Integrating MIP and SIP for Fast Handoff in IPv6 Networks

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Abstract

An effective mobility management protocol should be able to handle various types of transport protocols with acceptable delay as well as to keep sessions connected as a mobile node moves across networks. Mobile IP is not suitable for real-time RTP/UDP multimedia traffic due to the triangular routing, and SIP may cause the disconnection of ongoing TCP communications. To provide a full mobility support, it should combine both approaches to deal with different transport protocols. In this paper, a cross-layer fast handoff scheme that utilizes the link-layer trigger and IP address pre-allocation is proposed. The proposed scheme also takes into consideration the moving direction of a mobile node to avoid unnecessary handoffs. Experimental results show that the proposed scheme can effectively reduce not only the handoff latency but also the handoff frequency.

1. Introduction

With the popularity of wireless devices and wireless network deployment, people can easily access the Internet anytime and anywhere. The network has to provide the mobile node (MN) to maintain communications while changing its point of attachment from one network to another.

Mobile IP (MIP) [1][2] is a network layer protocol that supports terminal mobility. With MIP, when a MN moves to a new foreign network, it obtains a new care-of address (CoA). The MN sends a binding update (BU) message to the home agent (HA) to register its new CoA. Then packets between the correspondent node (CN) and the MN can be correctly routed via HA. However, MIP suffers from the triangular routing problem which introduces the extra delay. For delay-sensitive applications such as VoIP, the extra delay is unacceptable. Although route optimization can solve the problem, the CN requires handling the BU message from the MN.

Session Initiation Protocol (SIP) [3] is an application-layer signaling protocol that controls the establishment, modification, and termination for multimedia sessions. Besides, SIP also supports application-layer mobility [4]. When a MN moves to a new foreign network, it will acquire an IP address of the network. Then, the MN sends a re-INVITE message to inform CNs about its current IP address. However, SIP may break the connected TCP session whenever the MN changes its IP address. Some researchers, as in [5][6], have proposed solutions to enable SIP mobility to support for TCP connections.

In order to provide a full mobility support, it should combine both MIP and SIP [7][8] to handle different types of transport protocols. The handoff procedure of MIP is similar to SIP. We can divide the procedure into five phases: (1) link-layer handoff, (2) movement detection, (3) IP address acquisition, (4) IP address configuration, and (5) communication recovery. Among these phases, movement detection and IP address acquisition may cause the considerable delay [9]. In practice, three factors are critical for reducing the handoff latency. Firstly, we need to do some evaluation to determine when the current network is unsuitable for the MN. Secondly, how to choose the next suitable access point (AP) to avoid the unnecessary handoff during the movement of the MN. And the third, some mechanisms are necessary to acquire the IP address in advance, because Duplicate Address Detection (DAD) [10] is a time-consuming procedure.

In this paper, a cross-layer fast handoff scheme that utilizes the link-layer trigger and IP address pre-allocation is proposed. By taking into consideration of above three factors, with MIP and SIP integration, our study aims to reduce the handoff latency and handoff frequency to achieve the seamless mobility.

The remainder of the paper is organized as follows. Section 2 describes the related work. Section 3 introduces the cross-layer scheme and its handoff flow. Section 4 demonstrates the implementation details of the implementation and the experimental results. Section 5 concludes the study.

2. Related Work

To reduce the delay caused by movement detection and IP address acquisition, several solutions have been proposed. We classify these solutions into either link-layer assisted solutions, or Duplication Address Detection (DAD) improvement solutions.

2.1. Link-layer Assisted Solutions

Link-layer assisted solutions make use of layer 2 information to monitor the current network. In PAR-SIP [11] and CF-SIP [12], the MN uses active scan to search for next reachable APs when the Signal to Noise Ratio (SNR) value falls below a pre-defined threshold. The MN then selects a predictive AP with higher SNR and performs the proactive handoff procedure. In LLA-AP [13], each MN equips with two wireless interfaces. One is used to connect to the original wireless network, and the other one is dedicated to monitor the current network. If the signal strength falls below a pre-defined threshold, the MN uses the second interface to discover a new AP with higher signal strength and set up an alternative wireless path in advance.

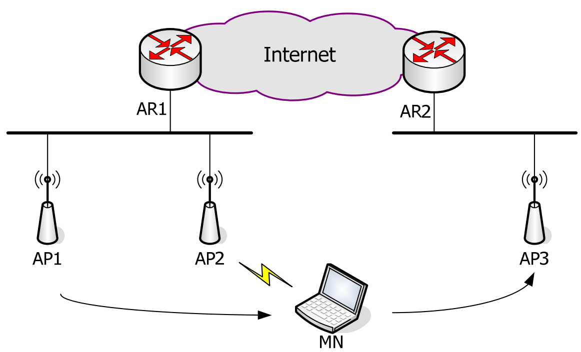

Figure 1. AP Selection

However, AP selection with the consideration of signal information only is inadequate, because it may select an unsuitable AP. For example, the moving direction of the MN was from AP1 to AP3, as shown in Figure 1. The MN originally connected to AP1 and kept moving forward. When the signal strength of the original AP fell below the threshold value, the MN must start to look for next reachable APs. If the MN performed the AP selection by using only Received Signal Strength Indicator (RSSI), it may select AP2 as its predictive AP. However, AP2 was located opposite to the moving direction of the MN, and AP2 would become unsuitable soon. Therefore, AP selection using only RSSI can not reflect the moving characteristic of the MN, and may lead the MN to perform more unnecessary handoffs.

2.2. DAD Improvement Solutions

DAD procedure is used to verify the uniqueness of an IPv6 address on a link. A node generates its IPv6 address by combining its local information, such as MAC address, and the information received from the router. It then sends a Neighbor Solicitation on the link to verify the uniqueness of the IPv6 address. If the node does not receive a Neighbor Advertisement corresponding to the Neighbor Solicitation within a period of time (RetransTimer), the address is assumed to be valid and can be assigned to the interface. An IPv6 address can have different states, as shown in Figure 2. A new untested IPv6 address is referred to as a tentative address and it is not allowed to be used by a node. However, the procedure of verifying the uniqueness address for validity, as the default value of RestransTimer is 1000 ms, may cause the significant delay.

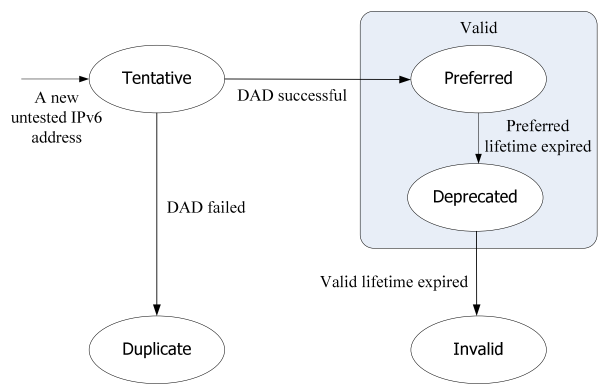

Figure 2. IPv6 Address States

There are two approaches to reduce the delay of time-consuming DAD process, which are Optimistic DAD [14] and Proactive DAD [15].

2.2.1. Optimistic DAD

Optimistic DAD (ODAD) allows a node to use an IPv6 address before verifying the uniqueness. If a host discovers that the address is already in use, it must immediately deconfigure the address. However, the collision may incur some penalty to the optimistic node, and some penalty to the rightful owner of the address. Although ODAD can effectively reduce the delay caused by DAD, it works well only if the probability of collision is low.

2.2.2. Proactive DAD

A MN performs Proactive DAD (PDAD) before network-layer handoff and it reserves a duplication-free IP address of the predictive network. The flow of the IP address pre-allocation with PDAD is depicted in Figure 3.

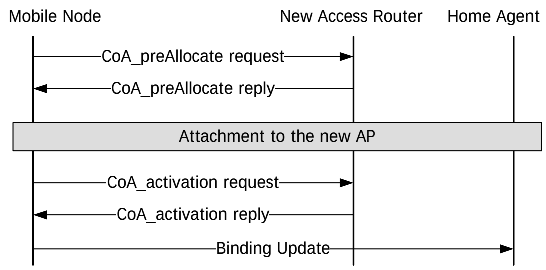

Figure 3. CoA Pre-allocation with PDAD

Before switching to the new AP, the MN uses the prefix of the predictive AP to generate a temporary IP address. The MN then sends a CoA_preAllocate request message to the new access router (AR). Upon receiving the request message, the new AR has to check the uniqueness of the temporary address and return the result in CoA_preAllocate reply message. If the temporary IP address is unique, the new AR must assure the availability of the IP address within its lifetime. After associating with the new AP, the MN activates the reserved IP address by sending a CoA_activation request message to the new AR. Upon receiving the CoA_activation reply message, the MN can directly use the reserved IP address. Otherwise, the MN has to perform DAD procedure to acquire a duplication-free IP address.

However, PDAD may suffer from the performance degradation due to the IP address pre-allocation procedure. Because the new AR has to spend time in checking the uniqueness of the temporary IP address. If the address is already in use, the MN has to perform another PDAD procedure.

3. Cross Layer Fast Handoff

Two servers are involved in the cross-layer fast handoff scheme: HA-SIP and Mobile Information Center (MIC). The functionalities of each server and the fast handoff procedures are introduced in the following.

3.1. System Architecture

The architecture of the proposed scheme is depicted in Figure 4. In the architecture, HA-SIP which consists of home agent and SIP server is located in MN's home network. The main operation of HA-SIP is to receive home registrations of the MN. Mobile Information Center (MIC) is another server which provides topology information and recommendation lists of APs. In order to achieve fast handoff, each domain must have one MIC. Besides, every access router is in charge of recording the IP address of the corresponding MIC.

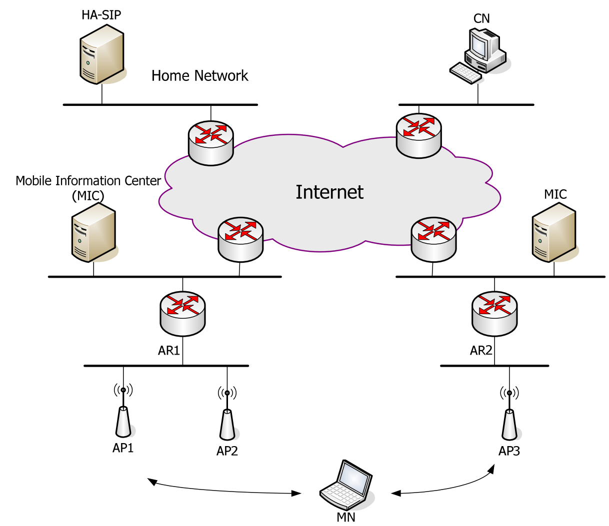

Figure 4. System Architecture

3.1.1. MIC Functions

We assume that each MIC knows its neighboring MICs, and can exchange information periodically. Each MIC maintains and processes topology information and recommendation list for its domain.

- Topology information: Each MIC maintains a neighboring topology information table which consists of the Basic Service Set ID (BSSID) of the AP and the IP address of the AP's access router, as shown in Table 1. The network administrator manages only the administrative domain without knowing neighboring information in advance. After exchanging the table with neighboring MICs, each MIC obtains a complete view of topology information.

- Recommendation list: The purpose of the recommendation list is to provide MNs an indication to predict the next suitable AP. In general, any MN tends to retain its direction of movement for a period of time [16]. Because of the characteristic of direction locality, the network administrator can roughly build a recommendation list by dividing APs into grids, as shown in Figure 5. Each AP forms its block, and the range of the block size is constructed according to the signal strength which is larger than the pre-defined threshold. APs outside the block are allocated to the nearby blocks. Table 2 shows a sample recommendation list stored in a MIC. For example, when a MN connects to AP2, it can request a recommendation list from the MIC by giving the previous AP which the MN connected to. If the previous AP is located in G block, the MIC returns a list of APs, L_{2C}, which is belonged to C block.

Table 1. Neighboring Topology Information

AR's IP address	AP's BSSID
2001:288:5001:10::1 (AR1)	00:40:05:AF:0E:5B
	00:19:5B:3E:FA:BC
2001:288:5001:11::1 (AR2)	00:0D:0B:EF:56:83

Table 2. Recommendation List

AP's BSSID	A	B	…	H
00:40:05:AF:0E:5B	L_{1A}	L_{1B}	…	L_{1H}
00:19:5B:3E:FA:BC	L_{2A}	L_{2B}	…	L_{2H}

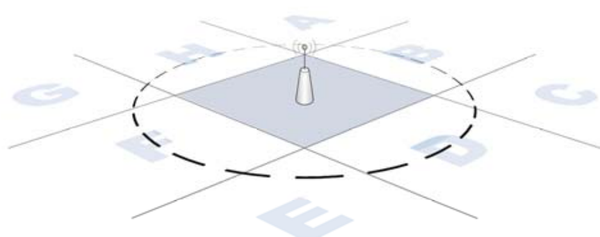

Figure 5. AP Blocks

3.2. Cross-layer Fast Handoff Algorithm

The proposed scheme utilizes link-layer information and IP address pre-allocation to reduce the handoff latency caused by movement detection and IP address acquisition phases. Besides, the proposed scheme also takes into consideration the moving direction of a MN with the assistance of the recommendation list to reduce the handoff frequency.

Figure 6 depicts the state transition diagram of the scheme. In the beginning, when a MN connects to an AP, it enters the Monitor state and retrieves the IP address of MIC from the new access router. In the Monitor state, the MN keeps monitoring the signal strength of the associated AP. When the signal strength falls below a pre-defined threshold, it transfers to the Discovery state.

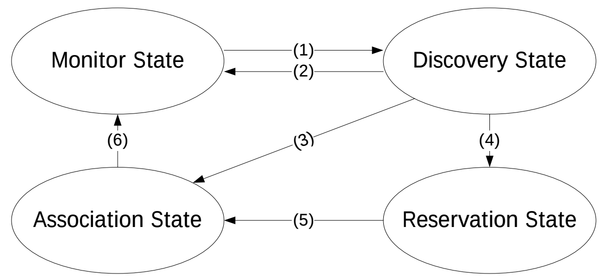

Figure 6. State Transition Diagram of the Handoff Scheme

After entering the Discovery state, the MN starts to scan reachable APs. If the signal strength of the original AP is still the strongest, the state goes back to the Monitor state and decreases the pre-defined threshold to avoid oscillation between the Monitor and the Discovery states. Otherwise, the MN starts to perform the predictive AP selection algorithm, as shown in Figure 7. Another pre-defined threshold, *reliable_threshold*, is defined to deal with the suitability of the recommendation list given by the MIC. An AP of recommendation list is reliable only if its signal strength is larger than *reliable_threshold*. The predictive AP selection algorithm utilizes dual thresholds to assure the availability of the predictive AP, because the unsuitable recommendation list may be filtered by the *reliable_threshold*.

Algorithm PREDICTIVE-AP-SELECTION(*SL*, *RL*)
Input: *SL* is the list of scanned APs. *RL* is the recommendation list acquired from the MIC
Output: The predictive AP
Sort *SL* according to signal strength descending
n ← length[*SL*]
m ← length[*RL*]
if n = 0 and m = 0
  then return null
if m = 0
  then return *SL*[0]
for i ← 0 to n – 1
  do if *SL*[i] < *reliable_threshold*
    then return *SL*[0]
    else if *RL*.contains(*SL*[i])
      then return *SL*[i]
return *SL*[0]

Figure 7. Predictive AP Selection Algorithm

After selecting a predictive AP, the MN looks up the neighboring topology information table, which is retrieved from the MIC, to check whether the predictive AP belongs to the same access router or not. If the predictive AP belongs to the same network, it transits to the Association state. Otherwise, it turns to the Reservation state and performs the IP reservation process.

In this proposed scheme, each access router has to maintain an IP pool which contains duplication-free IP addresses and a registration cache which records the mapping of the pre-allocation IP address to the MN's MAC address. Whenever the MN obtains the IP address of the predictive access router from the neighboring topology information table, it sends a *Reserve_IP_Request* to the predictive AR. Upon receiving the request, the predictive AR selects a unique IP address from its IP pool and records the mapping in the registration cache. Then, the predictive AR replies back a *Reserve_IP_Response* which contains the selected IP address for the MN. At this time, the AR must assure the uniqueness of the reserved IP address during its lifetime. That is, when another node wants to configure the reserved IP address, the AR has to declare that the IP address has been already in use. Once the MN receives the response, it becomes in the Association state.

In the Association state, the MN performs link-layer handoff, which changes the association of the MN from the current AP to the predicted one. If the previous state of the MN is the Reservation state, the MN must also perform network-layer handoff after finishing link-layer handoff. Before using the reserved IP address, the MN has to inform the new AR in advance by sending an *Activate_IP_Request*. Upon receiving the request, the AR looks up its registration cache to check whether the lifetime of the reserved IP address is expired or not. If the reserved IP address is still alive, the AR sends an *Activate_IP_Ack* to the MN, and the MN can assign the reserved IP address to its interface immediately. Otherwise, the MN has to generate a new IP address and perform the regular DAD procedure. Finally, the MN performs session recovery process by sending re-INVITE to MN and Binding Update message to the HA. The state then returns to the Monitor state and reset the pre-defined threshold.

3.3. Message Flow

Figure 8 depicts the original message flow of the handoff delay. The total delay consists of five parts: link-layer handoff (T1), movement detection (T2), IP address acquisition (T3), IP address configuration (T4), and session recovery (T5). T1 is the delay of switching AP depending on wireless access technology [17]. T2 is the delay of detecting a new router and a new link. T3 is the delay of performing DAD procedure. T4 is the delay of network configuration, and T5 is the delay of recovering ongoing communications. Among the above delay, T2 and T3 cause the significant delay. The message flow of the proposed scheme is depicted in Figure 9. T2 and T3 are eliminated because they are all done before link-layer handoff. However, the scheme introduces an extra delay (T6) to inform the new AR of activating the reserved IP address. Nevertheless, it costs only a round trip time within the same network. With the proposed fast handoff scheme, the overall handoff latency becomes T1 + T4 + T5 + T6.

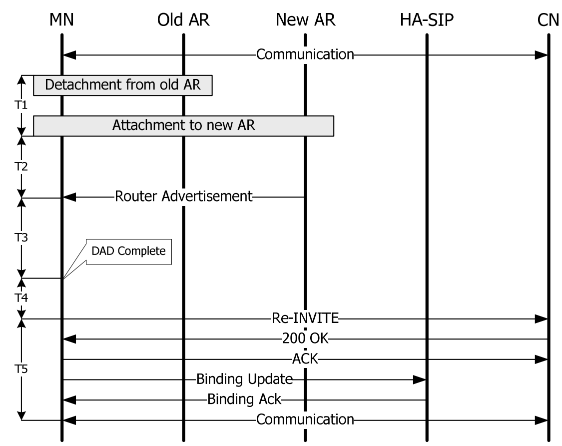

Figure 8. Original Message Flow

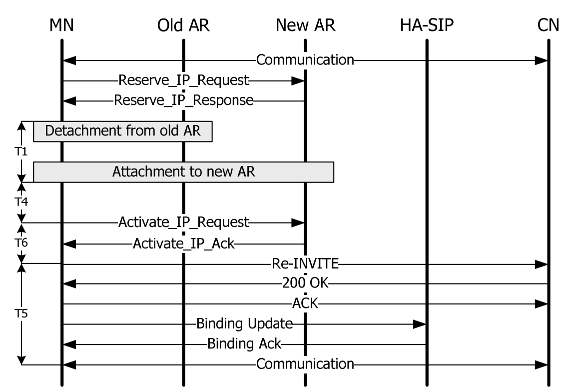

Figure 9. Message Flow of Fast Handoff

4. Performance Evaluation

Because the delay of link-layer handoff (T1) depends on link-layer technology, it is excluded from the performance analysis. In order to measure the handoff latency, we setup a testbed, as shown in Figure 10. The MN, CN and servers are running Linux with kernel 2.6. RADVD (Router Advertisement Daemon) [18] is executed in Linux to play the role of an IPv6 router. MIPL (Mobile IPv6 for Linux) [19] is used to support Mobile IPv6, and SER (SIP Express Router) [20] is used to provide SIP services. The MN is equipped with a prism-based WLAN card to communicate with the CN. Besides, we develop a SIP User Agent (UA) with IPv6 and mobility support by using MjSip SIP stack [21].

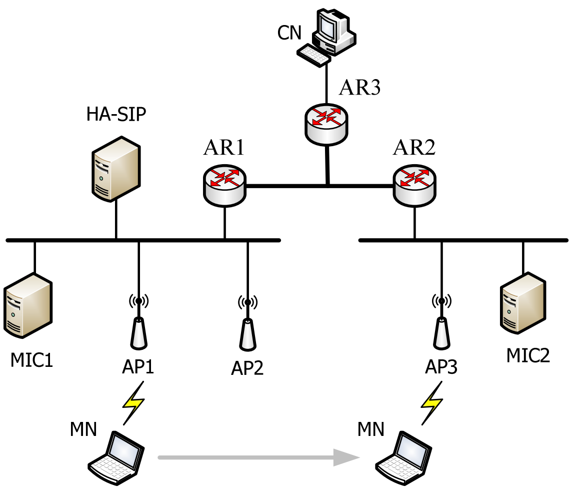

Figure 10. Experimental Environment

To efficiently support the mobility feature, we adjust some IPv6 parameters. One way to provide faster movement detection is to increase the sending rate of unsolicited Router Advertisements. MIPv6 [2] allows reducing the minimum interval to 0.03 seconds and the maximum interval to 0.07 seconds which are utilized in the experiments. The comparison of the handoff latency and handoff frequency between the original scheme and the proposed scheme in both SIP mobility and MIPv6 are conducted and reported in the following.

4.1. Handoff Latency

To investigate the handoff latency, a VoIP communication between the MN and the CN is established using the developed UA. With packet rate of 50 packets per second and the G.711 [22] codec being used, we examine the duration of the handoff latency beyond the link-layer handoff. In the application scenario, the MN originally connects to AP1 and moves toward AP3. The handoff latency is measured 10 times for both handoff schemes.

Figure 11 and Figure 12 show the experimental results for SIP mobility. The handoff latency of the proposed scheme is speeded up by around 4 times faster, 350ms vs. 1600ms. The reduced latency is due to the elimination of the time-consuming DAD procedure by IP address pre-allocation mechanism.

The experimental results for Mobile IPv6 also show the similar improvement in handoff latency which are depicted in Figure 13 and Figure 14.

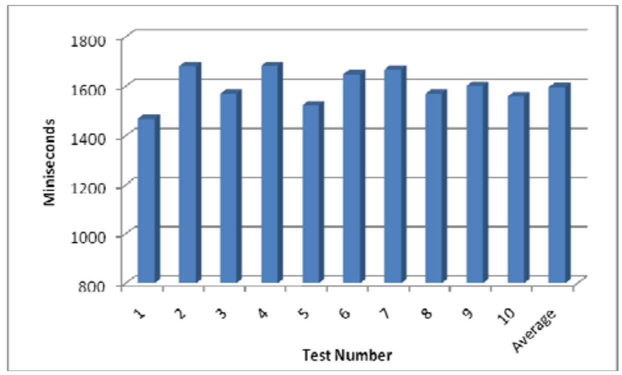

Figure 11. Orignal SIP Handoff Lateny

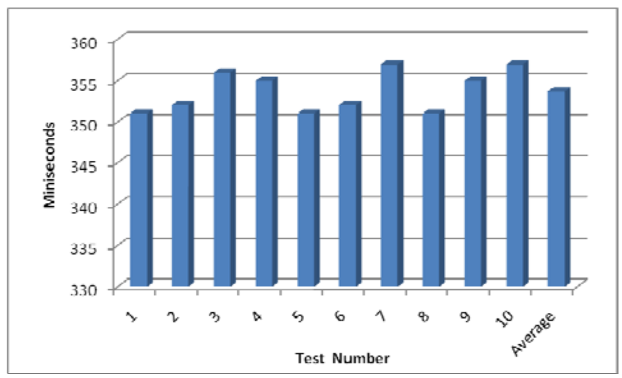

Figure 12. Cross-layer Fast Handoff for SIP

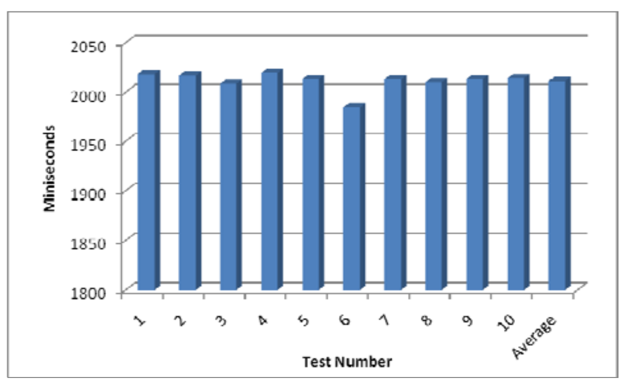

Figure 13. Orignal Mobile IPv6 Handoff Latency

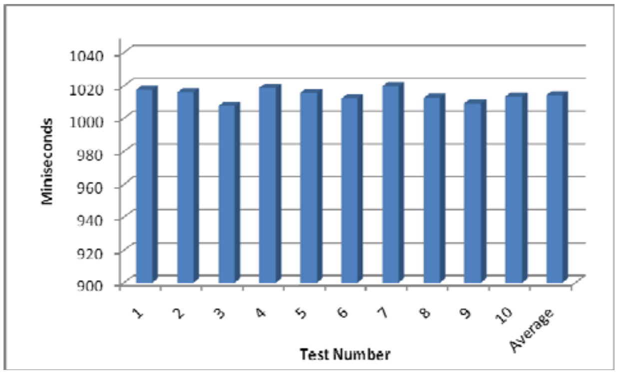

Figure 14. Cross-layer Fast Handoff for Mobile IPv6

Table 3 summaries the average handoff latency in various circumstances. MIP causes more delay than SIP due to MIP signaling. The time that HA processes the Binding Update message and responds with the Binding Acknowledgement message is around 1000ms. For delay-sensitive multimedia applications, SIP mobility is more suitable than Mobile IP.

Table 3. Average Handoff Latency

Scheme	SIP	Mobile IPv6
Original Scheme	1596.7 ms	2011.2 ms
Proposed Scheme	353.7 ms	1014.2 ms

4.2. Handoff Frequency

When the MN connects to AP1, it first requests the recommendation list from the MIC1. Because the moving direction of the MN is from AP1 to AP3, and AP2 is located inside the block of AP1, the MIC1 returns the recommendation list which contains AP3 but not AP2. When the signal strength falls below the pre-defined threshold, the MN scans reachable APs. After performing the predictive AP selection algorithm, the MN still chooses AP3 as the predictive AP even if the signal strength of AP2 is stronger than AP3. The MN should not connect to AP2 because it is located opposite to the moving direction of the MN.

With the help of the recommendation list, the MN can avoid unnecessary handoffs caused by selecting unsuitable APs.

5. Conclusions

In this paper, a cross-layer fast handoff scheme is proposed. With the integration of both MIP and SIP, it can effectively provide mobility support for different types of transport protocols. The experimental results show that the proposed scheme can effectively reduce the handoff latency caused by movement detection and IP address acquisition. The results also show that SIP mobility is more suitable for real-time RTP/UDP multimedia applications than Mobile IP.

Besides, the proposed scheme takes into consideration the moving direction of the MN. With the help of recommendation list provided by the MIC and the predictive AP selection algorithm, the MN can avoid unnecessary handoffs. In the future, the MIC can be extended to provide more information, such as the map surrounding the MN, to even reduce the frequency of handoff occurrences.

6. References

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