regional registration to GFA via FA19. FA19 also constructs multicast tree and group by sending PIM Join message to GFA and Inter-Agent Advertisement to FA20. FA20 then also joins the multicast group by sending PIM Join message to GFA. Once the registration is completed, the MN sends Paging Reply message to GFA. GFA then multicasts all buffered and incoming packets to FA19 and FA20. FA19 forwards incoming packets to MN while FA20 buffers recent incoming packets from GFA. As can be noticed from Figure 5.6, the first packet arrives at the same time as that of Paging Mobile IP Regional Registration in the previous section. The first packet arrives at time 108,470 ms. The same result can happen because Proposed Method 1 and Paging Mobile IP Regional Registration use the same paging method.

The construction of multicast tree and group do not influence the time that the first packet arrives at MN since that process takes place simultaneously with the registration process.

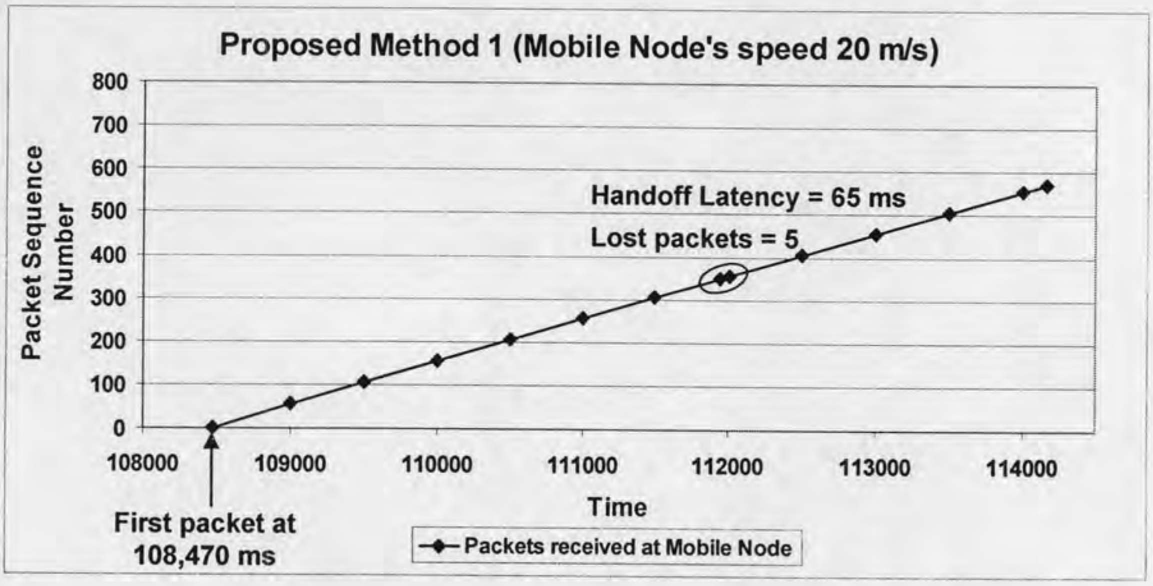

Figure 5.6 Proposed Method 1 packets received timing for the Mobile Node with 20 m/s speed.

When the MN leaves the overlapping area between FA19 and FA20 and is fully located within FA20's coverage area, the packets from FA19 are lost as explained in the discussion of Paging Mobile IP Regional Registration. The incoming packets continue to lose until the MN sends Regional Registration Request message to GFA after the MN receives Agent Advertisement sent from FA20. Accepting Regional Registration Request, FA20 forwards buffered data packets to MN. Here, MN does not need to wait until the registration process is finished to receive packets from FA20. Therefore, Proposed Method 1 has better performance than Paging Mobile IP Regional Registration in terms of handoff latency and lost packets. Figure 5.6 shows that the handoff latency and lost packets in the proposed method are 65 ms and 5 packets respectively. These results are slightly better than that of Paging Mobile IP Regional Registration where there are 80 ms and 7 packets. These results are also much better than the original Paging Mobile IP. The handoff latency and lost packets are still higher than that of Paging Mobile IP Post Registration since FA20 still has to wait for Regional Registration Request message to forward the buffered packets to MN after the MN leaves the coverage area of FA19 in Proposed Method 1. The packet whose number is 354 from FA20 arrives at time 112,005 ms at the MN. After the MN's state in the FA19's record changes to idle, FA19 sends PIM Join message to

GFA to leave the multicast group. The GFA then only sends packets to MN via FA20 until the end of simulation.

5.2.6 Simulation Results of Second Proposed Method

The movement of idle MN in the Proposed Method 2 follows the same procedure as in Paging Mobile IP. Idle MN registers when it receives Agent Advertisement from FA11 as the first FA in the second paging area. The first packet at the MN also arrives after GFA finishes the paging process to search for the MN. The first packet arrives at the same time as that of Paging Mobile IP Regional Registration and Proposed Method 1 at the MN which is 108,470 ms as demonstrated in Figure 5.7. In the Proposed Method 2, the multicast group is constructed by FA19 when it receives Paging Reply from MN. FA19 sends PIM Join message to GFA to construct multicast tree between them.

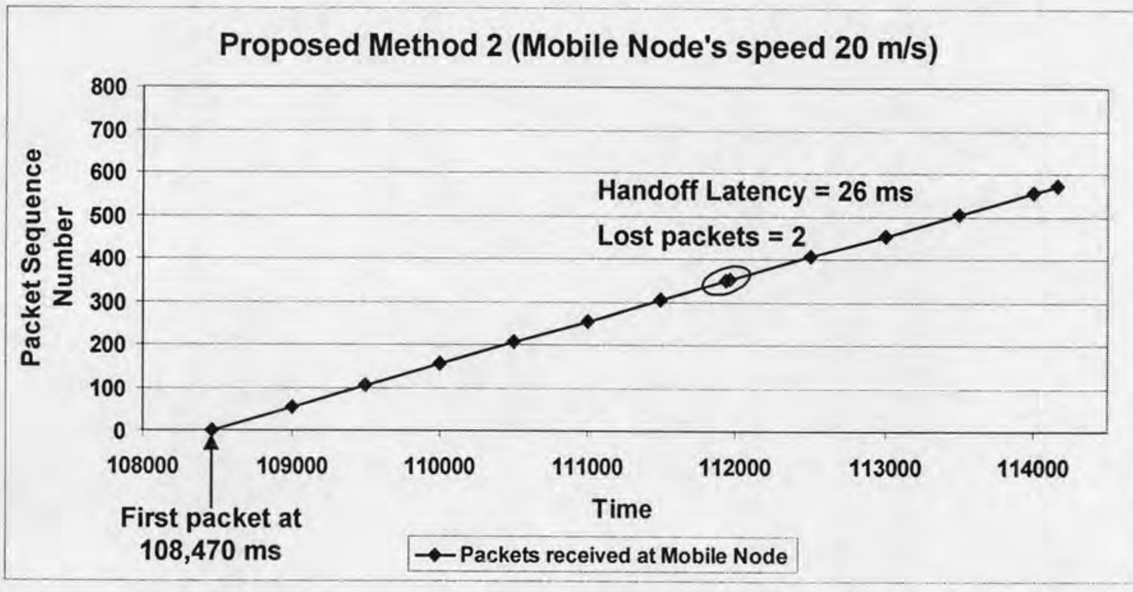

Figure 5.7 Proposed Method 2 packets received timing for the Mobile Node with 20 m/s speed.

MN in Proposed Method 2 monitors the received Link Layer beacon for movement detection. As can be seen from Figure 5.7, the handoff latency is only 26 ms with 2 lost packets. The explanation for these results is as follows. At the time 111,950 ms, the MN is supposed to receive packet number 350 from FA19. However, the MN has leaved FA19's coverage area. Consequently, that packet is lost. Before this time at time 111,901 ms, FA20 already sent Link Layer beacon in its cell and that beacon is received by MN since at that time the MN is located within the overlapping area between FA19 and FA20. The MN then associates with FA20 by sending

Association Request message. This message triggers FA20 to join the multicast group. FA20 sends PIM Join message to GFA after it receives Association Request message. Once it obtains the PIM Join message, the GFA forwards the multicast packets to FA19 and FA20. The packets are then forwarded by each FA to MN. The construction of multicast group lasts for short time so that the MN can receive multicast packet from FA20 soon after it leaves the coverage area of FA19. The MN receives packet number 352 from FA20 at time 111,966 ms so that the handoff process results in minimum time of handoff latency and number of lost packets. Proposed Method 2 also improves the performance of original Paging Mobile IP and better than Proposed Method 1. At time 112,001 ms, Agent Advertisement message is sent by FA20. The MN then conducts regional registration to GFA. FA19 also leaves the multicast group when the active state timer in its record expires.

5.3 Performance Comparison among All Protocols as the Function of Various Parameters in Terms of Handoff Latency, Lost Packet, Signaling Cost, and Data Hop

In this section, we compare the results of all methods in terms of handoff latency, number of lost packets, and signaling cost as the function of various parameters. These parameters are the number of cells in a paging area, MN's speed, and number of hops between GFA/router and HA. Data hop performance metric is also presented when we vary the number of cells in a paging area and number of hops between GFA/router and HA. We design different scenario for every parameter based on the environment that is needed in the simulation.

5.3.1 Performance Comparison as the Function of the Number of Cells in a Paging Area

The performance comparison as the function of the number of cells in a paging area is presented in this part. We vary the number of cells in a paging area to be 4, 9, 16, 25, 30, 36, and 40 cells. The total cells are then 8, 18, 32, 50, 60, 72, and 80 respectively. There are 30 hops between GFA/router to HA. MN with 30 m/s speed moves in straight direction from the center of the first FA in first paging area to the center of last FA in the second paging area. The duration of simulation and time 100% are adjusted which depend on the number of cells in a paging area. The active continues time when the HA sends packets to MN is 5% of total time 100%.

Figure 5.8 and Figure 5.9 show the comparison of handoff latency and the number of lost packets. The number of lost packets in Figure 5.9 follows the same trend as the handoff latency in Figure 5.8. This is because the number of lost packets has linear relation with the handoff latency. The longer the handoff latency, the higher the number of lost packets is. The number of lost packet and handoff latency in this scenario are both influenced by the movement detection used and total simulation time. Total simulation time is longer if the number of cells is increased. Longer simulation time lets the MN have more possibility to move to new cell in active time. Handoff latency and number of lost packets in Mobile IP and Paging Mobile IP (P-MIP) is the same and they have the worst performance in comparison with other methods. The reason is that both Mobile IP and Paging Mobile IP use Agent Advertisement sent every 1 second for movement detection. Moreover, the registration messages have to travel to far away HA before the MN can receive packets from new FA. Paging Mobile IP Regional Registration (P-MIP RR) and Proposed Method 1 reduce the registration delay in Mobile IP and Paging Mobile IP in which the MN only conducts regional registration to GFA. Proposed Method 1 has better performance than Paging Mobile IP Regional Registration since the new FA can forward the buffered multicast packets to MN once that FA receives Regional Registration Request. The instability of the results is because of the MN's waiting time for Agent Advertisement which is not similar for each number of cells.

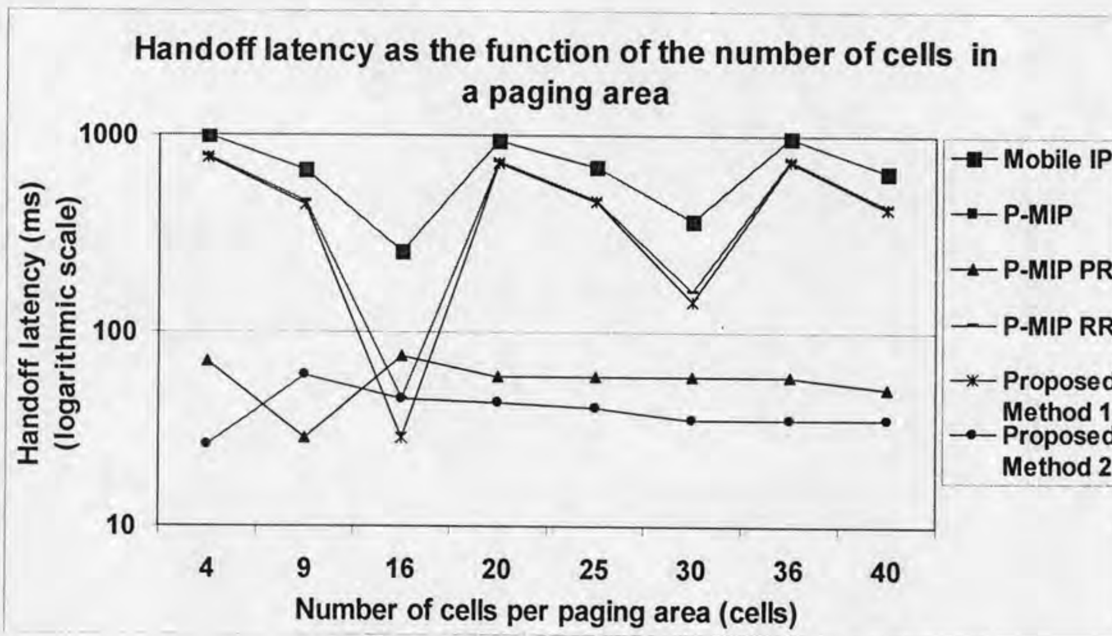

Figure 5.8 Handoff latency as the function of the number of cells in a paging area.

The use of Link Layer beacon sent every 100 ms in Paging Mobile IP Post Registration (P-MIP PR) and Proposed Method 2 improves the overall performance of four previous methods significantly. Here, the MN can detect that it has moved to new cell faster than the MN in four previous methods. The unusual result happens when the number of cells is 16 where Proposed Method 1 has the best performance among all methods. It happens because the MN can receive Agent Advertisement from new

FA soon after it leaves the previous FA. From Figure 5.8 and 5.9, it can be seen that Proposed Method 2 has better performance than Paging Mobile IP Post Registration in this scenario except when there are 9 cells in paging area. It is because in this scenario, the MN in Proposed Method 2 can receive Link Layer beacon faster than Paging Mobile IP Post Registration when the MN is located in the overlapping area between two FAs or after the MN has leaved the previous FA. Remember that in Paging Mobile Post Registration, Link Layer beacon is not broadcast at the same time as other methods after the first paging process. Moreover, signaling messages and data packets use longer route in Paging Mobile IP Post Registration than Proposed Method 2. The multicast group in Proposed Method 2 is also created fast after the MN finishes Link Layer handoff. However, when there are 9 cells in a paging area, the MN in Paging Mobile IP Post Registration can receive Link Layer beacon faster than that of Proposed Method 2 so that it has lower handoff latency and lost packets.

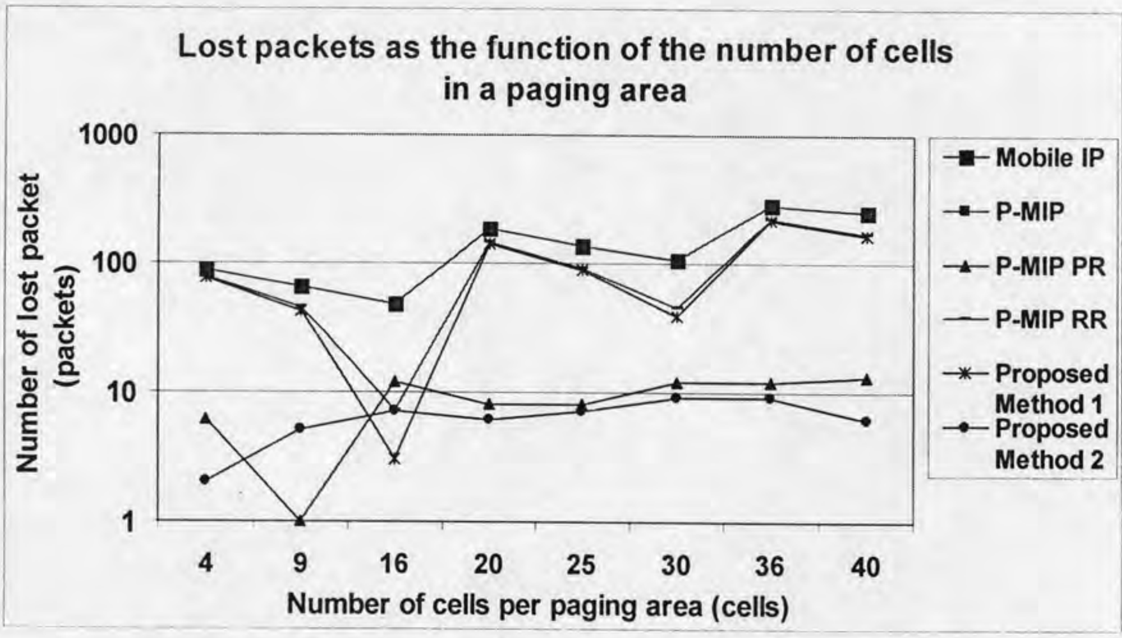

Figure 5.9 Lost packets as the function of the number of cells in a paging area.

Figure 5.10 illustrates the signaling cost comparison among all methods. Signaling cost rises as the number of cells in a paging area increases. In Mobile IP, which has the largest number of signaling cost, the MN always registers when it moves to new cell, even if the MN is in idle state. Other reason for Mobile IP is that more boundary crossings when there are more number of cells in a paging area. Paging techniques in five other methods reduce signaling cost in Mobile IP drastically. In five other methods, signaling cost is not only influenced by more boundary crossings but also by paging signaling messages. However, this trend happens for small number of cells in a paging area. The GFA or FA sends more paging messages if the number of cells in one paging area increases. If the number of cells in a paging area is very huge, paging messages could give significant impact to total signaling cost since more messages used in paging process. Therefore, it is important to select the suitable size of paging area.

Signaling cost in Paging Mobile IP is slightly better than that of Paging Mobile IP Post Registration. The reason is that in Paging Mobile IP Post Registration, the construction BET makes the system use more signaling messages. The signaling cost in these two methods, however, is higher than that of Paging Mobile IP Regional Registration, Proposed Method 1, and Proposed Method 2. The explanation for this result is that MN in Paging Mobile IP and Paging Mobile IP Post Registration has to registers to far away HA rather than GFA in three other methods. Among three other methods, Paging Mobile IP Regional Registration has the lowest signaling cost as Proposed Method 1 and Proposed Method 2 use more messages for the construction of multicast tree and group. Proposed Method 2 produces less signaling messages than Proposed Method 1 since the multicast group in Proposed Method 2 is constructed only in the active time based on the Link Layer handoff. In addition, Inter-Agent Advertisement message is also not necessary in Proposed Method 2 to construct the multicast group.

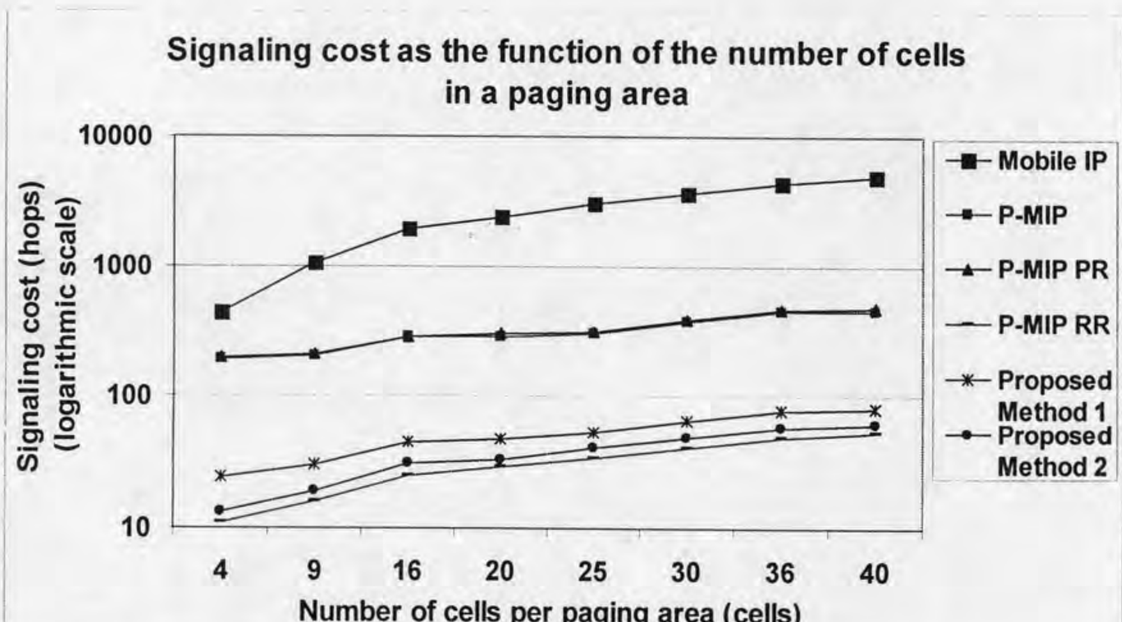

Figure 5.10 Signaling cost as the function of the number of cells in a paging area.

Table 5.1 reveals the comparison of data hop for all methods. Mobile IP (MIP) and Paging Mobile IP Regional Registration (P-MIP RR) have the same and the lowest total data hops. In Mobile IP, all packets from HA is sent to registered FA. The registered FA then directly forwards incoming packets in its cell. In Paging Mobile IP Regional Registration, packets from HA pass the same route as those in Mobile IP. It results in the same data hops although GFA has to buffer incoming packets for idle

MN. Total data hop in Paging Mobile IP (P-MIP) is more than that of two previous methods. Packets in Paging Mobile IP, especially the buffered packets in the registered FA, must travel via the router to reach the present FA. The reason is quite similar for Paging Mobile IP Post Registration (P-MIP PR), in which the buffered and incoming packets from previous FA must be routed via BET to the present FA before the MN conducts Network Layer registration. The total data hop in Proposed Method 2 (PM-2) is fewer than that of Paging Mobile IP Post Registration although the GFA has to multicast packets to previous and present FA. In Proposed Method 2, the multicast packet only passes one hop to reach the multicast group. Packets are also multicast for a short period of time until the MN conducts Network Layer registration to GFA from new FA. This does not happen for Proposed Method 1 (PM-1), where incoming packets are multicast by the GFA during MN's active time. It makes Proposed Method 1 has the greatest total data hops. Among all protocols, Proposed Method 1 utilizes most network resources when HA sends packets to MN.

Table 5.1 Data hops as the function of the number of cells in a paging area.

Cells/PA	MIP (hops)	P-MIP (hops)	P-MIP PR (hops)	P-MIP RR (hops)	PM-1 (hops)	PM-2 (hops)
4	4,352	4,398	4,612	4,352	4,490	4,504
9	10,592	10,638	10,916	10,592	10,955	10,702
16	19,232	19,278	19,492	19,232	19,837	19,232
20	24,800	24,846	25,294	24,800	25,579	25,080
25	30,432	30,478	30,810	30,432	31,387	30,604
30	36,832	36,878	37,148	36,832	37,989	36,904
36	44,832	44,878	45,608	44,832	46,239	45,264
40	50,623	50,669	51,187	50,623	52,213	50,957

5.3.2 Performance Comparison as the Function of Mobile Node's Speed

Handoff latency, number of lost packets, and signaling cost are the performance metrics that we observe when we vary the MN's speed. For the simulation scenario, there are 100 cells in the simulation environment which means that every paging area consists of 50 cells. The number of hop between GFA/router and HA is situated to be 40 hops. The duration for each simulation is 342.259 s. This time is measured from the time taken by the MN with 35 m/s to travel from the center of first FA to the center of last FA. There are three time 100% periods where every time 100% lasts for 112 s. It also means that the HA sends packets to the MN for three continuous times. We vary the speed of the MN to be 1, 5, 10, 15, 20, 25, 30, and 35 m/s. Following paragraphs and figures explain the simulation results.

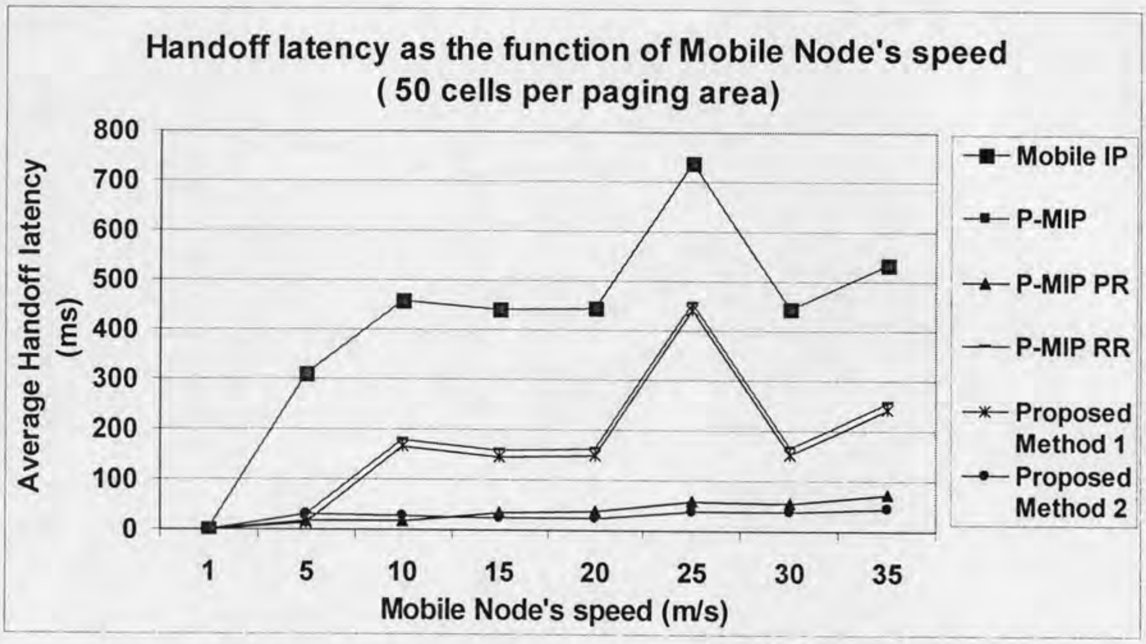

Figure 5.11 Handoff latency as the function of Mobile Node's speed.

Figure 5.11 displays the effect of the variation of MN's speed to average handoff latency. From the figure, we can see that all protocol have zero handoff latency when the MN's speed is 1 m/s. This is because during the active period, the MN at that speed moves slowly and remains to stay in one cell. For other speeds, as explained in the previous section, the handoff latency is related to the movement detection method used in each protocol. Paging Mobile IP Post Registration (P-MIP PR) and Proposed Method 2 have better performance than four other methods since the MN uses Link Layer beacon for movement detection. The handoff latency in Mobile IP and Paging Mobile IP (P-MIP) are the same and also the longest handoff latency among all methods. The average handoff latency for the MN with 25 m/s speed in Mobile IP and Paging Mobile IP is the longest in this simulation scenario since the MN has to wait long time for Agent Advertisement from new FA. The average handoff latency in Mobile IP and Paging Mobile IP is even much longer than P-MIP Regional Registration (P-MIP RR) and Proposed Method 1. The distance between GFA/router and HA which is 40 hops gives significant impact to signaling delay to HA after the MN accepts Agent Advertisement from new FA. MN in Paging Mobile IP Regional Registration and Proposed Method 1 diminishes the signaling delay by only carrying out regional registration. Among all protocols that use Agent Advertisement for movement detection, Proposed Method 1 has the best performance since the multicast packets are already available at the new FA and directly forwarded to the MN after the new FA receives Regional Registration Request from the MN. Handoff latency when the MN's speed is 5 m/s is even the best among all protocols since the MN can accepts Agent Advertisement from new FA soon after it leaves the previous FA's coverage area.

The average handoff latency for Paging Mobile IP Post Registration and Proposed Method 2 is likely to increase when the MN's speed increases. It is caused by the following reason. At higher speed, the possibility that the MN leaves the overlapping area between old and new FA without receiving Link Layer beacon from new FA is also higher. This situation makes the BET in Paging Mobile IP Post Registration and multicast group in Proposed Method 2 are late to be constructed. The average handoff latency for the MN's with 5 and 10 m/s speed in Paging Mobile Post Registration are shorter than that of Proposed Method 2. At these speeds, the MN in Post Registration methods can receive Link Layer beacon to create BET faster than that of Proposed Method 2 to create the multicast group. On the other hands, at other higher speeds, the MN in Proposed Method 2 can receive Link Layer beacon faster than of Paging Mobile IP Post Registration. Therefore, Proposed Method 2 in this simulation scenario is better than Paging Mobile IP Post Registration at medium up to high speed (15 – 35 m/s).

The number of lost packets has a tendency to increase when the MN moves with higher speed as shown in Figure 5.12. At higher speed, the possibility of the MN to cross the cell boundary is getting bigger. In addition, movement detection method also has significant impacts to the number of lost packets. However, some unusual results may happen in the simulation. The examples are in Mobile IP and Paging Mobile IP where they normally have the same number of lost packets since they also use the same movement detection method. As can be seen from the figure, Paging Mobile IP has higher number of lost packets than Mobile IP when the MN moves with 30 m/s speed. This result occurs because at the time the registered FA, let say FAX, finishes the paging process to search for the MN that is located at one FA (FAY) and forwards the buffered packets to that FA, the MN has moved to another new FA (FAZ). It causes the buffered packets from FAX can not reach the MN that has moved to FAZ cell. In contrast, Mobile IP has more number of lost packets than Paging Mobile IP when the MN's speed is 35 m/s. The reason is that the MN in Mobile IP has leaved the last registered FA in the record of HA when HA starts to send packets to it. The packets continue to be lost until the MN registers to HA via the new FA. Paging Mobile IP, on the other hand, does not suffer from this situation since the last registered FA will first buffer the incoming packets and conduct paging process to determine the precise location of the MN so that the last registered FA can forward the data to MN correctly. Simulation results for other protocols follow the same trend as that of handoff latency. Proposed Method 1 has the lowest number of lost packets among all protocols that utilize Agent Advertisement for movement detection while Proposed Method 2 and Paging Mobile IP Post Registration method have low number of lost packets.

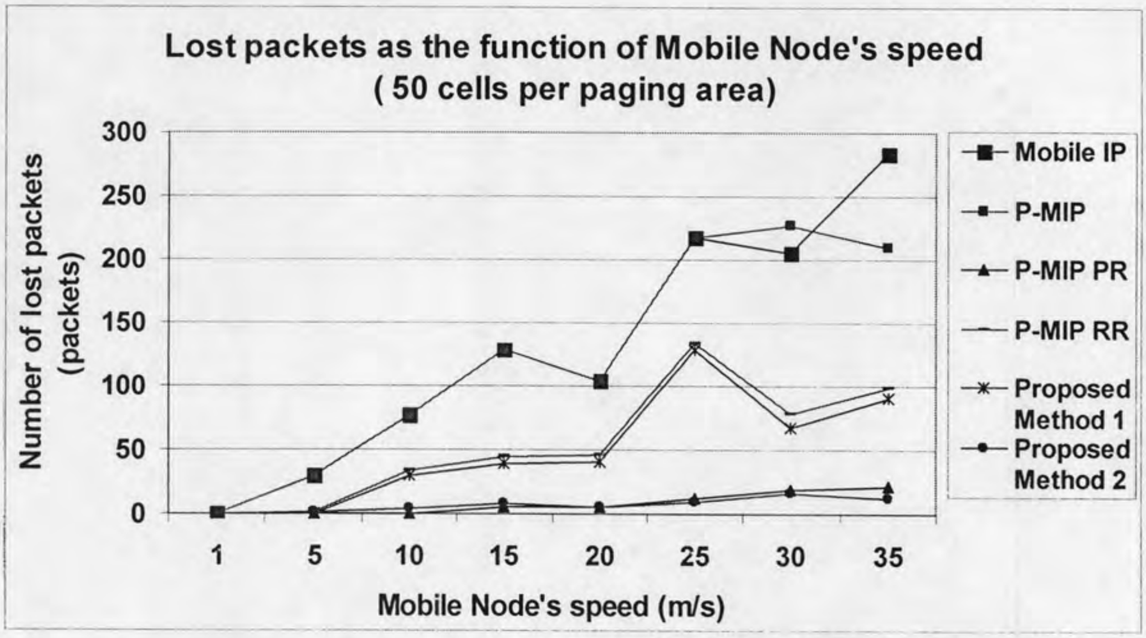

Figure 5.12 Lost packets as the function of Mobile Node's speed.

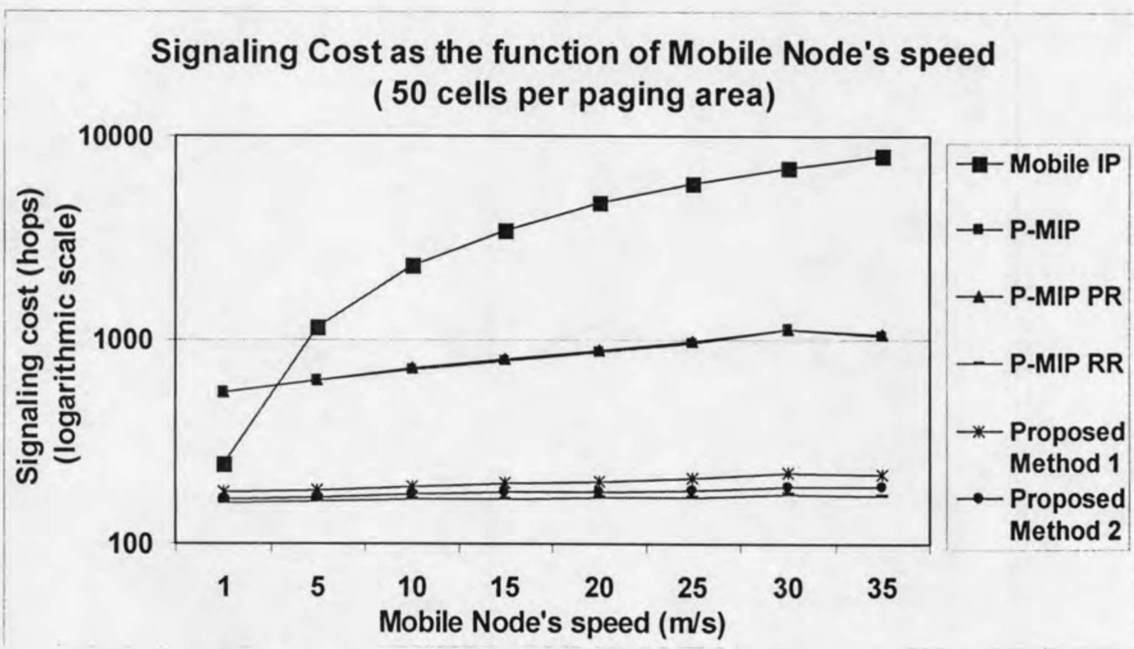

Figure 5.13 Signaling cost as the function of Mobile Node's speed.

Signaling cost comparison as the function of MN's speed is demonstrated in Figure 5.13. As the speed of the MN gets higher, the signaling cost of all methods also increases. The more the speed, the more the cell boundary crossing and registration are. The signaling cost for Mobile IP is lower than that of Paging Mobile

IP (P-MIP) and Paging Mobile IP Post Registration (P-MIP PR) at speed 1 m/s. At this low speed, it is likely that the MN will remain to stay in one cell longer than the MN with high speed. Therefore, MN hardly ever conducts registration and paging gives more burdens to total signaling cost. The signaling cost in three above methods is still higher than Paging Mobile IP Regional Registration (P-MIP RR), Proposed Method 1 and Proposed 2 since Mobile IP, Paging Mobile IP, and Paging Mobile IP Post Registration use home registration to far away HA when the MN roams in the visited network. Paging Mobile IP Regional Registration, Proposed Method 1 and Proposed 2 utilize regional registration if the active MN moves within the GFA domain. Multicasting messages in Proposed Method 1 and Proposed Method 2 let them have more signaling cost than that of Paging Mobile IP Regional Registration.

5.3.3 Performance Comparison as the Function of the Number of Hops between Gateway Foreign Agent/Router and Home Agent

We vary the number of hops between GFA/router and HA to check its effects to the performance of all methods in terms of handoff latency, number of lost packets, signaling cost, and data hops. Those hops are 10, 25, 40, 55, 70, 85, and 100. In the simulation scenario, there are 30 cells in two paging areas. The MN with 30 m/s speed moves from the center of the first FA to the last FA for the duration of 116.967 s. There is one time 100% period that last for 110 s.

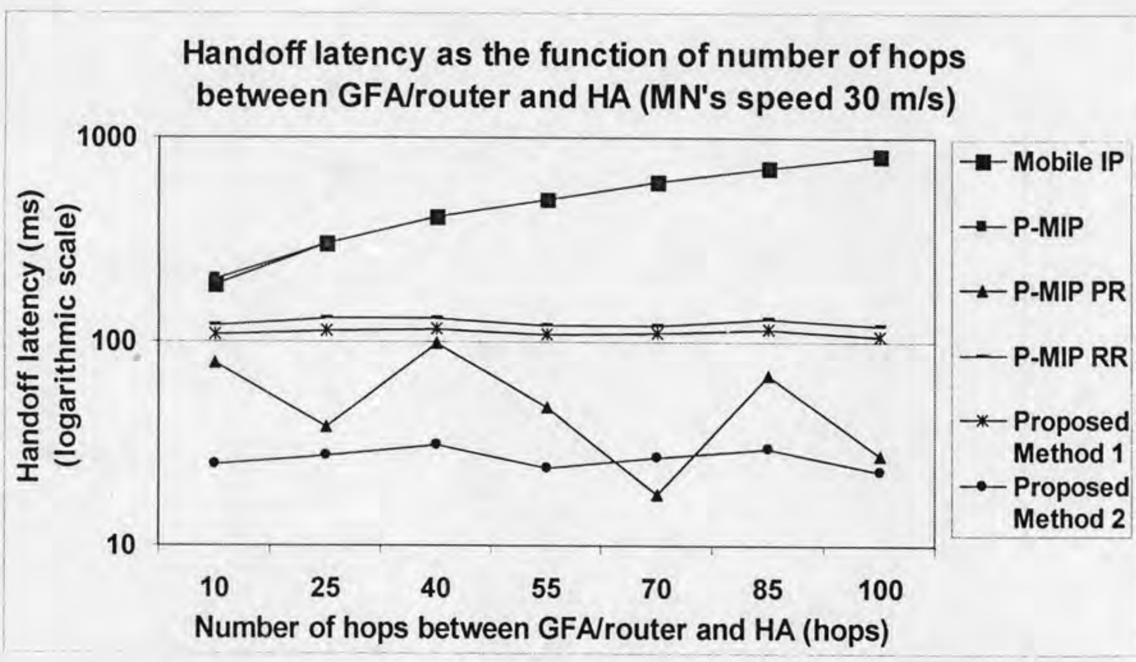

Figure 5.14 Handoff latency as the function of the number of hops between Gateway Foreign Agent/router and Home Agent.

Handoff latency and number of lost packets for Mobile IP and Paging Mobile IP (P-MIP) increase linearly when the distance between HA and router rises as shown in Figure 5.14 and Figure 5.15. Mobile IP and Paging Mobile IP have the same handoff latency and number of lost packets in this scenario since they use the same handoff and registration algorithm. Here, the MN has to wait for a long time to complete home registration to HA since the registration messages have to experience long signaling delay. It causes the MN to experience long handoff latency that results in high number of lost packets. In Paging Mobile IP Regional Registration (P-MIP RR) and Proposed Method 1, the handoff latency and number of lost packets are relatively stable since the MN only registers to GFA. Higher number of hops between GFA and HA only influences the time that the first packet arrives at the MN and does not have effects on regional registration. From explanations above, it can be concluded that regional registration is effective to improve the performance of the system that uses Network Layer movement detection in terms of handoff latency and number of lost packets.

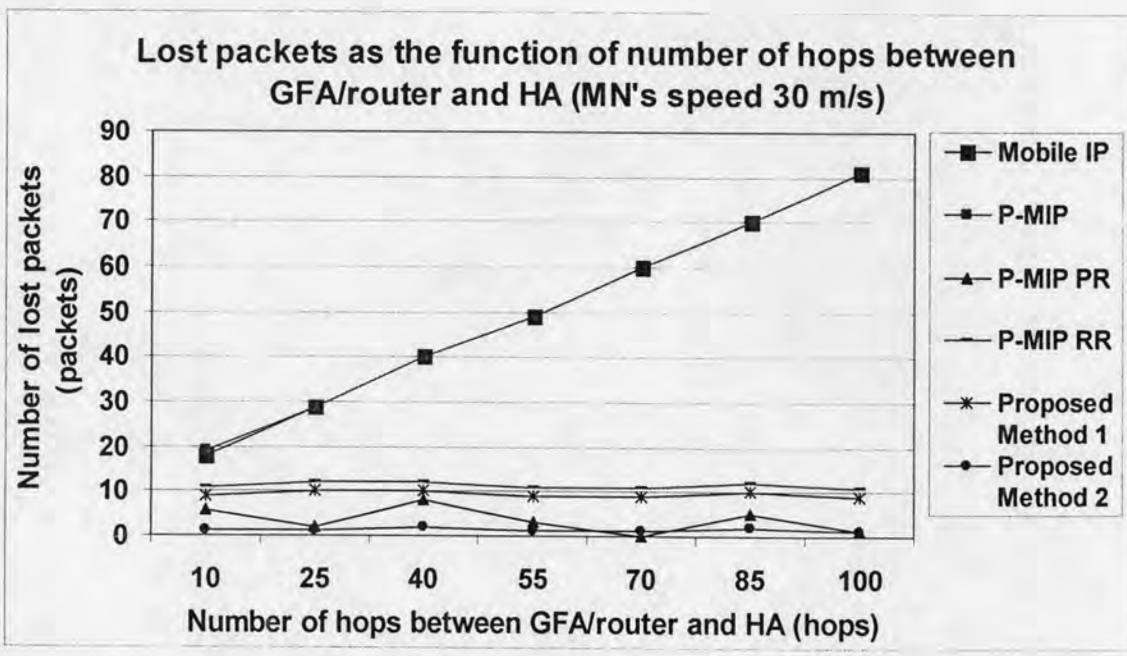

Figure 5.15 Lost packets as the function of the number of hops between Gateway Foreign Agent/router and Home Agent.

The handoff latency and number of lost packets in Paging Mobile IP Post Registration (P-MIP PR) and Proposed Method 2 do not have the same trend as four previous methods. Handoff latency and number of lost packets in Paging Mobile IP Post Registration and Proposed Method 2 are determined by how fast the MN can receive Link Layer beacon from new FA when the MN is moving within the overlapping area or after the MN totally enters the new cell. Performance comparisons in Figure 5.14 and Figure 5.15 confirm that the handoff latency and number of lost packets in these two methods are smaller in comparison with four other methods and not influenced by the number of hops between GFA and HA. In this scenario, Proposed Method 2 has better overall performance than Paging Mobile IP Post Registration. The MN with 30 m/s speed in Paging Mobile IP Post Registration is likely to have leaved the overlapping area between two cells before the MN receives Link Layer beacon from new FA. Consequently, the old and new FA can not build BET between them before the MN totally moves to new cell and it results in lost packets until the BET is constructed after the MN receives Link Layer beacon in the new cell. Proposed Method 2, in contrast, can create the multicast group and tree soon after the MN detects that it has moved to new cell so that the handoff time and number of lost packets can be reduced to be minimal.

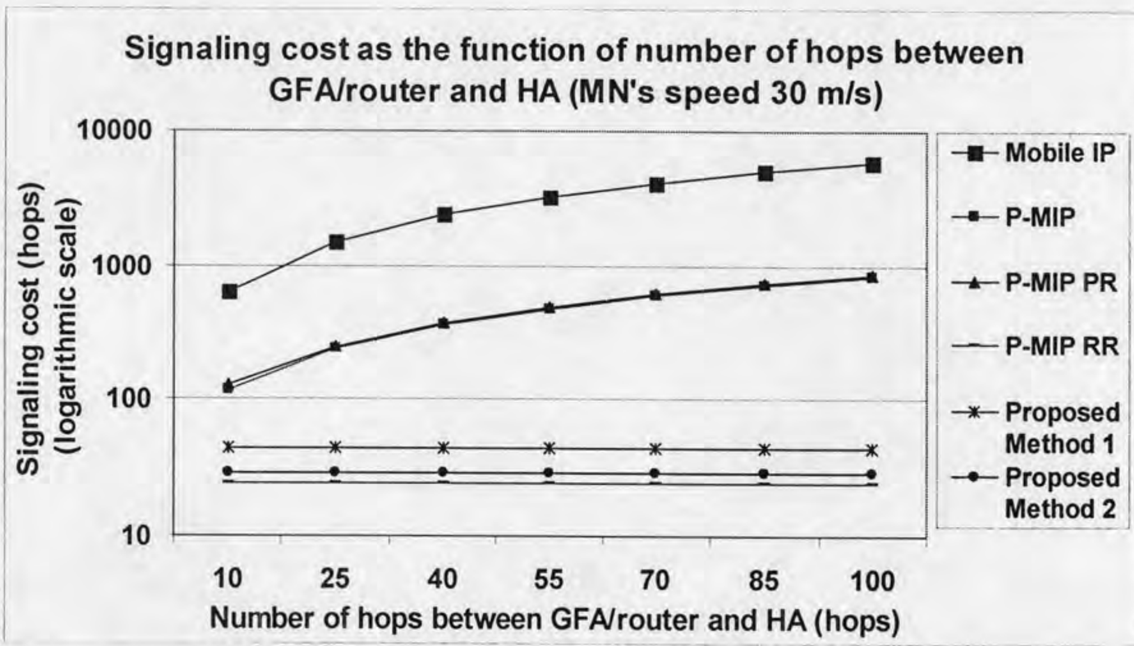

Figure 5.16 Signaling cost as the function of the number of hops between Gateway Foreign Agent/router and Home Agent.

Signaling cost in Paging Mobile IP Regional Registration, Proposed Method 1, and Proposed Method 2, as shown in Figure 5.16, is constant for all number of hops between GFA and HA. It is because registration, paging, and multicasting signaling messages in those methods only travel within the GFA domain and are not influenced by other entities outside the GFA domain. Proposed Method 1 and Proposed Method 2 reduce the signaling cost in Paging Mobile IP drastically. Although their signaling cost is higher than Paging Mobile IP Regional Registration because of multicasting messages, their signaling cost is still much lower than Paging Mobile IP. Mobile IP method has the highest number of signaling cost among all methods since the MN has to register to HA every time it accepts Agent Advertisement from the new cell. Larger distance between HA and router makes the signaling messages travel longer distance to HA thus results in higher signaling cost. Paging Mobile IP and Paging Mobile IP Post Registration can reduce the unnecessary registration in Mobile IP by utilizing the idle state of the MN. Nevertheless, signaling cost of Paging Mobile IP and Paging Mobile IP Post Registration still increases if the number of hops between HA and router gets larger since the MN still has to registers to HA after the MN receives Agent Advertisement from new FA.

Data hops in Table 5.2 increase significantly in each protocol as we increase the distance between GFA/router to HA because packets from HA also have to travel longer distance. Total data hops in Mobile IP (MIP) and Paging Mobile IP Regional Registration (P-MIP RR) have the lowest number of total data hops. Their total of data hops are followed by Proposed Method 2 (PM-2), Paging Mobile IP (P-MIP), Paging Mobile IP Post Registration (P-MIP PR), and Proposed Method 2 (PM-2). Proposed Method 2 has lower total data hops than Paging Mobile IP because GFA does not send significant number of multicast packets to MN's multicast group. Last registered FA in Paging Mobile IP still has to forward the buffered packets via router to present FA so that the total data hop is more than that of Proposed Method 1. Paging Mobile Post Registration even uses longer route than Paging Mobile IP since the packets are transmitted via BET after the MN completes Link Layer handoff with new FA. Finally, Proposed Method 1 has the highest number of data hops since the GFA has to multicast packets to the group during active time.

Table 5.2 Data hops as the function of the number of hops between Gateway Foreign Agent/router and Home Agent.

Hops GFA-HA	MIP (hops)	P-MIP (hops)	P-MIP PR (hops)	P-MIP RR (hops)	PM-1 (hops)	PM-2 (hops)
10	6,612	6,632	6,744	6,612	7,165	6,632
25	14,877	14,917	15,049	14,877	15,430	14,897
40	23,142	23,202	23,334	23,142	23,695	23,162
55	31,407	31,487	31,635	31,407	31,960	31,427
70	39,672	39,772	39,940	39,672	40,225	39,692
85	47,937	48,059	48,221	47,937	48,490	47,957
100	56,202	56,344	56,526	56,202	56,755	56,222

5.4 Performance Comparison between Proposed Method 2 and Paging Mobile IP Post Registration for Non-Overlapping Cell Scenario

In the previous sections, we have discussed the simulation results and performance comparison of all methods. We can find there that Paging Mobile IP Post Registration and Proposed Method 2 have better overall performance in terms of handoff latency and number of lost packets than other protocols since these two methods use Link Layer information for movement detection. Furthermore, it can be seen that Proposed Method 2 has better performance than Paging Mobile IP Post Registration in terms of signaling cost and data hop in all scenarios. We also notice that Proposed Method 2 is better in terms of handoff latency and number of lost packets than Paging Mobile IP Post Registration for MN with medium and high speed. The reason is that the MN in Proposed Method 2 can receive Link Layer beacon to construct multicast group faster than that of in Paging Mobile IP Post Registration to build BET in most scenarios. Proposed Method 2 also has a benefit that it does not modify Link Layer to conducts paging process. Paging Mobile IP Post Registration, as explained in previous sections, has to transmit not periodic Link Layer beacon after the first paging process. Moreover, every FA must be equipped with buffer in Paging Mobile IP Post Registration to storage incoming packets for idle MN. This is not the case in Proposed Method 2 since only GFA that must have buffer.

Proposed Method 2, however, also has several disadvantages. In Proposed Method 2, packets from previous FA are still forwarded to the MN although the MN has received packets from new FA. In addition, MN can receive similar packets from both old and new FA if the MN is still moving within the overlapping paging area between old and new FA after the multicast group is constructed. Considering the advantages and disadvantages above, especially the disadvantage because of multicast packets duplication received at MN, we simulate one more scenario which is non-overlapping cell scenario for Paging Mobile IP Post Registration and Proposed Method 2. We then vary the MN's speed to monitor the effects on the handoff latency and number of lost packets. In this scenario, MN in both methods fully relies on the Link Layer beacon received from new cell after the MN leaves the previous MN to construct BET in Paging Mobile IP Post Registration and multicast group in Proposed Method 2. For this reason, the MN will not receive similar packets in Proposed Method 2 in this scenario.

In this scenario, the number of cells in the simulation environment is 20 cells. The distance between GFA/router and HA is set to be 40 hops. The MN's speed is varied to be 5, 10, 15, 20, 25, 30, and 35 m/s. The duration of simulation is adjusted at every speed based on time needed by the MN to travel from the first FA to the last FA. Figure 5.17 and 5.18 demonstrate the simulation results.

As shown in figures 5.17 and 5.18, the number of lost packets follows the trend of handoff latency. The longer the handoff latency, the higher the number of lost packets is. Handoff latency in Paging Mobile IP Post Registration has range from 48 to 118 ms while Proposed Method 2 has range from 31 to 91 ms. In non-overlapping cell scenario, the packets from previous FA are lost until the MN conducts Link Layer handoff. The BET in Paging Mobile Post Registration (P-MIP PR) and multicast group can not be constructed before the MN leaves previous FA so that it is almost impossible to have zero lost packets in both methods. From the figures, it can be seen that Proposed Method 2 is better than Paging Mobile IP Post Registration even for the MN with low speed (5 and 10 m/s). In this scenario, Proposed Method 2 can create multicast group faster than BET in Paging Mobile IP Post Registration after the MN leaves previous FA. There are two reasons for these results. The first is that the MN in Proposed Method 2 may receive Link Layer beacon faster than that of Paging Mobile IP Post Registration in this scenario. As discussed in the previous paragraphs, MN in Paging Mobile IP Post Registration relies on not periodic Link Layer beacon from new FA. If the waiting time for this not periodic beacon in Paging Mobile IP Post Registration is longer than that of periodic beacon in Proposed Method 2, the MN in Paging Mobile IP Post Registration will have longer handoff latency.

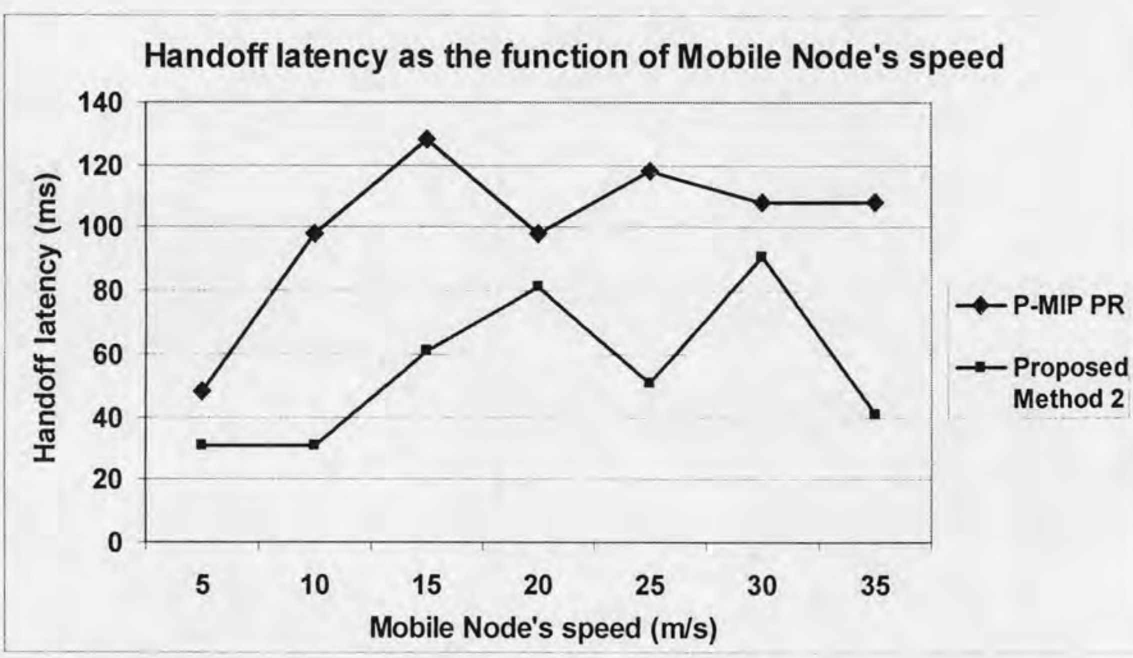

Figure 5.17 Handoff latency in Proposed Method 2 and Paging Mobile IP Post Registration as the function of MN's speed for non-overlapping cell scenario.

The second reason is that the construction of BET to forward packets from old FA to present FA in Paging Mobile IP Post Registration takes longer time than the construction of multicast group in Proposed Method 2. Signaling messages to build the BET must travel from new FA to old FA via the router. On the other hand, multicasting messages travel directly from new FA to GFA. This situation also happens for data packets. In Paging Mobile IP Post Registration, packets from old FA must pass router before they arrive at the new FA while it does not happen in Proposed Method 2 because GFA directly multicast incoming packets to new FA. From all performance comparisons, therefore, it can be concluded that Proposed Method 2 has better overall performance than Paging Mobile IP Post Registration both in overlapping and non-overlapping cell scenario.

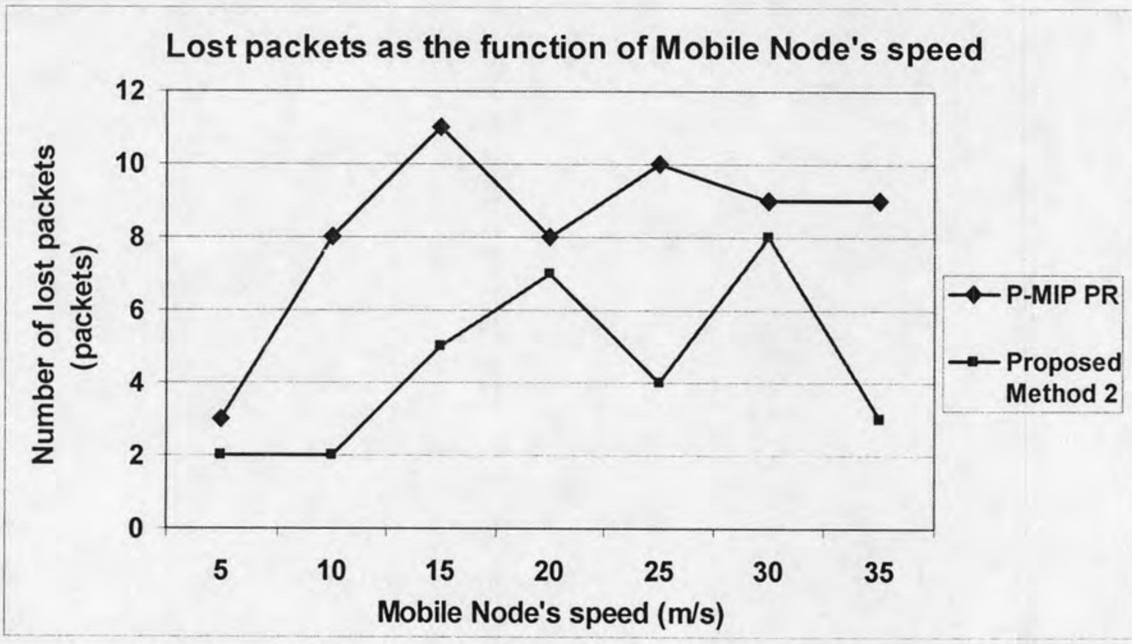

Figure 5.18 Lost packets in Proposed Method 2 and Paging Mobile IP Post Registration as the function of MN's speed for non-overlapping cell scenario.