# WiMap: Fast Handover for 802.11 Mobile Devices

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*Abstract*— **Low latency handover is desired to support real time applications, such as VoIP. We introduce WiMap, a new handover scheme that uses past information of handovers. Through our analysis and simulation, we show that WiMap performs 50% faster than traditional handover solutions. WiMap does not require modifications to the Access Points or WLAN infrastructure and thus can be efficiently implemented.**

## I. INTRODUCTION

The main reason for the huge success of the widely deployed Wi-Fi networks is that they provide mobility and ‘anywhere’ connectivity for the user. The low-priced 802.11 [7] NICs (Network Interface Cards) have been incorporated into various devices such as laptops and ultra-mobile PCs (UMPC). This economical Internet availability is driving the use of new applications such as VOIP and gaming on mobile devices. These applications need constant connectivity and fast handovers.

IEEE 802.11b has been the most popular standard in the deployed Wi-Fi networks. 802.11b works in the 2.4 GHz ISM band and has 11 channels to operate in. Each Access Point(AP) transmits on one assigned channel and periodically broadcasts a beacon frame on this channel. A mobile device has two ways to search for available APs: active scanning or passive scanning.

Figure 1 shows the sequence diagram of the handover procedure in a 802.11 network. We will refer to the AP that the station (STA) disconnects from as the previous AP and the new AP that the STA will connect to as the current AP. The handover procedure involves two phases. In the first phase the STA chooses the best AP to associate with. In the second phase the STA authenticates and associates with the chosen AP. The authentication and association takes less than 20ms during this handover [4]. Most of the delay incurred in the handover procedure is due to the active scanning of the channels which takes about 300ms [4]. According to the 802.11 standard the active scan procedure for each channel is as follows:

1) Broadcast a probe request on the channel.
2) If the channel is not busy, wait for $MinChannelTime$.
3) Else wait for $MaxChannelTime$.
4) Process all the probe responses.

Real-time applications such as VOIP will not endure the high latency posed by the 802.11 handovers. We observed this during an in-building experiment of a laptop based Skype call while roaming within a Wi-Fi network. For the duration of this experiment, the signal to noise ratio (SNR) of the APs radio signal is examined using the NIC’s driver. Figure 2 shows the plot of the recorded values of SNR. The signal strength began to decrease as the user walked away from its AP. When the radio reported the broken wireless connection, the Skype call was dropped.

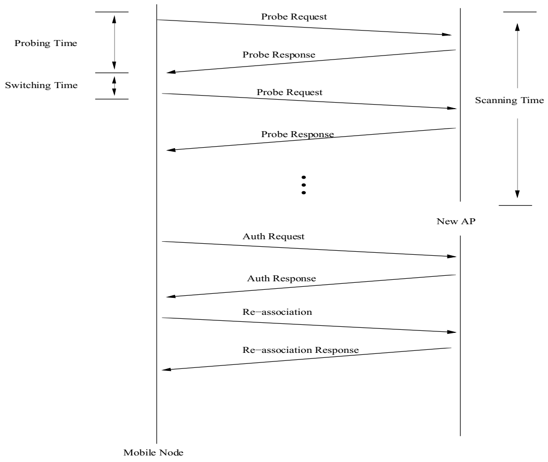

Fig. 1. Handoff Procedure in 802.11

One of the approaches for reducing handover latency is to use neighbor graphs of APs as proposed in [4], [5], [6]. This requires additional message exchanges between APs and modification of the APs. Another approach to faster 802.11 handover called Syncscan [1] proposes that the beacons transmitted by APs on different channels be offset by a certain time. The STA can then spend less time scanning each channel. The drawback of this scheme is that it leads to hardware change of APs due to the synchronization requirement between APs. The handover scheme proposed by Wu et al. [8] uses triggers to proactively scan the channels to find the best AP. This approach divides the scanning phase into small intervals before the actual handover. This approach does not consider the impact of this periodic scanning on the energy consumption. We propose recording the location of the STA (Station) at the time of the handover. Along with the location we also record the results of the scanning for each channel. This information is logged in the STA. By using these records from the history we reduce the number of channels to scan during handover. Considerable amount of power is consumed by the wireless NIC to scan a channel. By scanning only limited number of channels the STA conserves power. Using simulation result based analysis we see a 52% decrease in the average scanning latency during handover. The advantage of our approach is

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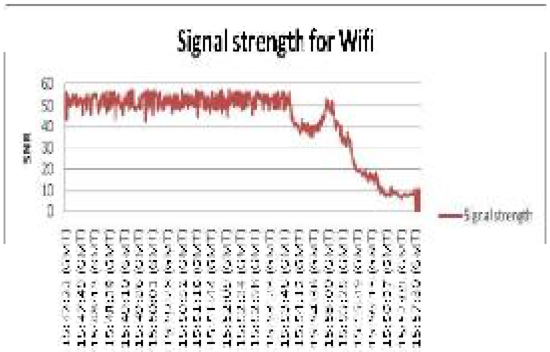

Fig. 2. SNR values observed

| Location | AP id | Channel | RSSI |
|---|---|---|---|
| location1 | AP1 | c1 | RSSI1 |
|  | AP2 | c2 | RSSI2 |
|  | AP3 | c3 | RSSI3 |
|  | . | . | . |
|  | . | . | . |
|  | APn | cn | RSSIn |

TABLE I

WIMAP RECORD FOR LOCATION 1

that it does not involve any change to the AP or the ESS infrastructure.

The rest of the paper is organized as follows: in section II we present our solution. Section III gives the simulation and results. Section IV analyzes the solution and finally section V concludes the paper.

## II. WIMAP BASED FAST HANDOVER

In this section we present a detailed description of our approach. Our solution is made up of two phases. In the first phase the STA constructs WiMap. The second phase achieves a faster handover by making use of the WiMap from the first phase.

### *A. WiMap construction*

STA starts scanning each channel during the handover. The information obtained during the scanning, such as the AP/s on the channel and the Received Signal Strength Index(RSSI) of the AP/s will be recorded by the STA in the data structure which we call WiMap. Each record in the WiMap will be indexed by the location of the STA. Figure 3 shows a symbolic representation of a WiMap record.

In recent years both Apple and IBM have introduced accelerometers [12] in their laptops to protect the hard disk from damage due to sudden drop or vibration. The accelerometer is an electromechanical device that measures the acceleration forces along each axis. By sensing the amount of acceleration, one can calculate the direction and speed of the STA. Based on the calculated speed, direction and the time of movement one can calculate the relative location. A STA can also have GPS capability which can be used to obtain the location information.

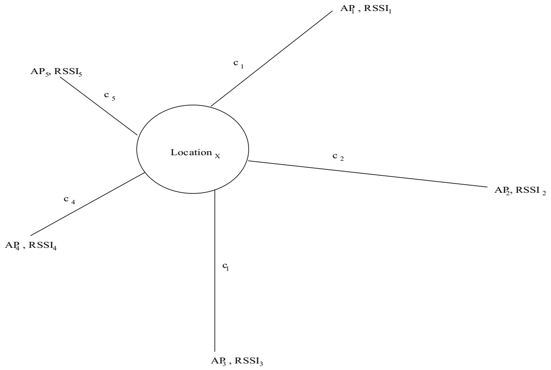

Fig. 3. Wimap Record information

### *B. Selecting APs based on WiMap*

Upon losing the connectivity with the current AP the STA will execute the prediction algorithm listed below which returns a set of the probable APs. R is a system parameter that indicates the radius of a circle within which it is likely for a node to find a good AP. Based on the the information available in the WiMap for the locations within radius R of current location, our algorithm returns a set of potential APs. The STA restricts the scanning to the channels of the APs returned by the algorithm. If Algorithm 1 returns an empty $ProbableSet$ then the STA scans all channels.

**Algorithm 1** Prediction($R, WiMap$)

```
1: $ProbableSet = \phi$
2: $LocationSet$ = set of locations in WiMap that lie within the circle of radius R from the current location of the STA.
3: for each $location$ in $LocationSet$ do
4:     $ProbableSet$ = $ProbableSet$ + WiMap record at $location$
5: end for
6: Sort $ProbableSet$ in descending order of RSSI
7: Return $ProbableSet$
```

We can further optimize our algorithm by reducing the number of APs in a probable set that we need to consider. We assume that at walking speeds, the probability density function [14] is shown as:

$$f_\theta(\theta) = \begin{cases} \frac{1}{\Pi} & \text{if } \frac{-\Pi}{2} \leq \theta \leq \frac{-\Pi}{2} \\ 0 & \text{otherwise} \end{cases}$$

Here $\theta$ is the angle of movement. The movement is assumed to be uniformly distributed in the range (-Π/2,Π/2). This implies that when a user is moving in a particular direction, the probability of turning more than 90 degrees to the left or right is negligible. Hence we can optimize step 2 of Algorithm 1 to only consider APs that lie within (-Π/2,Π/2) degrees relative to the current direction.

## III. SIMULATION AND RESULTS

The simulation of the proposed handover scheme is implemented using Microsoft Visual C#. The goal is to obtain the percentage of handovers that successfully found the AP using the probable set. This would give us an estimate of the average time spent on the scanning procedure during handover. The simulation consisted of mobility of the STA and its connectivity with access points, and did not include the data sessions.

### A. Simulation model

*1) RSSI calculations:* The radio signal strength calculation was based on the distance to the access point. A simplified path loss model was used for the signal strength calculations. The following equation represents the model:

$$RxPower = TxPower * K * (D/d)^{\gamma} \quad (1)$$

where:

- $TxPower$: transmission power of the AP, set to 19dbm (80mw).
- $d$: distance from the transmitter.
- $\gamma$: path loss exponent assumed to be 3.
- $D$: reference distance assumed to be 1 meter.
- $K$: a constant based on D and wavelength $\lambda$

*2) Handover Simulation:* We placed 677 APs in the network area of 2500*2500 meters, such that the APs are 150 meters apart and it is possible for a STA to find more than one AP at any location. This scenario is similar to what we observed in the campus area where at any particular location there are multiple APs within range.

The STA disconnected from the current AP when the following condition is met:

$$RSSI \leq RSSI_{Th} \quad (2)$$

where $RSSI_{Th}$ is the threshold of RSSI and assumed to be -80dbm. The mobile node chooses the AP with the best RSSI value to connect to.

From Equation 2 and the -80dbm threshold value, we can deduce that the coverage radius of an AP is about 92 meters. Accordingly we have chosen 50 meters to be the value of R for Algorithm 1.

*3) Mobility Models:* The simulations were executed for two different mobility models:

Random Waypoint: A number of way points are distributed over the entire network area. The STA moves from a randomly chosen waypoint towards the next random waypoint. Each time the STA may pause for a certain time period when they reach the way point. The speed of the mobile remained the same throughout the simulation. One of the trajectories followed by the STA is shown in Figure 4.

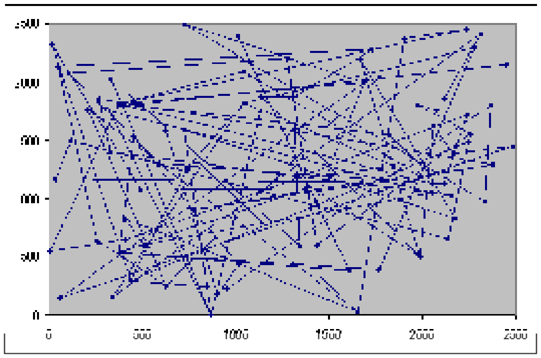

Fig. 4. Trajectory of mobile node using random way point

Restricted Random Waypoint with City Section [14]: We have used 2400*2400 section of the street map that was converted into a graph by Saha and Johnson [14]. Each node starts at one of the randomly chosen vertices of the graph. Then it chooses another randomly chosen vertex as its destination. The STA moves to its destination by following the single source shortest path calculated using Dijkstra's algorithm. If there is no path toward the destination, the STA moves toward it on a straight line. An example of the trajectory followed by the STA using this model is given in Figure 5.

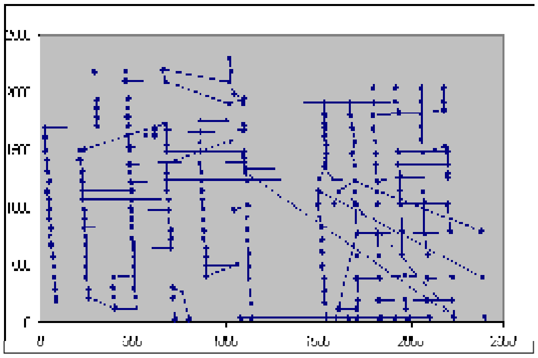

Fig. 5. Trajectory of a mobile node using restricted random waypoint

### B. Simulation Results

We executed the simulations for both the mobility models mentioned in the previous section. For each mobility model we repeated the experiments using three different speeds of the mobiles at 1m/sec, 5m/sec and 15m/sec. The results mentioned in this section are averaged over multiple simulation runs with each run having an average of 1000 handovers. The non empty retrieval values shown in Table 2 denote the number of times algorithm 1 returned a non empty set. We call the first AP in the probable set as the correct AP if it is the same as the AP that the STA connects to after the handover. The success ratio of our algorithm is defined as the number of times the correct AP is selected by algorithm 1 divided by the number of times algorithm 1 returns a non-empty probable set. Figure 6 shows the success ratios for the different mobility models and mobile speeds.

## IV. ANALYSIS

In this section we will evaluate the average delay incurred by the STA to find the best AP. Equation 3 [4] gives the

| Mobility Model | Speed | Non empty retrieval by Alg 1 |
|---|---|---|
| Random Waypoint | 1m/s | 51% |
| | 5m/s | 53% |
| | 15m/s | 52% |
| Restricted Random Waypoint | 1m/s | 68% |
| | 5m/s | 66% |
| | 15m/s | 66% |

TABLE II
RESULTS OF ALGORITHM 1

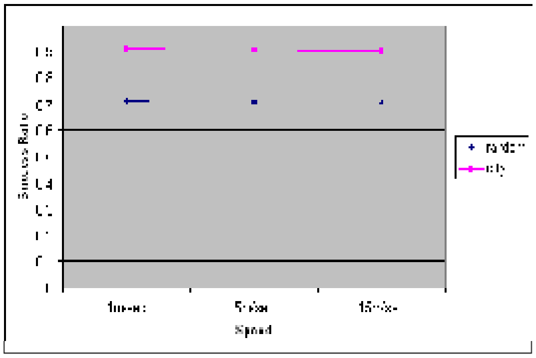

Fig. 6. Uniform distribution of movement

average delay to find the best AP:

$$E[D] = SwitchingDelay + ScanDelay \tag{3}$$

where: $SwitchingDelay$ is the time taken for the receiver to switch between channels and resynchronize on the new channel, and

$$ScanDelay = \sum_{c=1}^{N_c} (1 - P(c)) * Min + P(c) * Max$$

where:

- $N_c$ is the number of channels.
- $P(c)$ is the probability of finding an AP on channel $c$.
- $Min$ is the amount of time the STA will wait to receive the response for a probe request.
- $Max$ is the amount of time the STA will wait to hear from other APs on this channel.

Experimental results [4] have shown $Max$ and $Min$ to be 11ms and 7ms respectively and the $SwitchingDelay$ to be 19ms. Assuming $N_c$ to be 11 and that the channels are uniformly distributed among the APs, we get $P(c) = 1/11$. Using these values we calculate $E[D]$ to be 271ms.

With our approach whenever Algorithm 1 returns the correct AP, the STA scans only one channel and in this case:

$$E[D] = Max + SwitchingDelay = 30ms$$

Hence if the fast handover proposed by this paper is utilized, the average delay to find the best AP is given by Equation 4.

$$E[D'] = 30 P_h P_s + (1 - P_h P_s) * E[D] \tag{4}$$

where:

- $P_h$ is the percentage of times Algorithm 1 returns a non empty probable set of APs.
- $P_s$ is the success ratio of Algorithm 1.

The average values of $P_h$ and $P_c$ from our simulation results turned out to be 0.64 and 0.9 respectively for the restricted random waypoint mobility. Therefore we get $E[D']$ to be 129ms in contrast the 271ms calculated earlier. This is an improvement of 52% as compared to the current handover scheme of random channel scanning. Similarly we get an improvement of 34% for random waypoint mobility model.

## V. CONCLUSION AND FUTURE WORK

We propose a solution for reducing the handover latency in 802.11 networks. Our solution requires no changes at the AP and no protocol changes to 802.11. First we build a WiMap by recording the signal strengths of APs at the location where the handover occurs. Secondly we use this information during future handovers to reduce the number of channels scanned to find the best AP. We assume that the STAs will be equipped with modules such as accelerometer or GPS that can provide its location. Using the simulation results we analyzed the average latency of the scanning procedure. The analysis showed that the average latency is reduced by 52% and 34% respectively for the random waypoint and restricted random waypoint mobility. Our approach relies on the fact that location of the STA can be detected accurately. If the error in the location discovery process is bounded our algorithm can still produce the best AP with a certain probability.

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