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An Improved Inter-Domain Handover Scheme Based on a Bidirectional Cooperative Relay

Jianbo Yang, Xinsheng Ji

China National Digital Switching System Engineering &Technological R&D Center, Zhengzhou 450002, Henan, China
Email: yl8046@163.com

Abstract: *In the process of inter-domain handover, according to the partner-based hierarchical mobile IPv6 protocol (PHMIPv6), the longer configuration time for a new care-of-address may cause an interrupt in the current wireless connections and cause higher handover latency and packet loss rate. This paper proposes an improved handover mechanism based on PHMIPv6, named B-CDHO. A fPN and bPN are defined respectively in B-CDHO as cooperative relay nodes during the handover process. fPN can get the new care-of-address instead of a mobile terminal before the handover triggers and bPN can avoid connection interrupt if the pre-handover time is longer. The analysis and simulation results both show that B-CDHO can reduce the handover latency and packet loss in comparison to HMIPv6 and PHMIPv6 in case the pre-handover delay is longer.*

Keywords: *Heterogeneous wireless network, fast handover, hierarchical mobile IPv6, cooperative relay.*

1. Introduction

With the rapid development of mobile communication technology, the mobile users put forward requirements for high-speed and high-quality multimedia communications. The advanced handover management mechanism has become the key, supporting technologies for mobile users with seamless roaming. Currently, the mobile communication network is evolving to all-IP communication networks, and gradually it is developing into heterogeneous converged networks, based on IP core network with various wireless access technologies. On the other hand, with the emergence of multi-mode terminals, the mobile communication users can use different radio access at the same time. To adapt to the rapid development of the mobile network architecture and its business applications, the purpose and mechanisms of handover management should meet the demand for development of new network forms.

Handover management mechanism for multi-mode terminals in heterogeneous wireless network environment can be divided into three categories at the level of the protocol, including the link layer handover management, the network layer handover management and the transport layer handover management [1]. The network layer handover management mechanism can protect the different link layers of various wireless access and reduce the handover complexity and handover delay.

The representative network layer handover management currently is connected to introducing cooperative relaying and cross-layer design into Hierarchical Mobile IPv6 (HMIPv6). The mobile terminal can increase the handover success rate and reduce the handover delay time by selecting the cooperative partner, but this scheme is greatly limited by the mobility prediction algorithm. Moreover, there are still many problems to be solved, such as selection of a cooperative partner, handover decision and how to balance the handover success rate and delay time.

2. Related work

In recently years the research of the handover management based on MIPv6 protocol has achieved a lot of new results. Through introducing the linker layer trigger mechanism, R. Koodli proposed a Fast Mobile IPv6, by which the mobile station can register to a target access point by a prediction mechanism before it is apart from the source access point. This protocol can realize fast handover and gives the support for real-time service [2]. H. Soliman proposed Hierarchical Mobile IPv6 (HMIPv6), that divided the sub-network management domain by setting a Mobile Anchor Point (MAP). According to the region care-of address (R-CoA), the handover could be divided into two cases including intra-domain and inter-domain handover. HMIPv6 can eliminate the need for binding the update operation with a home agent and correspondent node, and reduce the intra-domain handoff delay, but it cannot efficiently shorten the inter-domain handoff latency [3].

In the case of inter-domain handover, the mobile node still needs frequent information transmission between the home agent and the correspondent node to complete the time-consuming process, such as region care-of address configuration, Duplicate Address Detection (DAD) and binding update operation. It is difficult to meet the requirements for seamless and fast handover because of the longer handover delay. To this moment, Van Nguyen'H proposed the Fast Hierarchical Mobile IPv6 protocol (FHMIPv6), which combines the advantages of the above-mentioned two handover protocols, and uses the handover prediction to further reduce the inter-domain handover delay on the basis of hierarchical division for network domains. But FHMIPv6 did not propose a specific predict algorithm and handover decision criteria [4].

Currently, the merge of cellular networks and wireless relay LAN is one of the trends of the mobile networks. Through signals' relay amplification and forwarding, the wireless relay node can efficiently improve the quality of the communication signal and expand the communicat coverage. Moreover, it can obtain a diversity gain using the cooperative diversity and reduce the probability of the handover interruption. Y. S. Chen proposed a partner-based hierarchical mobile IPv6 protocol (PHMIPv6), its main idea being to select a collaboration node and establish short-distance distributed communication (ad hoc) in the coverage of the target cell by a mobile prediction algorithm when the mobile node is about to leave the current access point. And the collaboration node can complete the address configuration and binding operation instead of the mobile node to the target access point before the handover process [5]. Compared to FHMIPv6, this method shortens the handover latency by introducing cooperative nodes of the network layer for handover preparation and speeds up the handover process for longer prediction time. But when choosing cooperative nodes, this method considers only the signal strength, it does not take into account its mobile trends and communication security, so it is difficult to guarantee the successful handover operation.

T a l e b and L e t a i e f [6] improved two aspects in PHMIPv6, which can select the cooperative node by introducing the Link terminated Time (LET) and gave formula to calculate LET according to Doppler's shift and Global Positioning System (GPS) respectively; on the other hand, it clarified the cooperative node's function further in order to reduce the dependence time for collaboration nodes in the process of predicted switching and ensured successful rate of the pre-handover, that is instead of the mobile terminal forwarding a pre-handover request to the target access point, and the subsequent operation is completed by the target access point. Thereby, the improvement can reduce the communication time of the mobile node and cooperative nodes, as well as the dwell time of the cooperative nodes in the target cell.

The handover mechanisms above mentioned are all based on the idea of handover prediction in advance, that is to say, the mobile terminal needs to predict the target access point before leaving the current access point through a certain mobility prediction algorithm, and perform a handover preparation operation in advance to reduce the service interruption time. However, this type of mechanism is strongly dependent on the mobility prediction algorithm and requires predictable time that is long enough. In addition, the mobility prediction algorithm must reach a certain prediction accuracy, in order to ensure appropriate handover success rate.

In order to take account of the predictable time and accuracy, [7] proposed a new handover mechanism based on Cooperative Diversity (CDHO). By selecting a heterogeneous cooperative node in the source base station, this mechanism can extend the communication connection time with its source base station, and provides a longer time license for the handover. But the mechanism does not take into account the role of the pre-handover operation for improved handover speed.

The prerequisite for successful implementation of PHMIPv6 is completing the pre-handover operation before the handover trigger time, such as the configuration of Care-of-address. But if the overlapping coverage is smaller and the address configuration time is longer, the communication connection may be interrupted before finishing the pre-handover. Aiming at this problem, this paper proposes an improved handover mechanism based on PHMIPv6, the mobile terminal must detect a cooperative node in the current access station by its ad hoc wireless interface and extend the connection time with the current station before the communication is forced to interrupt.

3. Handover mechanism based on a bidirectional cooperative relay node (B-CDHO)

3.1. Handover scene modelling

Fig. 1 indicates B-CDHO mechanism handover scene, a mobile terminal (MH) moving along the direction of the arrows, and across the coverage area of two Base Stations – BS1 and BS2. The two base stations belong to different management domains. pMAP and nMAP are the mobile anchors respectively. Before the trigger handover, MH sending the data packet to the Corresponding Node (CN) via the base station BS1, the access router pAR and mobile anchor pMAP. Similarly, CN sends the packet using Region Care-of Address (R-CoA) and Link Care-of Address (L-CoA) to pMAP and pAR, and finally reaches MH. During the handover of B-CDHO, two cooperative nodes are required in order to complete the handover process.

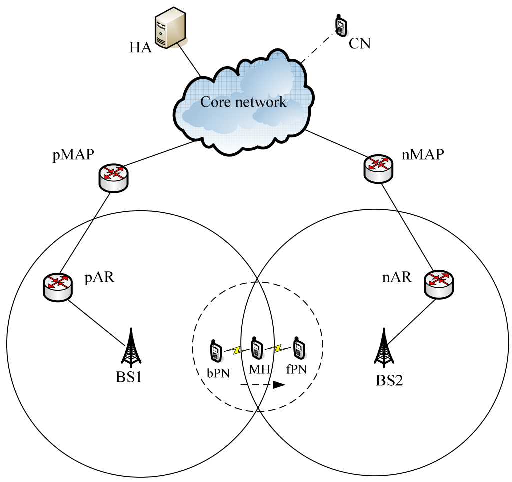

Fig. 1. System architecture of B-CDHO

Definition 1. Backward cooperative node (bPN). It is located within the coverage of the source base station (BS1) and has a relatively fixed location, can communicate with MN by ad hoc interface, its role is to extend the connection length of MH and BS1via a relay packet of MH, and get enough time to complete the pre-handover process.

Definition 2. Forward cooperative node (fPN). It is located within the coverage of the target base station (BS2), can communicate with MN by ad hoc interface, and has a relatively fixed location. It can replace MH to perform address configuration, binding the update and other pre-handover processes to speed up the handover.

3.2. Main idea

As shown in Fig. 1, MH is about to leave the coverage of BS1 coverage, the received signal strength continues to decline and when it is below a pre-set threshold value, MH starts to scan for a fPN close to BS2, using Ad hoc interface, then fPN begins a pre-handover operation instead of MH to get its new care-of address. On the other hand, MH calculates the Link Expiration Time (LET) with the current BS using a mobility prediction algorithm; if it is shorter than the average pre-handover delay, then MH selects a bPN in BS1 and gives its context information to bPN. MH can maintain its wireless connection with BS1 through bPN using amplifier-and-forward. When fPN finishes the pre-handover and gets the new care-of address from nMAP, MH can trigger layer 2 and layer 3 handover immediately. We can see from this handover process, that MH is not forced to disconnect with the current BS until it does not complete the pre-handover process.

3.3. Implementation steps of B-CDHO

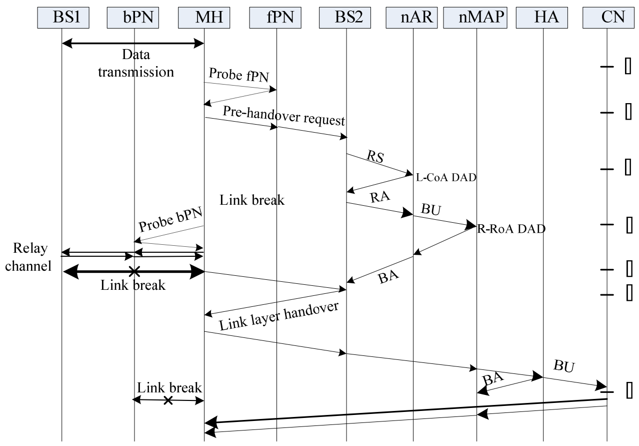

Fig. 2. Implementation steps of B-CDHO

The steps of B-CDHO are six.

Step 1. Execute the mobile prediction algorithm and determine the target access base station. As shown in Fig. 2, when MH reaches the edge of BS1, the received signal strength of MH continues to drop, and execute $D_S(\alpha,\beta)$ algorithm [8] to determine the target access base station.

Step 2. Probe of the fPN. MH broadcasts “forward cooperative node detection message” through its Ad hoc interface within the coverage of the target access base station (BS2), the message provides a signal quality threshold of QoS which meets the requirements of the current service. The mobile nodes which can connect with MN using ad hoc by one hop, decide whether to answer the detection message based on the state of the wireless interface and the received signal strength. According to the selection method for PN given in [6], the cellular interface state is IDLE and LET values with MH meet the requirements, then it responds to this detection message. The candidate cooperative nodes are sorted according to their

LET values, and the largest is selected as fPN. If MH does not receive an answer message, the algorithm goes back to the initial HMIPv6 protocol [9, 10].

Step 3. Perform a pre-handover operation. MN sends its context information through the Ad hoc interface to fPN, then fPN sends a pre-handover request to BS2. BS2 receives its LCoA from nAR by routing requests and routing advertise messages, then it continues to request the configuration for RCoA from nMAP and perform duplicate address detection.

Step 4. Probe of the bPN. The same as Step 2 – MH chooses a qualified bPN within the BS1 coverage, and establishes a heterogeneous relay cooperative channel with BS1, the relay channel including the ad hoc connection between MH and bPN, and the cellular network connection between bPN and BS1.

Step 5. When RSS from BS1 declines and the link layer is broken, MN begins to perform layer 2 handover. During the handover, MN still receives data from BS1 with the help of bPN by its ad hoc interface. When MN finishes layer 2 handover and establishes wireless connection with BS2, if it has completed the configuration for a new CoA, then it triggers layer 3 handover and begins to perform binding update to CN; If MN has not yet received the new CoA, it needs to wait for a certain length of time in order to start the network layer handover. During this process, MN can still receive data from BS1 through bPN.

Step 6. Because of the higher latency of binding the update for layer 3, when MN is farer from BS1, MN may be forced to break the ad hoc connection with bPN before completing the binding update, and thus cause a communication interrupt. Until MN completes the binding update, it can continue to receive packets from BS2.

It can be seen from the handover process above described, that B-CDHO mechanism does not need MN to perform a prediction algorithm and estimate the pre-handover latency before probing fPN. It needs MN to probe competent cooperative nodes for successful implementation of B-CDHO mechanism, otherwise we can only perform the initial PHMIPv6 mechanism.

4. Performance analysis

In order to intuitively analyze B-CDHO handover latency, Fig. 3 shows the distribution of the various steps for B-CDHO handover process in time. As can be seen from Fig. 3, the communication interruption time consists of two phases. The first phase is between t_3 and t_4, MN needs to probe bPN before disconnecting layer 2 connection, and establish multi-hop wireless connection with BS1. If the prediction algorithm is not accurate enough, the link may be disconnected before probing of the cooperative node and establishing the multi-hop connection, and cause a packet loss. The second phase occurrs between t_7 and t_8, because of the longer layer 3 handover latency for binding update, MN continues to go away and the ad hoc communication range is limited, MN may be forced to disconnect communication with bPN before completing layer 3 handover process, and thus cause communication interruption time.

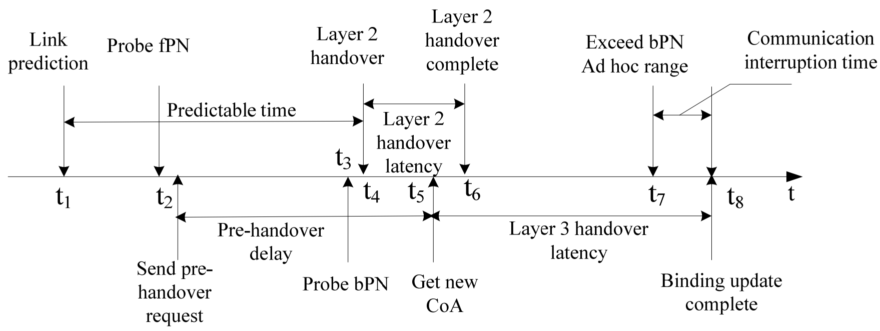

Fig. 3. Analysis of the handover latency for B-CDHO

From the above analysis we can see that by improving the accuracy of the prediction algorithm of the link layer, MN can probe bPN and establish multi-hop communication before layer 2 handover, but the handover delay for receiving data from the cellular interface to the Ad hoc can not be avoided. For the second interrupt period, it entirely depends on the ad hoc connection time between MN and bPN.

As shown in Fig.1, if $t_7 > t_8$, MN can receive the data packets from BS1, using ad hoc interface through bPN during the whole layer 3 handover process, and begin to receive data from BS2 through the cellar interface after completing the binding update; If $t_7 < t_8$, the handover latency can be calculated by $t_8 - t_7$.

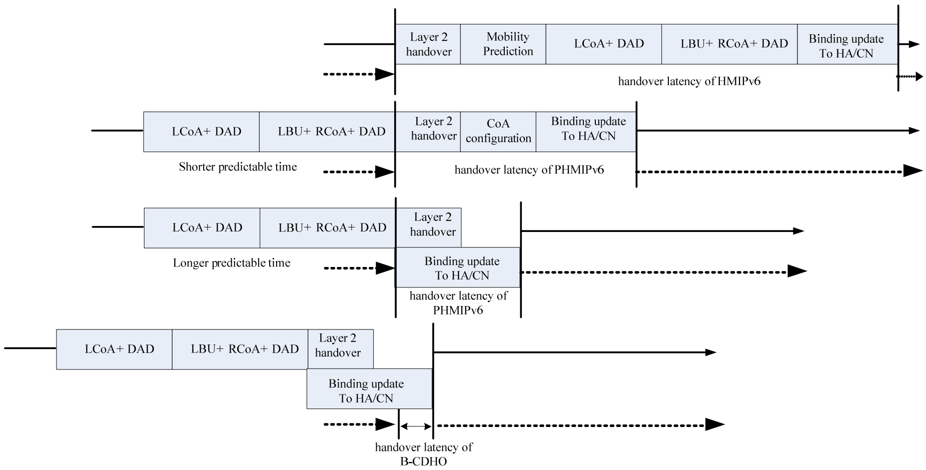

Fig. 4. Handover latency comparison

Fig. 4 indicates the handover latency of HMIPv6, PHMIPv6 with shorter predictable time and longer predictable time, and B-CDHO handover mechanism, proposed in this paper. As can be seen from Fig. 4, HMIPv6 handover interruption time consists of a link layer handover process and a network layer handover process, the latter including route discovery, care-of address configuration, and the entire process of binding update.

When the predictable time is shorter for PHMIPv6, MN does not complete the pre-handover before layer 2 handover, and needs to wait for CoA configuration to perform the binding update, so that the handover latency includes layer 2 handover delay, the time waiting for CoA configuration and the time for binding update. If the predictable time is longer for PHMIPv6, MN can trigger the link layer handover and network layer binding update at the same time, because MN has already got the new CoA. Since the time for binding update is much longer than layer 2 handover delays, under this condition the handover latency can be expressed by the former only. For B-CDHO mechanism, MN prolongs the time of its connection with the original base station using bPN, and can also receive packets through ad hoc interface, so the handover latency is a part of the binding update delay time.

In accordance with Fig. 4, through mathematical analysis of different links characteristics, we can compare the handover delay of various protocols. The parameters used in the analysis and their meaning are shown in Table 1.

Table 1. Network parameters

Parameter	Meaning	Parameter	Meaning
BW_w	Bandwidth of the wired backbones	S_{ctr}	Average size of the control message
BW_{wl}	Bandwidth of the wireless link	n	Number of hops between the MH and AR
L_w	Latency of the wired link	t_{D_DAD}	Average delay of the DAD time
L_{wl}	Latency of the wireless link	t_{D_int}	Average delay of the backbones
t_{D_MAP}	Average delay between AR and MAP	t_{D_HA}	Average delay between AR and HA
t_{D_CN}	Average delay between AR and CN	t_{D_lay2}	Layer-2 handover delay
t_{D_lay3}	Layer-3 handover delay		

Firstly, the time for MH to detect PN is

(1) $$t_{PN\_dico} = \frac{n}{\beta}\left(\frac{S_{ctr}}{BW_{wl}} + L_{wl}\right), \qquad n = \beta, 2\beta, \ldots,$$

where β presents the parameter of link layer $D_S(\alpha, \beta)$ algorithm.

MH discovers a new base station using the probe algorithm and gets the subnet prefix information. AR will send routing advertisement messages proactively in a certain time interval, MH will also send a route request message, the messages in both directions have the same average delay time, so the movement detection delay can be expressed as

(2) $$t_{move\_det} = 2\left[\left(\frac{S_{ctr}}{BW_{wl}} + L_{wl}\right) + n\left(\frac{S_{ctr}}{BW_{w}} + L_{w}\right) + t_{D\_int}\right].$$

The delay time t_{D_DAD} for fPN to perform DAD of R-CoA and L-CoA are equivalent. Then the binding update delay can be expressed as

(3)
$$t_{\text{binding\_MAP}} = t_{\text{binding\_MAP\_ack}} = \\ = (\frac{S_{\text{ctr}}}{\text{BW}_{\text{wl}}} + L_{\text{wl}}) + n(\frac{S_{\text{ctr}}}{\text{BW}_{\text{w}}} + L_{\text{w}}) + t_{\text{D\_MAP}},$$

where $t_{\text{binding\_MAP}}$ and $t_{\text{binding\_MAP\_ack}}$ represent the delay time for fPN to send binding update to nMAP and receive a response message from nMAP.

From (1)-(3) the total delay time of the pre-handover for fPN is obtained as

(4)
$$t_{\text{pre\_handover}} = 2t_{\text{D\_DAD}} + t_{\text{binding\_MAP}} + t_{\text{binding\_MAP\_ack}} = \\ = 2[(\frac{S_{\text{ctr}}}{\text{BW}_{\text{wl}}} + L_{\text{wl}}) + n(\frac{S_{\text{ctr}}}{\text{BW}_{\text{w}}} + L_{\text{w}})] + 2t_{\text{D\_DAD}} + 2t_{\text{D\_MAP}}.$$

According to Fig. 4, the handover delays of each mechanism are:

(5)
$$t_{\text{HMIPv6}} = t_{\text{D\_lay2}} + t_{\text{move\_det}} + t_{\text{D\_DAD}} + 2(t_{\text{binding\_MAP}} + t_{\text{binding\_HA}} + t_{\text{binding\_CN}}) = \\ = t_{\text{D\_lay2}} + 8[(\frac{S_{\text{ctr}}}{\text{BW}_{\text{wl}}} + L_{\text{wl}}) + n(\frac{S_{\text{ctr}}}{\text{BW}_{\text{w}}} + L_{\text{w}})] + 2(t_{\text{D\_MAP}} + t_{\text{D\_HA}} + t_{\text{D\_CN}} + t_{\text{D\_DAD}});$$

(6)
$$t_{\text{PHMIPv6}} = t_{\text{D\_lay2}} + t_{\text{D\_lay3}} - t_{\text{move\_det}} - t_{\text{PN\_disc}} + t_{\text{wait}} = \\ = t_{\text{D\_lay2}} + t_{\text{binding\_HA}} + t_{\text{binding\_CN}} + t_{\text{wait}} = \\ = t_{\text{D\_lay2}} + 4[(\frac{S_{\text{ctr}}}{\text{BW}_{\text{wl}}} + L_{\text{wl}}) + n(\frac{S_{\text{ctr}}}{\text{BW}_{\text{w}}} + L_{\text{w}})] + 2(t_{\text{D\_HA}} + t_{\text{D\_CN}});$$

(7)
$$t_{\text{B-CDHO}} < t_{\text{binding\_HA}} + t_{\text{binding\_CN}} = 2(t_{\text{D\_HA}} + t_{\text{D\_CN}}).$$

From (5)-(7) we can conclude that $t_{\text{B-CDHO}} < t_{\text{PHMIPv6}} < t_{\text{HMIPv6}}$.

5. Simulation and analysis

We use NS-2 to simulate the handover process for HMIPv6, PHMIPv6 and B-CDHO mechanisms respectively under the same condition, and the analysis of the simulation results is based on a statistical packet sequence number comparing the communication interruption time during the handover [11]. All wired and wireless link bandwidth unified set is up to 50 MB, we use a gateway instead of a core network to connect with HA and CN, AR and BS are deployed into a single entity. The link delay during the handover process is displayed in Fig. 5. Assume that during the simulation, MN is able to detect fPN and successfully send a pre-handover request to BS2, the predictable time is limited and relatively fixed, the communication radius of the base station is set to 400 m, the distance between two stations is set to 800 m.

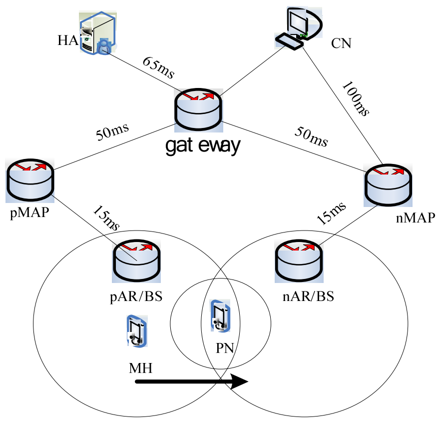

Fig. 5. Simulation structure and parameters setting

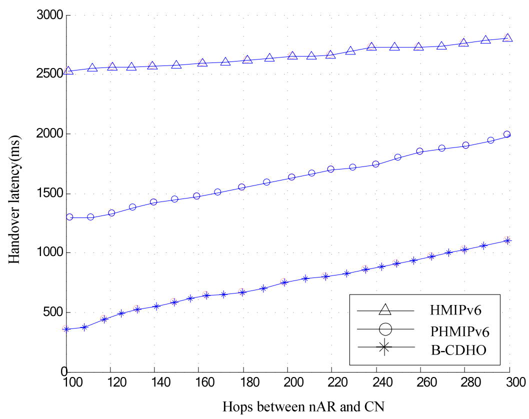

Fig. 6. Handover latency with hops between nAR and CN

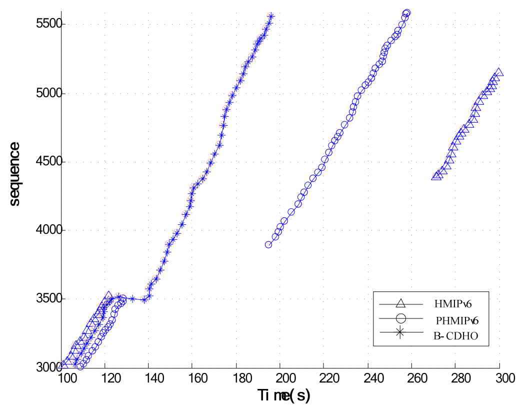

Fig. 7. Packet sequence number in time

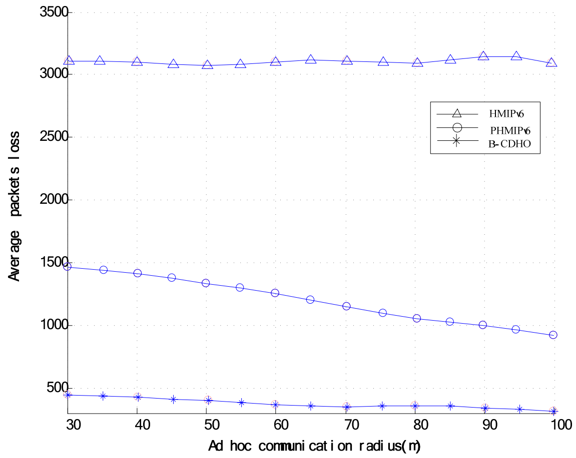

Fig. 8. Average packet loss within the ad hoc communication radius

Fig. 6 shows the relationship between the handover latency and hops of HMIPv6, PHMIPv6 and B-CDHO respectively. Each mechanism handover latency includes the time for binding update, and the handover latency increases with more hops between nAR and CN, but B-CDHO has shorter handover latency compared to the other two mechanisms. Fig. 7 shows the trend of the received packet sequence number in time during the handover process, we can see from the figure that HMIPv6 has the longest handover latency and the largest packet loss number, while B-CDHO mechanism has the shortest handover latency and the least packet loss number. Fig. 8 shows the relationship between the average packet loss and ad hoc communication radius. Because HMIPv6 does not need to probe the cooperative node, its packet loss number is independent with respect to the ad hoc communication radius. But for PHMIPv6 and B-CDHO mechanism, the average number of the packet loss is decreased when the ad hoc communication radius increases, and B-CDHO has relatively the least packet loss number.

6. Conclusion

PHMIPv6 can reduce the inter-domain handover latency by detecting a cooperative node in the target access station, and performing a pre-handover to reduce the handover latency. But for longer pre-handover time, PHMIPv6 cannot solve efficiently the problem of a high drop rate. Aiming at this problem, we have proposed an improved handover mechanism, named B-CDHO, based on PHMIPv6. According to B-CDHO, the mobile terminal must detect another cooperative node in the current base station by its ad hoc interface in order to maintain wireless connection, if the pre-handover does not finish before handover triggering. The simulation results show that B-CDHO can reduce the inter-domain handover latency and the packet loss efficiently in case that the pre-handover is longer.

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