Performance of MIP/WLAN in Rapid Mobility Environments

Jun Tian and Abdelsalam (Sumi) Helal
Mobile and Pervasive Computing Laboratory
Computer & Information Science and Engineering Department
University of Florida, Gainesville, FL 32611-6120, USA
{jtian, helal }@cise.ufl.edu

Abstract

In this paper, the performance of Mobile IP (MIP) over Wireless LAN is evaluated using a testbed at different vehecular speeds. The result shows that current MIP protocol is not suitable for rapidly moving environments. Through careful analysis of the relationship between performance and speed, and through a breaking down analysis of the handoff latency of MIP/WLAN, we propose a speed adaptive MIP protocol extension. In this protocol extension, a concept, handoff rate, is defined and is used to extend the MIP protocol. An evaluation of the speed adaptive MIP shows that it greatly improves the performance of MIP/WLAN in rapid moving environments.

1. Introduction

Wireless local area networks (WLAN) have experienced incredible growth over recent years. The success of WLAN lies in the following factors. First, WLAN uses license-free band. 802.11b and 802.11g use Industrial, Scientific, and Medical (ISM) 2.4GHz radio band while 802.11a operates in the 5 GHz National Information Infrastructure (UNII) radio band. Second, WLAN offers reasonably high available data rates. 802.11b can transmit data up to 11 Mbps while 802.11g and 802.11a can provide data rate up to 54Mbps. Finally, there are lots of commercially available WLAN products around the world. Even though WLAN has been designed and used for mostly indoor applications, the possible use of WLAN technologies for high mobility outdoor applications, such as, telemetry, traffic surveillance, rescue operations, and outdoor data networking can provide reasonably high data rates at minimal operational costs. For outdoor applications WLANs provide support for link-layer handoff, which is used to switch a mobile node (MN) from one access point (AP) to another. For WLANs connected by an IP backbone, Mobile IP [1] is the protocol for location management and network-layer handoff. These attractions led us to investigate the performance of MIP/WLAN in outdoor rapid moving environments.

IEEE802.11 standard was originally devised to replicate in a wireless fashion the structures of the wired LANs. Only recently the idea of utilizing IEEE802.11 technology for high mobility scenarios has been taken into account and the range of WLAN based applications has been enriched. In [2], Pierpaolo Bergamo from UCLA and Don Whiteman from NASA, experimentally studied the behavior of an IEEE802.11 wireless network when the nodes are characterized by mobility up to the speed of 240 km/h. The authors studied the survivability and the performance of a connection under various aggressive mobility conditions. These studies may be adapted for data telemetry from mobile airborne nodes to fixed networks or between airborne nodes. In [3], authors assessed the performance of WLANs in different vehicular traffic and mobility scenarios. The network throughput and the quality of the wireless communication channel, measured on IEEE 802.11b compliant equipment, are observed to degrade with increasingly stressful communication scenarios. [4] presents a project using a WiFi-like network for military telemetry applications. For military telemetry, aircrafts and/or cars equipped with IEEE802.11 enabled devices will communicate with a fixed backbone infrastructure. The authors of [4] focused on aspects like frequency selection and network security. In [5], authors developed their own frequency hopping transceiver working at 900 MHz for telemetry purposes. In [6], authors assured through analytical considerations that these kinds of transceivers can guarantee an impressive tolerance to rapid moving environments.

A review on recent research on MIP shows a great amount of efforts contributed to reducing MIP handoff latency. Malki [7] proposed two mobility protocols, pre- and post-registration, using L2 trigger. In pre- registration, MN may communicate with both oFA and nFA. In post-registration, data are cached in nFA before the registration is completed. Fast-handover [7] for Mobile IPv6 network combines the about two methods. But they all depend on L2 information. S-MIP[9], uses MN location and movement patterns to 'instruct' the MN when and how handoff should be carried out. [10] also uses MN's movement model to predict handoff. But all these efforts didn't consider the speed factor of MN, which may cause problems when the MN moving rapidly. In [17], Akyildiz gives an overview of the mobility management in IP-based wireless systems.

The organization of this paper is as following. Section 2 gives a global view of the handoff procedure of MIP/WLAN. The performance of MIP/ WLAN and its relationship to speeds are shown in section 3. Section 4 breaks down the handoff procedure of MIP/WLAN to present a deep view of the handoff latency. A Speed Adaptive MIP(SA-MIP) is proposed in section 5 to improve the performance of MIP/WLAN in rapid moving environment. The performance of SA-MIP is evaluated in section 5 as well.

2. MIP/WLAN Handoff Procedure

In RFC3344, C. Perkins defines three functional entities: MN, HA and FA. MN is a movable device whose software enables network roaming capabilities. HA is a router on the home network serving as the anchor point for communication with the MN; it tunnels packets from a device on the Internet, called a CN, to the roaming MN. FA is a router that may function as the point of attachment for the MN when it roams to a foreign network, delivering packets from the HA to the MN.

Mobile IP is designed independently for all Layer 2 technologies, so it can run on any layer 2 infrastructures. But such kind of independency also costs more overhead. Figure 1 is a global view of the handoff procedure of MIP over two WLANs. When a MN moves from WLAN1 to WLAN2, it performs a layer2 802.11b handoff between Access Point 1 (AP1) and Access Point 2(AP2). After the layer2 handoff, the MN begins a layer3 handoff, which is MIP handoff. Suppose there is a communication, for example a TCP stream, between MN and CN before the handoff. After the layer2 and layer3 handoff, it will require a significant time interval to recover the communication. This time internal is called layer4 handoff delay, which is also a part of the whole handoff cost. Equation 1 gives the life-cycle of MIP/WLAN handoff procedure:

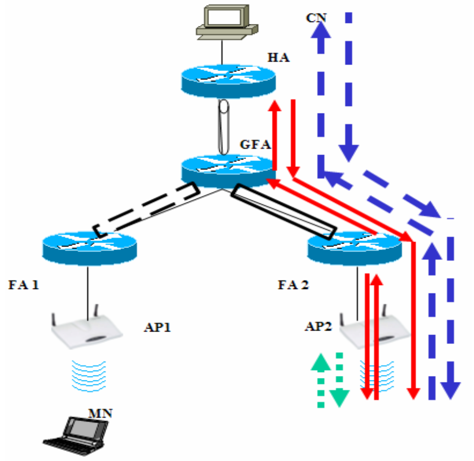

Figure 1: Global view of MIP/WLAN handoff

$$t_{handoff} = t_{L2handoff} + t_{L3handoff} + t_{L4handoff} \qquad (1)$$

Where $t_{handoff}$ is the total handoff delay of MIP/WLAN, $t_{L2handoff}$, $t_{L3handoff}$, $t_{L4handoff}$ are the handoff cost of Layer2, Layer3 and Layer4 separately.

In section 3, we evaluate the performance of MIP/ WLAN and examine its relationship to moving speeds.

3. Performance of MIP/WLAN in Rapid Moving Environments

In order to evaluate the performance of MIP/WLAN, we build up a Rapid Mobile Network emulator, RAMON[11]. RAMON consists of a Pentium II pc as Emulator, a circuit board as Controller, three JFW Industries Attenuators with Antennas, three Cisco 350 Access Points, three FAs, a HA and one or more MNs. The FAs, HA, and MN, which are the major entities of MIP, are running Linux kernel 2.4.20 and are installed with HUT dynamic MIP implementation version 0.8.1[12]. The Attenuators are program controllable device. The Emulator manipulates the Attenuators by the Controller to control the signal strength coming out from the Access Points. By increasing or decreasing the signal strength of one AP, we can emulate the MN moving towards to or away from the AP. By varying the increasing or decreasing speed of the signal strength, we can emulate the speed changes of the MN. Using RAMON, we emulated HUT-MIP in the scenario in Figure2. In this scenario, a rapid moving MN will travel trough 8 APs. Each AP is wired to a FA. The distance between every two consecutive APs is d=500m or 1000m. The moving speed of MN varies from 10m/s to 80m/s. In our experiments, a large ftp file was transferred from the CN to the MN. The experiment results showed that the time-sequence graph and throughput graph at speed 20m/s and d=1000m is similar to those at 10m/s and d=500m. Also graphs at 80m/s and 1000m are similar to those at 40m/s and 500m.

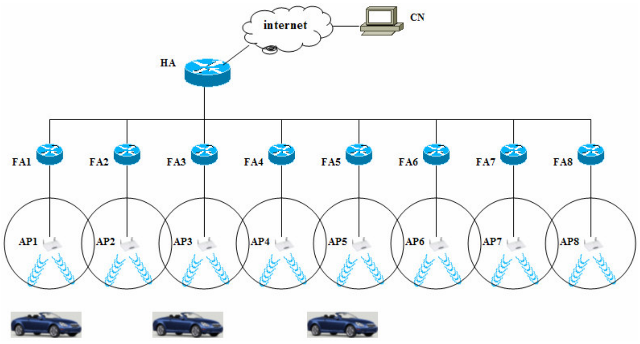

Figure 2**:** Emulation scenario for MIP/ WLAN

To compare the performance of MIP/ WLAN at different speeds and different AP distances, we list the experiment data in table 1. In the table, the bytes transferred are the total bytes transferred from when the MN enters the first cell to when it moves out of the last cell. The average throughput is calculated by dividing bytes transferred by travel time. The total handoff time is the summary of the handoff latency of 7 times handoffs. The effective time is the time for effectively transferring data, which equals to the travel time minus the total handoff time.

Table1 shows the average throughput drops when the MN's speed goes up. At the same speed of 20m/s, the average throughputs are 196.970kB/s for d=1000m and 167.172kB/s for d=500m. At the speed of 40m/s, the average throughputs are 94.359kB/s for d=1000m and 93.877kB/s for d=500m. The table shows that if we double the speed and at the same time double the AP distance, the average throughput shows no suggestive difference.

The analysis of table 1 also shows: (1). The total handoff time doesn't change with speed. (2). Effective-time/total-travel-time ratio drops when the speed goes up. This is the reason why higher speed has lower throughput.

Table 1. Throughput at different speeds and AP distances

Speed (m/s)	AP distance (m)	Bytes transferred (kB)	Travel Time (s)	Average throughput (kB/s)	Total handoff time(s)	Effective time(s)	PMaxavg (kB/s)	Handoff Rate (FAs/s)
20	1000	78000	396	196.970	58	338	232.5	0.02
40	1000	33000	197	167.512	57	140	234.31	0.04
60	1000	16700	130.5	127.969	56	74.5	234.07	0.06
80	1000	9200	98.5	94.359	57	41.5	232.673	0.08
10	500	78500	397	197.733	58	339	233.01	0.02
20	500	33100	198	167.172	56	142	234.4	0.04
30	500	16600	129	128.682	56	73	232.86	0.06
40	500	9200	98	93.877	58	40	232.8	0.08

In order to figure out the relationship between the performance of MIP/ WLAN and the moving speed, we measured the throughputs of MIP/WLAN at different moving speeds and AP distances when there are no handoffs. We call this throughput, P_{Maxavg}, the average throughput without handoff. The P_{Maxavg} at different moving speeds and AP distances are listed in table 1.

Let P_{avg} – Average throughput

P_{maxavg} – Average throughput without handoff

T_{travel} – Total travel time

$T_{effective}$ – Total effective time for ftp transmission

$T_{handoff}$ – Total handoff time while traveling

$K_{handoff}$ – The number of handoffs while traveling

$t_{handoff}$ –Average handoff time among 7 times of handoff

Then, $P_{avg} = (P_{maxavg} / T_{travel}) \times T_{effetive}$

$= P_{maxavg} (T_{travel} - T_{handoff})/ T_{travel}$

$= P_{maxavg} (1 - T_{handoff} / T_{travel})$

$= P_{maxavg}(1 - K_{handoff} \times t_{handoff} / T_{travle})$

$= P_{maxavg}(1 - (K_{handoff} / T_{travle}) \times t_{handoff}))$

Since $t_{handoff}$ doesn't change, The change of P_{avg} is caused by $K_{handoff}/T_{travel}$ ratio.

We define MN handoff rate as $r_h = v/d$, which is the ratio of the MN's speed and the cell size(AP distance). It means that how many APs or FAs the MN hands over in one second. r_h is also equal to $K_{handoff} / T_{travel}$.

The relationship between the performance of MIP/WLAN and the moving speed is presented in equation 2:

$$Pavg = Pmaxavg(1 - rh \times thandoff)) \qquad (2)$$

Where P_{avg} is the average throughput at the MN; P_{Maxavg} is the average throughput without handoff. $t_{handoff}$ is the average handoff time for each handoff procedure.

Since $t_{handoff}$ doesn't change, the change of P_{avg} is caused by handoff rate r_h. At handoff rate 0.02 FAs/s, the average throughput is 197.35 kB/s. When the handoff rate goes up to 0.08 FAs/s, the average throughput drops to 94.118 kB/s.

This section shows that the performance of MIP/ WLAN is depending on the MN handoff rate. In section 5, we will propose an idea of how to make use of this throughput/handoff-rate relationship to improve the performance of MIP/ WLAN in rapid moving environment. In the following section, we will take a deep view of the handoff latency by breaking down the handoff procedure of MIP/ WLAN.

4. Breakdown of MIP/WLAN handoff latency

Equation 1 shows that the life-cycle of MIP/WLAN handoff is the summary of Layer2, Layer3 and Layer4 handoff delay.

In the case of IEEE 802.11b WLAN, Layer2 handoff is the change of APs. It causes an interruption of data frame transmission. In our experiment, we split the Layer2 handoff time into three parts and named them as: movement detection, AP searching and reassociation[13]. The Layer2 handoff involves three participating entities, the station(here is the MN), an old AP(oAP) and a new AP(nAP). The oAP is the access point which the station had layer2 connectivity prior to the handoff, while the nAP is the access point to which the station gets layer2 connectivity after the handoff. The handoff process among 2 APs also includes information exchanges. This information typically consists of the station's credentials and accounting information. The message exchange between APs can be done by Inter Access Point Prototcol(IAPP) or via a proprietary protocol. [13] gives a brief analysis of the three phases of Layer 2 handoff.

The layer2 handoff delay can be expressed in the following equation.

$$t_{L2handoff} = t_{L2detection} + t_{L2seraching} + t_{L2reassociation} \qquad \mathbf{(3)}$$

Where $t_{L2detection}$, $t_{L2seraching}$ and $t_{L2reassociation}$ are the time costs for Layer2 movement detection, Layer2 AP searching and Layer2 reassociation.

Only after the layer 2 link has been established could the Layer 3 handoff start, because the MN can only communicate with the FA on the same link[14]. The Layer 3 handoff involves 2 phases, agent discovery and registration.

The well know agent discovery algorithms are Lazy Cell Switching(LCS) and Eager Cell Switching(ECS)[14]. The LCS method is a reactive handoff initiation strategy. In LCS the MN keeps receiving Agent Advertisement messages from the oFA and refreshes the lifetime of the CoA and stays in the original network until it moves and loses contact with oFA for the duration of three advertisement(FA broadcast Agent Advertisement message every 1 second), which means oFA becomes unreachable. A handoff will be initiated if a nFA is discovered after this moment. If the nFA hasn't been discovered before the oFA becomes unreachable, the handoff latency will be much higher. An advantage of the LCS is to reduce the frequency of handoff when the MN hangs around among several FA. As to MIP/WLAN, because the MN can only keep physical link with one FA, the new agent can't be discovered before the old agent becomes out of range. ECS is a proactive initiation strategy. It dictates an immediate MIP handoff as soon as a new agent is discovered. ECS is effective for the moving patterns that the MN rarely change its moving direction.

When a MN realizes that it is on a foreign network and has acquired a care-of-address from the nFA, it needs to notify the HA so that the HA can forward IP packets between MN and CN. This is done by registration. The registration process involves four steps:

1 The MN sends a registration request to nFA.
2 The nFA relays this request to the GFA(Gateway Foreign Agent) or HA.
3 The HA either accepts or denies the request and sends a registration reply to nFA. If it accepts the request, it will build a tunnel downward to nFA(if foreign agent decapsulation is used).
4 The nFA relays this reply to the mobile node. If the registration reply is positive, it will build a tunnel upward to HA or GFA.

If the mobile node is using a co-located care-of-address, it will register directly with the HA, which is not the case in this paper.

The layer3 handoff delay can be split into equation 4.

$$t_{L3handoff} = t_{mipagentdicovery} + t_{mipregistration} \qquad (4)$$

TCP is a connection-oriented, end-to-end reliable protocol designed to support error recovery and flow control. Reliability is insured by a sliding-window acknowledgement and retransmission mechanism. All data sent by TCP must be acknowledged by the receiver. TCP maintains a variable-sized window of data that is unacknowledged for a given time. If the window is full, no data will be sent until an acknowledgement is received. TCP maintains a Retransmission Time Out (RTO) timer. If no ACK has been received when the RTO timer expired, TCP assumes that the data has lost and retransmits all of the data in the window. The retransmission follows the exponential back-off algorithm. According to this algorithm TCP doubles the timeout value on unsuccessful successive retransmissions[15]. In our case, during the Layer2 and layer3 handoff, the TCP doubles the retransmission timeout value several times. So even after the layer2 and layer3 handoff is over, TCP still have to wait for RTO to timeout to recover the retransmission. This latency is cost by TCP exponential back-off algorithm. We call it TCP back-off delay $t_{tcp\text{-}back\text{-}off}$.

$$\text{Define:} \quad t_{L4handoff} = t_{tcp\text{-}back\text{-}off} \qquad (5)$$

According the equations 1, 3, 4 and 5, the handoff delay for MIP/ WLAN is shown in equation 6.

$$t_{handoff} = t_{L2detection} + t_{L2seraching} + t_{L2reassociation} \qquad (6)$$

$$+ t_{mipagentdicovery} + t_{mipregistration} + t_{tcp\text{-}back\text{-}off}$$

We used RAMON introduced in section 3 to emulate the same scenario as in Figure2. We did 20 times experiments to get the average handoff latency. The experimental result of the handoff latencies of MIP/WLAN is listed in table 2. Table 2 gives 20 times of experiment data. Each row is one experiment. Each column is the time latency for that handoff phase. The data in the last column are the total handoff latencies for every experiment. The number in the bottom right cell is the average handoff latency.

Table 2. Handoff latencies of MIP/ WLAN

Delay (s) / Exp#	L2 movement detection	L2 AP searching	L2 reassociation	MIP agent discovery	MIP registration	TCP backoff	Handoff delay
1	1.033	0.06	0.00	2.99	0.07	5.05	9.22
2	1.064	0.04	0.00	1.94	0.04	6.01	9.51
3	1.133	0.06	0.00	3.02	0.05	5.34	9.62

4	1.032	0.10	0.00	2.56	0.05	5.32	9.07
5	1.044	0.06	0.00	2.75	0.05	5.12	9.04
6	1.131	0.05	0.00	2.57	0.04	5.00	8.81
7	1.009	0.05	0.01	2.43	0.06	5.62	9.19
8	1.120	0.06	0.00	3.00	0.70	5.00	9.89
9	1.023	0.05	0.02	2.21	0.05	4.99	8.37
10	1.039	0.07	0.00	3.00	0.05	5.00	9.18
11	1.100	0.04	0.03	2.77	0.04	5.72	9.71
12	1.013	0.04	0.01	2.54	0.04	4.76	8.42
13	1.021	0.05	0.00	3.00	0.06	5.20	8.89
14	1.006	0.04	0.01	2.60	0.04	5.31	9.02
15	1.104	0.06	0.00	2.59	0.04	4.54	8.36
16	1.003	0.06	0.01	2.67	0.06	4.80	8.62
17	1.110	0.05	0.01	2.78	0.05	5.70	9.71
18	1.100	0.06	0.00	3.01	0.05	5.60	9.84
19	1.302	0.05	0.00	2.34	0.07	5.71	9.49
20	1.098	0.04	0.00	2.40	0.06	5.17	8.78
Avg	1.074	0.05	0.01	2.66	0.08	5.25	9.14
Avg	1.143			2.746		5.25	9.14

5. Speed Adaptive MIP

From section4's analysis of handoff latencies, we can see the largest part is the TCP back-off delay $t_{tcp\text{-}back\text{-}off}$. Because of TCP exponential back-off algorithm, if we reduce the L2 and L3 delay, $t_{tcp\text{-}back\text{-}off}$ will be reduced exponentially. The next largest part is L3 latency. In this paper, we first deal with L3 latency, and L2 and L4 latencyies will be considered later. In section3, we define MN handoff rate as $r_h = v / d$. It means how many APs or FAs the MN moved through per second. Equation 1 shows that the performance of MIP/ WLAN depends on the MN handoff rate. r_h is also equal to the ratio of $K_{handoff}/T_{travel}$. Where $K_{handoff}$ is the number of handoffs occurred during the MN traveling. T_{travel} is MN's total travel time. To reduce r_h without changing total travel time, we can reduce the number of handoffs. The optimal is $K_{handoff} = 0$

Let N be total FA numbers on the way MN traveling. Let's assume somehow M is the number of FAs with whom the MN can communicate without L3 delay. The optimal is M=N. But it costs too many resources, especially when the number of active MNs is large. Also we don't know how long will the MN travel at the beginning.

We call M the size of the FA Set with whom the MN can communicate without L3 handoff delay. From IP level of view, M is the number of FAs that MN has registered to and can communicate with at that moment.

The first problem SA-MIP needs to deal with is to decide FA set size M. In SA-MIP algorithm, M is decided by the following equation.

$$M = \left| t_{handoff} \times r_h \right| + 1 \qquad (7)$$

Where $t_{handoff}$ is the handoff time for every handoff procedure, and r_h is the handoff rate. Here, we use the experimental average handoff time 9.142s for $t_{handoff}$. r_h is dynamic. For example, at speed 40m/s, AP distance 500m, $M = |9.142 \times 40/500| + 1 = 2$. At speed 80m/s, AP distance 500m, $M = 3$.

The second problem is how to guarantee MN can communicate with a FA set just like it can do with one FA. Our solution is to let MN pre-register M potential FAs along the way MN traveling, at the same time multicast IP packets to those FAs in this FA set. So MN won't feel any handoff delay from the IP level of view. In SA-MIP, the set of FAs that MN can talk to without L3 latency is extended from one point at low moving speed to a line at high moving speed. The length of the line dynamically changes with the MN handoff rate. The behavior of SA-MIP will automatically adapt to the handoff rate of the MN so that the performance of SA-MIP won't decline dramatically in rapid moving environments. At the same time SA-MIP only cost reasonable resource that is as much as enough for seamless handoff.

In this paper, we assume the MN has GPS system to detect its location. When the MN moves at speed v, if v < 30m/s (108km/h), it performs a normal registration. If 30m/s < v < 40m/s (144km/h), it initializes registration after receiving two successive agent advertisements. If v > 40m/s, we assume the MN won't change its direction largely in a short distance. It initializes registration once it gets a new agent advertisement. MN's registration message is extended by speed extension. According to Mobile IP Vendor/ Organization-Specific- Extensions[16]. Two kinds of Extensions are allowed for MIP, Critical (CVSE) and Normal (NVSE) Vendor/Organization Specific Extensions. The basic difference is when the CVSE is encountered but not recognized, the message containing the extension must be silently discarded, whereas when a NVSE is encountered but not recognized, the extension should be ignored, but the rest of the Extensions and message data must still be processed. We use the NVSE extension to extend MIP with handoff rate information.

Whenever the MN needs to handoff to a new FA set, after it gets that many times of agent advertisements which is determined by speed(step 1 in Figure 3), it sends a registration request with up-to-date handoff rate information to the very first FA in a new FA set(step 2). The first FA relays the registration request to upper FA or HA(step 3). Meanwhile, it decapsulates the speed extension, refill the MIP header and authentication extension and then forward it to other FAs(M-1 FAs) in this FA set(step 4). These other FAs relay the registration request to upper FA or HA as well, just like the request comes from the MN (step 5). When the GFA or HA receives these registration requests, it builds up tunnels downwards to each FA and responses with registration reply (step 6 and 7). When the FA receives the registration reply, it builds up tunnel upwards to the GFA or HA. Whenever the MN setups the Link-layer contact with the FA, the later forwards the registration reply to the former (step8, 9 or 10). The MN gets the care-of-address from agent advertisement message (step 10 or 9) or registration reply message (step 9 or 10), and begins data communication. At the same time, it sends registration requests to the new FA with up-to-date speed information (step 11). This new FA decapsulates the message, sets up a new FA set, forwards the request (12,13) and repeats the above process.

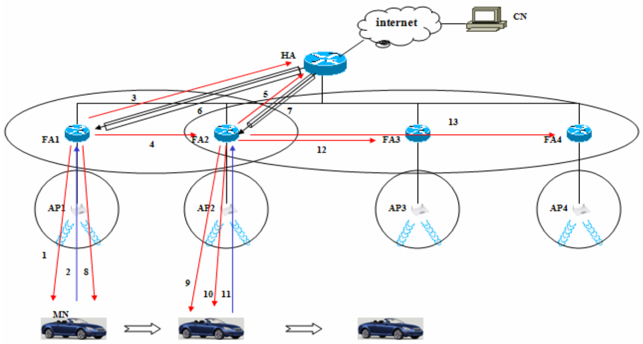

Figure 3: Speed adaptive handoff procedure

In Figure3, the FA set size M changes from 2 to 3 when the MN handoff rate changes from 0.08 to 0.12. We evaluate the performance of speed-adaptive MIP/ WLAN under the same scenario as in Figure2 except the SA-MIP is installed. The average throughput at different speed is listed in table 3.

Table 3. Average throughput for SA-MIP

Speed (m/s)	AP distance (m)	Bytes transferred (kB)	Travel Time (s)	Arg throughput (kB/s)
20	1000	85000	399	213.03
40	1000	37500	198	189.39
60	1000	19400	130	149.23
80	1000	11600	99	117.17
10	500	84400	398	212.06
20	500	37400	198	188.89

30	500	19500	131	148.55
40	500	11500	98	117.34

After installing SA-MIP, at handoff rate 0.02 FA/s, the average throughput is improved by (212.54 – 197.35)/ 197.35 = 7.69%. At handoff rate 0.04, 0.06 and 0.08 FA/s, the average throughput is improved by 13.02%, 15.97% and 24.73% respectively.

6. Conclusion

In this paper, in order to evaluate the rapid mobility of MIP in a laboratory environment, we build a performance evaluation testbed on Wireless LAN. The emulation experiments showed that MIP is not suitable for rapidly moving environments. We depicted the relationship between the performance and the handoff rate of MN and quantitatively analyzed the handoff latencies of the MIP/ WLAN. A Speed Adaptive MIP is proposed and evaluated. The emulation showed that the SA-MIP can improve the performance from 8% to 25% when the handoff rate changes from 0.02 FA/s to 0.08 FA/s. Compared to the mechanisms of Malki[7] and Koodli's mechnism[8], SA-MIP combines the pre- and post-registration methods, but keeps indenpendency from L2 infrastructure. Compared to Hsieh[9] and Wijngaert's mechnism[10], SA-MIP not only predicts its next move but also involves next M number of FAs according to MN's moving speed.

In this paper, SA-MIP only deal with L3 handoff latency. But there is still physical link break from the Layer 2 handoff. And also we noticed that even in SA-MIP, the biggest part of handoff delay was still the layer4 TCP back-off-latency. In future works, we are going to apply the speed adaptive scheme to layer 2 and layer 4 handoff latencies.

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