# Rapid Mobility of Mobile IP over WLAN

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**Abstract.** In this paper, the rapid mobility of MIP/WLAN is emulated on a test-bed. The performance of MIP/WLAN at different moving speeds is evaluated. The result shows that current MIP protocol is not suitable for rapid moving environments. This paper depicts the relationship between the performance and the moving speed and breaks down the handoff latency of MIP/WLAN. A Speed Adaptive MIP extension is proposed and implemented on Hierarchical MIP. The emulation result shows that the Speed Adaptive MIP greatly improves the performance of MIP/WLAN in rapid moving environments.

## 1. Introduction

Mobile IP [1] is a promising technology to eliminate the barrier of location for the increasing wireless internet usagage. Third generation (3G) wireless networks that are based on a set of radio technology standards such as CDMA2000, EDGE and WCDMA combine high speed mobile access with IP-based services. Mobile IP can be the common macro mobility management framework to merge all these technologies in order to allow mobile users to roam between different access networks.

WLAN provides wireless users with an always-on, wireless connection network. There are currently three major WLAN standards, 802.11b, 802.11a and 802.11g. The performance of WLAN decreases as the distance from the antenna increases. As an example, the bandwidth of 802.11b in an open area will drop from 11, 5.5, 2 to 1 Mbps when the distance increases from 160, 270, 400 to 550 meters. The smaller the cell size the higher the bandwidth, but this indicates more frequent handoffs.

Throughout history, the economic wealth of people or a nation has been closely tied to efficient methods of transportation. A person can drive a car on high way at speed of

12km/h. High speed trains such as France TGV, Japanese bullet, German maglev can travel at speeds of over 320km/h. Could those people surf the internet, communicate with families and enjoy an online movie while traveling at high speeds? In another word, could the current network infrastructure support rapid mobility?

The organization of this paper is as following. Section 2 introduces a rapid mobility emulator. 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 and presents a quantitative analysis of the handoff latency. A Speed Adaptive MIP (SA-MIP) is proposed and its performance is evaluated in section 5.

## 2. Rapid Mobility Emulator

In order to evaluate the performance of MIP/ WLAN, we build up a Rapid Mobile Network emulator, RAMON [2]. 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[3]. 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.

## 3. Performance of MIP/WLAN in Rapid Moving Environments

Using RAMON, we emulated HUT-MIP in the scenario in Fig.1. 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.

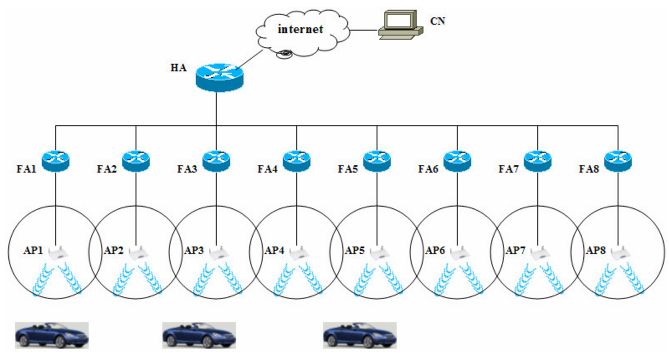


**Fig. 1.** Emulation scenario for MIP/ WLAN

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 92.50kB/s for d=1000m and 76.26kB/s for d=500m. At the speed of 40m/s, the average throughputs are 77.50kB/s for d=1000m and 51.49kB/s for d=500m. If we double the speed and at the same time double the AP distance, the average throughput will stay the same.

**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 hand-off time(s) | Effective time(s) |
|---|---|---|---|---|---|---|
| 20 | 1000 | 37000 | 400 | 92.50 | 64 | 336 |
| 40 | 1000 | 15500 | 200 | 77.50 | 64 | 136 |
| 60 | 1000 | 8500 | 130 | 65.38 | 64 | 66 |
| 80 | 1000 | 4650 | 98 | 48.46 | 64 | 34 |
| 10 | 500 | 36900 | 397 | 92.94 | 64 | 333 |
| 20 | 500 | 15100 | 198 | 76.26 | 64 | 134 |
| 30 | 500 | 8400 | 129 | 65.11 | 64 | 65 |
| 40 | 500 | 5100 | 101 | 51.49 | 64 | 37 |

The analysis of table 1 also shows: (1). The 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. (3). The relationship between the performance of MIP/ WLAN and the moving speed is presented in equation 1:

$$P_{avg} = P_{maxavg}( 1 - r_h \times t_{handoff} )) \tag{1}$$

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

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 $K_{handoff}$ / $T_{travel}$. Where $K_{handoff}$ is the number of handoffs while traveling and $T_{handoff}$ is the total handoff time while traveling.

Since $t_{handoff}$ doesn't change, The change of $P_{avg}$ is caused by handoff rate $r_h$. Fig.2 shows the relationship between average throughput and handoff rate in equation 1. At handoff rate 0.02 FAs/s, the average throughput is 92.72 kB/s. When the handoff rate goes up to 0.08 FAs/s, the average throughput drops to 49.97 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.

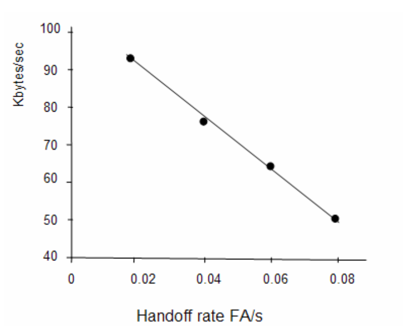


**Fig. 2.** Average throughput/handoff rate

## 4. Quantitative Analysis of the Handoff Latency

MIP, proposed by C. Perkins in RFC3344, is designed independently from all Layer 2 technologies. But such kind of independency also indicates more overhead. Equation 2 gives the life-cycle of MIP/ WLAN handoff procedure:

$$t_{handoff} = t_{L2handoff} + t_{L3handoff} + t_{L4handoff} \tag{2}$$

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

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[4]. The detail analysis of three phases of Layer 2 handoff is not given in this paper. The layer2 handoff delay can be expressed in equation 3.

$$t_{L2handoff} = t_{L2detection} + t_{L2seraching} + t_{L2reassociation} \quad \textbf{(3)}$$

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[6]. The Layer 3 handoff involves 2 phases, agent discovery and registration. The layer3 handoff delay can be splitted into equation 4.

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

TCP is a connection-oriented, end-to-end reliable protocol designed to support error recovery and flow control. TCP retransmission follows the exponential back-off algorithm[7]. 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 $t_{tcp\text{-}back\text{-}off}$.

We define $$t_{L4handoff} = t_{tcp\text{-}back\text{-}off} \quad \textbf{(5)}$$

According the equations 2, 3, 4 and 5, the handoff delay for MIP/ WLAN is shown in equation 6.

$$t_{handoff} = t_{L2detection}+t_{L2seraching}+t_{L2reassociation}+t_{mipagentdicovery}+t_{mipregistration}+t_{tcp\text{-}back\text{-}off} \quad \textbf{(6)}$$

Fig. 3 depicts the handoff latencies of MIP/ WLAN. We used RAMON introduced in section 2 to emulate the same scenario as in Fig.1. 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. The handoff latencies are also shown in Fig. 3.

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.

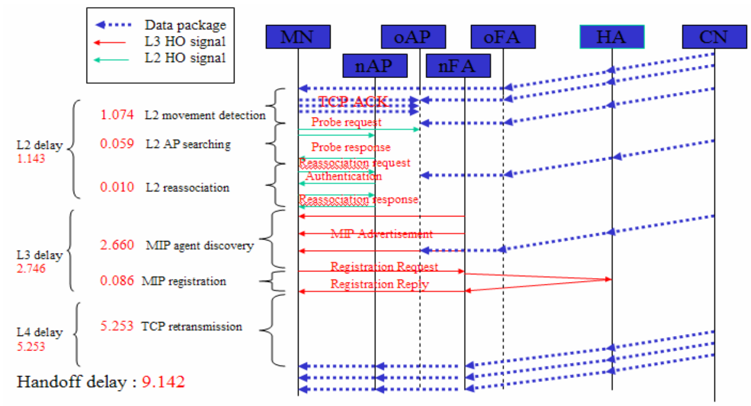


**Fig. 3.** Handoff latencies with message exchange

Table 2. Handoff latencies of MIP/ WLAN

| Delay / Exp# | L2 movement detection | L2 AP searching | L2 reassociation | MIP agent discovery | MIP registration | TCP backoff | Handoff delay |
|---|---|---|---|---|---|---|---|
| 1 | 1.033 | 0.061 | 0.005 | 2.996 | 0.073 | 5.058 | 9.226 |
| 2 | 1.064 | 0.044 | 0.009 | 1.945 | 0.042 | 6.01 | 9.511 |
| 3 | 1.133 | 0.063 | 0.006 | 3.023 | 0.052 | 5.345 | 9.622 |
| 4 | 1.032 | 0.100 | 0.008 | 2.563 | 0.050 | 5.323 | 9.076 |
| 5 | 1.044 | 0.065 | 0.003 | 2.756 | 0.052 | 5.125 | 9.045 |
| 6 | 1.131 | 0.057 | 0.004 | 2.578 | 0.043 | 5.004 | 8.817 |
| 7 | 1.009 | 0.056 | 0.010 | 2.436 | 0.060 | 5.625 | 9.196 |
| 8 | 1.120 | 0.060 | 0.006 | 3.001 | 0.704 | 5.002 | 9.893 |
| 9 | 1.023 | 0.059 | 0.026 | 2.213 | 0.054 | 4.998 | 8.373 |
| 10 | 1.039 | 0.076 | 0.005 | 3.008 | 0.053 | 5.006 | 9.187 |
| 11 | 1.100 | 0.045 | 0.030 | 2.770 | 0.041 | 5.728 | 9.714 |
| 12 | 1.013 | 0.049 | 0.010 | 2.545 | 0.042 | 4.768 | 8.427 |
| 13 | 1.021 | 0.051 | 0.009 | 3.001 | 0.065 | 5.202 | 8.896 |
| 14 | 1.006 | 0.043 | 0.017 | 2.600 | 0.046 | 5.312 | 9.024 |
| 15 | 1.104 | 0.069 | 0.006 | 2.598 | 0.047 | 4.544 | 8.368 |
| 16 | 1.003 | 0.064 | 0.013 | 2.674 | 0.062 | 4.806 | 8.622 |
| 17 | 1.110 | 0.054 | 0.010 | 2.783 | 0.054 | 5.705 | 9.716 |
| 18 | 1.100 | 0.064 | 0.006 | 3.012 | 0.057 | 5.602 | 9.841 |
| 19 | 1.302 | 0.056 | 0.009 | 2.349 | 0.070 | 5.71 | 9.496 |
| 20 | 1.098 | 0.044 | 0.004 | 2.404 | 0.062 | 5.172 | 8.784 |
| Avg | 1.074 | 0.059 | 0.010 | 2.660 | 0.086 | 5.253 | 9.142 |

## 5. Speed Adaptive MIP

The above quantitative analysis of handoff latencies shows 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.

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

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 x 40/500| + 1 = 2. At speed 80m/s, AP distance 500m, M = 3.

The second problem for SA-MIP 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 a rapid moving environment. 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[9]. 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 Fig. 4), 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. In Fig.4, the FA set size M changes from 2 to 3 when the MN handoff rate changes from 0.08 to 0.12.

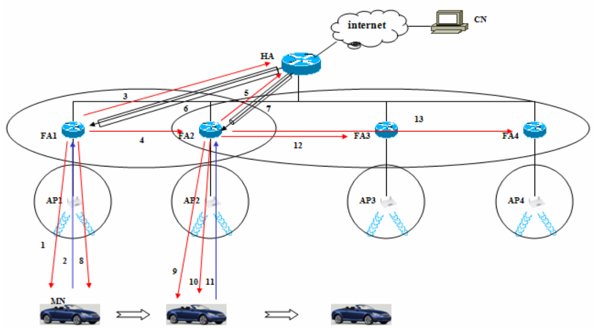


**Fig. 4.** Speed adaptive handoff procedure

We evaluate the performance of speed-adaptive MIP/ WLAN under the same scenario as in Fig.1 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 | 40300 | 399 | 101.00 |
| 40 | 1000 | 18400 | 198 | 88.38 |
| 60 | 1000 | 10000 | 130 | 76.92 |
| 80 | 1000 | 6250 | 99 | 63.13 |
| 10 | 500 | 39500 | 398 | 99.24 |
| 20 | 500 | 17000 | 198 | 85.86 |
| 30 | 500 | 9900 | 131 | 75.57 |
| 40 | 500 | 6200 | 98 | 63.26 |

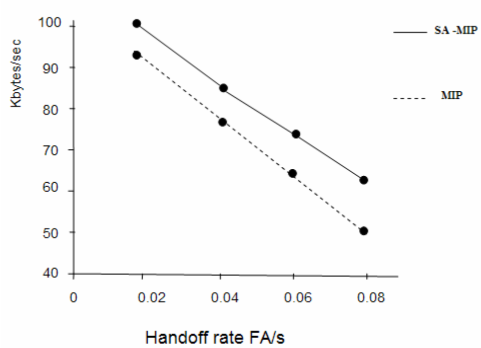


**Fig. 5.** Performance of SA-MIP

Fig. 5 shows average throughput vs. handoff rate before and after the SA-MIP is installed. At handoff rate 0.02 FA/s, the average throughput is improved by (100.12 – 92.72)/ 92.72 = 7.98%. At handoff rate 0.04, 0.06 and 0.08 FA/s, the average throughput is improved by 12.99%, 16.81% and 26.45% respectively.

## 6. Conclusion

In this paper, the emulation experiments showed that MIP is not suitable for rapidly moving mobile clients. 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 27% when the handoff rate changes from 0.02 FA/s to 0.08 FA/s. 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 work, we are going to apply the speed adaptive scheme to layer 2 and layer 4 handoff latencies.

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