Pedestrain Monitoring System using Wi-Fi Technology And RSSI Based Localization

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ABSTRACT

This paper presentsa new simple mobile tracking system based on IEEE802.11 wireless signal detection, which can be used for analyzingthe movement of pedestrian traffic. Wi-Fi packets emitted by Wi-Fi enabled smartphones are received at a monitoring station and these packets contain date, time, MAC address, and other information. The packets are received at a number of stations, distributed throughout the monitoring zone, which can measure the received signal strength. Based on the location of stations and data collected at the stations, the movement of pedestrian traffic can be analyzed. This information can be used to improve the services, such as better bus schedule time and better pavement design. In addition, this paper presents a signal strength based localization method.

KEYWORDS

Mobile Tracking, Localization, Wi-Fi; Captured Packets, Channel Hopping, RSSI, EMD, EEMD

1. INTRODUCTION

Wi-Fi networks have been widely deployed in homes, enterprises and organizations. Wi-Fi technology is defined in various IEEE 802.11 standards (including 802.11a, 802.11b, 802.11g, and 802.11n). It is a popular method to provide Internet access for wireless users. Nowadays, smartphone has become a common device and important part of everyone's daily life. Most people carry smartphones during working, shopping and leisure time.Asmartphone can be identified by using its unique IDs like International Mobile Equipment Identity (IMEI) number or Media Access Control (MAC) address of the handset. The IMEI is sent once when a mobile registers with a network, whereas the MAC address is on every data packet sent by Wi-Fi enabled mobile handset. Each MAC frame includes destination and source MAC addresses.

Wi-Fi MAC address can be used to identify a mobile device and it can be used to determine the location of a mobile device when it is combined with received signal strength at multiple locations. A good applicationis to monitor patients in a hospital [1] or in location sensing [2]. However, there are some problems when Wi-Fi positioning is applied in outdoor conditions. A few localization methods can be applied for outdoor. The use of wireless positioning technologies have been discussed by several researchers in the past few years [3] and the most common

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localization approach is using received signal strength (RSS). Specifically, one method uses a propagation model to covert RSS to the distance and applied triangulation method to determine the location of the transmitter.

Another method is an empirical model which uses fingerprinting method. This method uses some RSS measured at a number of points within an area as reference point (RP). Thereafter, ituses RP to compare with the measured RSS of wireless device to estimate the location. There are a number of problems with the finger printing method (a) a general wireless device such as Wi-Fi adapter provides receiver signal strength indicator (RSSI) not RSS,(b)finger printing method requires a static outdoor environment ,(c) It has been proven that the RSSI cannot be reliably used for localization [4], due to inconsistent behaviour and the error in measured RSSI value increases as distance increases.

The idea of using Wi-Fi enabled smartphone to monitor pedestrian traffic or individual movement has been discussed in the literature in recent years. Inside a building, the pedestrian monitoring can be easily achieved by using the Wi-Fi enabled smartphone and access point (AP) [4, 5]. All the smartphones have to communicate with an AP to obtain a Wi-Fi connection. During the communication process, the AP extracts the information which is needed for smartphone tracking, for instance, the MAC address and RSSI. Therefore, the pedestrian traffic in an area of interest can be investigated by using the information. However, the smartphone based pedestrian monitoring has a lot of challenges in an outdoor environment. Most of the traffic monitoring systems deployed today uses some special purpose sensors such as magnetic loop [6], cameras [7] and RFID tag-reader. These methods are applicable with vehicles instead of pedestrians and very costly.

This paper introduces a new solution for the problems mentioned above by proposing a mobile tracking system. This system captures MAC layer information of a smartphone by using wireless sniffing and uses a method of RSSI based localization to implement positioning. The purposes of this system are pedestrian traffic monitoring and people density monitoring based on smartphone tracking in a street. This information can be used to improve the service provided to people such as better bus schedule time and better pavement design.
In the rest of this paper, Section II describes the system structure and the challenges. Section III discusses the solution for the challenges. Section IV introduces a RSSI based localization method and Section V presents and analyzes the test results. The conclusion summarizes the contributions of this paper in Section VI.

2. METHODOLOGY

2.1 System Structure

This tracking system consists ofa sniffing block and an administration block.The system structure is depicted in Figure 1. The sniffing station is used for capturing and processing packets from Wi-Fi channels. Database and tracking server are two components in the administration block which stores the processed packets from sniffing stations..

Sniffing station: It contains Wi-Fi antenna, adapter, processor, 3G module and local database. The Wi-Fi adapter uses the Wi-Fi antenna to monitor channels and capture packets sent by mobile devices. These captured packets will be sent to the processor, and then the processor reads the packets, filters out useful information such as MAC address. The data is stored in local database as a backup and sent to next block via 3G module simultaneously.

Tracking server: It contains a server and a database. This block receives the data sent from sniffing block and stores them in a database. The tracking server also allows users access to the database for acquiring information.

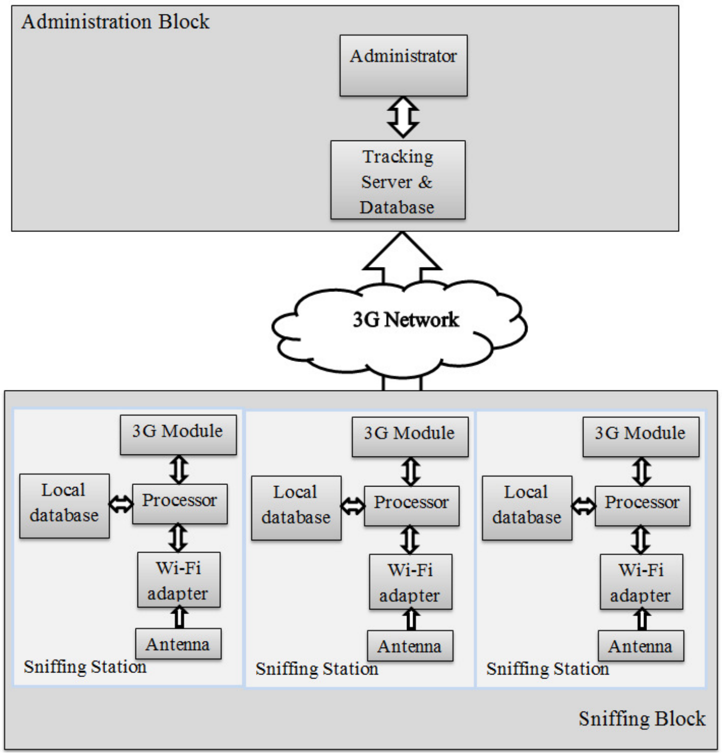


Figure 1: System structure

3G network is used as an interface between sniffing station and tracking server in this system. Using 3G networkdeliver the collected data to the tracking server can improve the coverage and availability of this system. As 3G network is widely deployed in cities, it can provide a reliable wireless communication in any places, for instant, in a park.

In addition, to configure or modify the sniffing station on site would be inconvenient in most of the situations. This system can conduct remote control and monitor the sniffing stations easily via 3G connection.

In order to reduce the amount of data transmitted through 3G interface, the data need to be filtered to onlyinclude:

- Date: date and time when the packet is captured.
- Station: station number where packet is detected.
- Device type: Wi-Fi or Bluetooth (optional)
- MAC address: The MAC address of the mobile device from which packets originate.
- Signal strength (dBm): Received signal strength from the mobile device.

2.2 Packets Sniffing

A Wi-Fi enabled smartphone in a street sends packets to discover available Wi-Fi network intermittently. The typical packet involved in this discovery process is a probe request which contains the MAC address. Therefore, system performance can be defined as device detection (amount of captured MAC addresses) and packets detection (amount of captured probe request). Forasmuch, the object allocated to the system is to maximize the number of device detected and number of packets detected. This paper describes two methods for packets sniffing: passive sniffing and active sniffing.

Using passive sniffing method, the sniffing station listens to the channel only instead of establishing communication with smartphone by sending packets. The sniffing station extracts the MAC address from each captured packet and measures the received signal strength.

The active sniffing method is achieved by using probe response injection. According to IEEE802.11 standard, Wi-Fi station (Wi-Fi enabled smartphone) communicates with the access point which is shown inFigure 2. After the station sends the probe request, it waits for the probe response in a certain time. Once the station received the probe response, it sends an acknowledgement back to the access point. The acknowledgement contains the sending station's MAC address which is necessary for tracking. The probe response injection can increase the packet sent by smartphone which is benefit to the mobile tracking system.

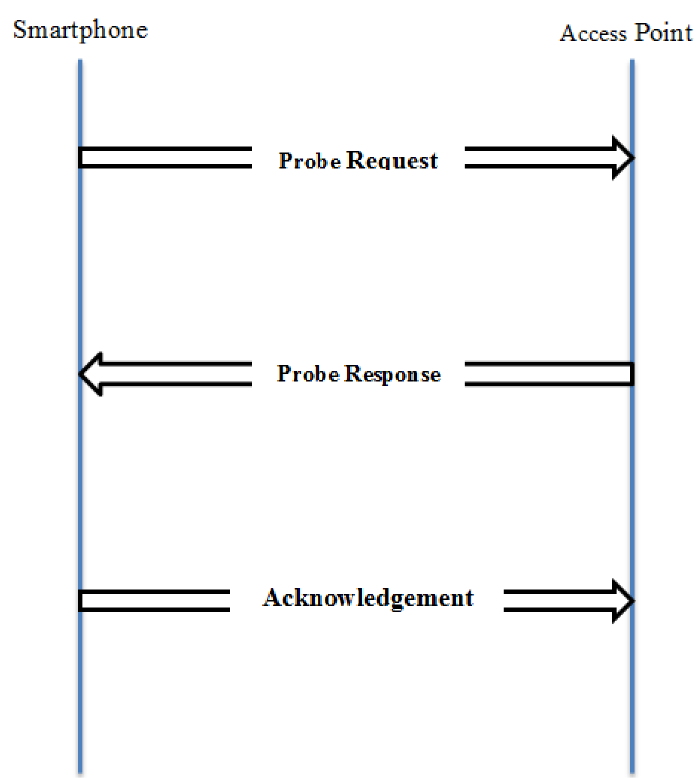


Figure 2: The probe request processing

2.3 System Challenge

This mobile tracking system facesa number of challenges. By our system design, the sniffing stationis mountedin the street to detect smartphones. However, the real world conditionsare complex. There are vehicleson the road and pedestrians with different walking speeds as they enter a building or board on a bus. Wi-Fi enabled handsets send packet slackly and randomly in the street. Therefore, this system requires a mechanism to increase the packets captured efficiently and measured RSSI accurately.

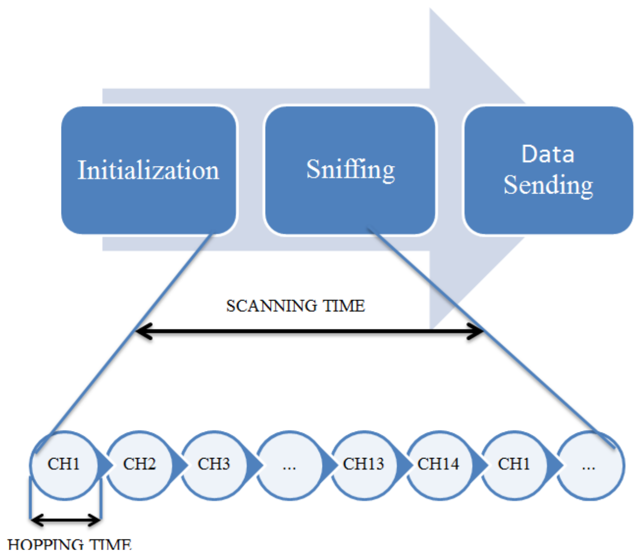


Figure 3: Hopping Time vs. Scanning Time

The radio spectrum used for 802.11 is divided into several channels, such as 802.11b/g separating the 2.4GHz spectrum into 14 channels spaced 5MHz each and Wi-Fi adapter can only operate on one frequency channel at any time. Therefore, channel hopping or frequency hopping will be used in the adapter. In order to monitor all the channel traffic without losing any packet in sniffing area, 14 measurement devices are required. Obviously it increases sniffing difficulty and cost. Therefore, channel hopping is used in this paper as a solution. This system chooses a simple packet loss avoiding method, which is achieved by using scanning time Ts and hopping time Th. As shown in Figure 3, one detecting circle is divided to sniffing phase and data sending phase. In the sniffing phase, the adapters hop on all selected channels and in this scanning period all the received signal strength values for one specific MAC address will be calculated to an average result. Scanning time and hopping time in Figure 3are the duration of one sniffing phase and the duration of adapter collecting data from one channel respectively.

Specifically, hopping time will define the hopping frequency which can tell how many channels can be scanned in one sniffing phase (i.e. scanning time). Scanning time will define result output frequency.

The relation between scanning time and hopping time is shown as the equations below

$$\frac{T_S}{T_H} = N_C (1)$$

$$N_p = \frac{f_i}{N_C} \times T \times N_{MAC} (2)$$

$$N_P = \frac{f_i \times T_H}{T_S} \times T \times N_{MAC} (3)$$

where N_c is the number of hopped channels in one scanning time period, N_p is the total number of captured packets, $f_i$is the packet sending frequency for one unique MAC address, (this frequency value is dynamically based on the network status and data demand), T is the total sniffing time and N_{MAC} is the total number of MAC addresses which stay in the sniffing area during a sniffing period.

There is a trade-off between hopping time and scanning time:

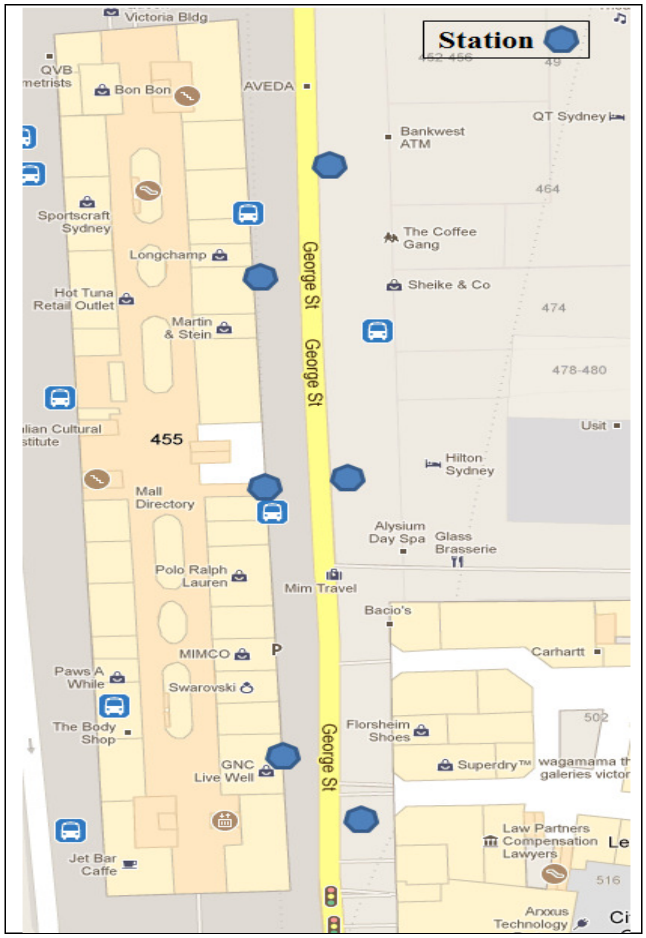
- Shorter hopping time will cause packets loss in one specific channel. Because it spends less time to monitor one channel. On the other hand, longer hopping time will cause packets loss in other channels.
- Shorter scanning time will reduce the number of scanned channels. But longer scanning time will reduce the data volume and the data accuracy which shows the possible location in a movement trace, because pedestrian is moving and the system calculates all the captured packet*s* into one average result only within a scanning time.

2.4 Test Bed

The sniffing stations were mounted on George St. which is one of the main streets in Sydney CBD asshown inTable 1.The table also describes the Wi-Fi device which is installed in sniffing station. According to the collected data, thesmartphone involved in the tests include all majorbrands in market. (Apple, HTC, Samsung, Sony, Sharp, Blackberry, Nokia and etc.).

Table 1: The deployment of sniffing stations (Google Map)

Antenna Gain	Sensitivity
2dBi	-93dBm
Deployment	



3. TEST RESULT AND ANALYSIS

3.1 The Probe Response Injection

Figure 4 demonstrated the comparison between passive and active sniffing. Thedata are collectedfor one day in the street. From the figure, we found that the active sniffing increases the number of captured packets for around 10% of observed. In this result, the contribution of active sniffing is fewer than what it has been expected.

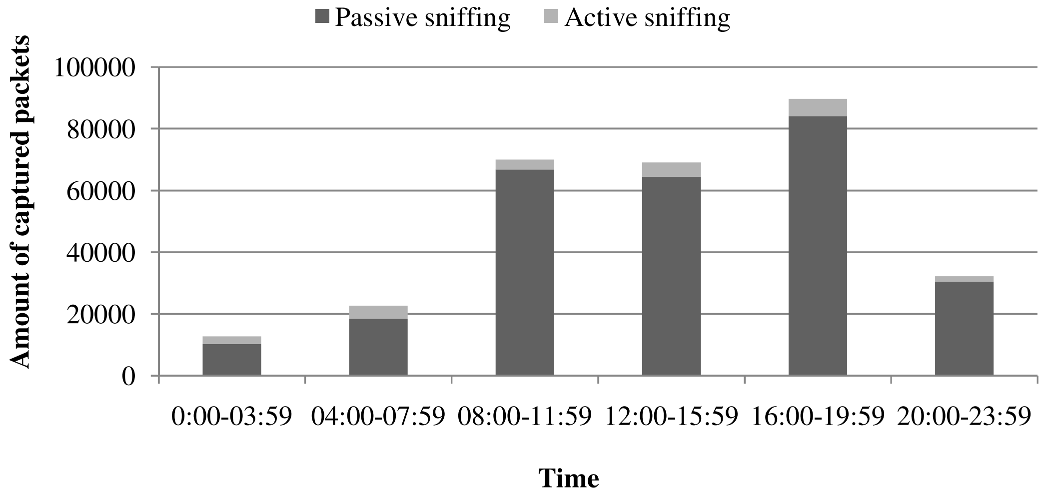


Figure 4: The comparison between passive and active sniffing

Two reasons can explain the few number packets. First, the smart phone does not reply acknowledgment for power saving which is configured by operation system. A further test was carried for different smart phone operation system. The result is presented inTable 2. Based on the result, the Apple phones and Blackberry phone never reply with acknowledgment. Second, the smartphone and sniffing station is not tuned to the same channel, so that the probe response cannot be received by smartphone.

Table 2: The smartphone responses

Brands	Operation System	Sniffing	Packet Injection
HTC Corporation	Android	YES	YES
Apple Inc.	IOS	YES	NO
Sony Mobile	Android	YES	YES
Samsung Corporation	Android	YES	YES
Blackberry	Blackberry OS	YES	NO

3.2 Hopping Time and Scanning Time Selection

During these tests, scanning time was set to 1s, 3s and 5s. Under each scanning time the hopping time was set to 10ms, 50ms, 100ms, 250ms and 500ms and all the 14 channels were selected to scan.

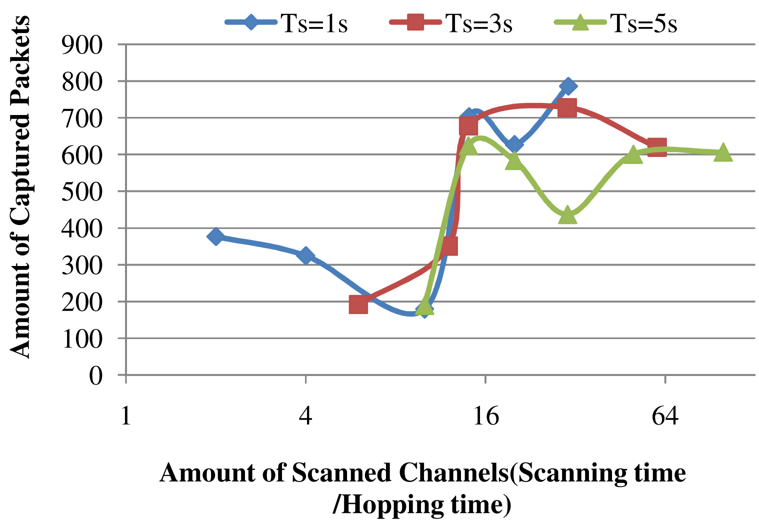


Figure 5: Scanning Time VS. Hopping Time

The result of the tests shows when the ratio between scanning time and hopping time (Eq. 3) is around multiplenumbers of selected channels, the system can capture the highest number of packets.The channel selection for packets transmitting is highly depends on the environment and the connection state. Therefore, it is hard to predict packet distribution on the channels. In this case, the time is evenly allocated to each channel for packets sniffing. This is a balance for the trade-off which is mentioned above.

Table 3: Test parameter selection

Scanning Time (s)	**Hopping Time (ms)**	**Ratio**	**Hopping Time (ms)**	**Ratio**
1	33	30.3	71	14.08
3	100	30	214	14.01
5	166	30.1	357	14.01

The graphs in Figure 5 illustrate test results in Table 3. It shows that when the ratio is around 14, the system captured largest number of packets.

Table4: Parameter selection for fixed test duration

Scanning Time (s)	**Hopping Time (ms)**	**Ratio(*Ts/Th*)**	**Test duration (min)**
1	71	14.08	2
2	142	14.08	4
3	214	14.01	6
4	285	14.03	8
5	357	14.01	10
6	428	14.01	12

Then, follow the parameters in Table 4 to fix the scanning time and hopping time ratio to 14. The corresponding test duration is used to guarantee the number of result output times is same for different setting. The result is shown in Figure 6.

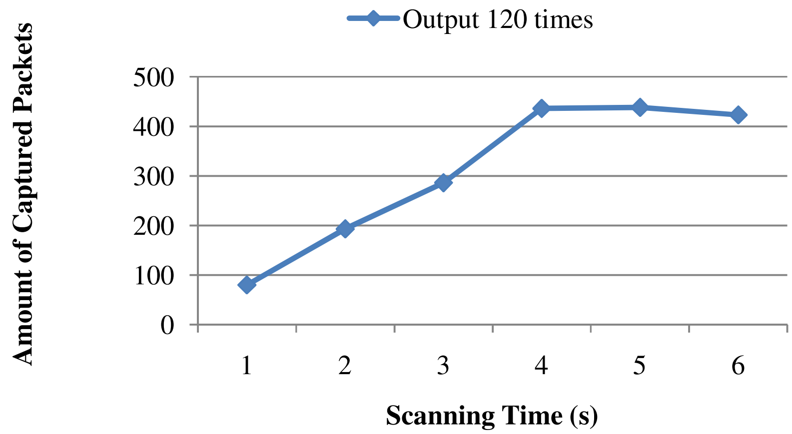


Figure 6: Fixed output amount testing result

In these tests, the scanning time does not affect the results, because the number of output is fixed. In other words, the amount of captured packets isonly affected by hopping time. Figure 6 shows that there is a limitation when hopping time is between 285ms and 357ms. A longer hopping helps sniffing station to capture more packets from one channel but lose packets from other channels. Therefore, there is a balance point between packet capturing and loss. Based on the test result, T_s=4s and T_h=285ms is the best collocation for 14 channels case.

4. RSSI Based Localization Method

Received Signal Strength Indicator (RSSI) is a parameter representing the power of received radio signal. It is measured by wireless end equipment's antenna. . However, there is not a clear relationship between RSSI and received signal power level or received signal strength (RSS).
The wireless end equipment measures the signal power level RSS and then converts this analog result to digital number which is RSSI. During the converting processing, the Analog to Digital Convertor (ADC) decides to choose the reference voltage and converting algorithm. Therefore, the same RSSI value present different RSS in different equipment.

Some related works [8, 9] present that the RSSI approach to the ten times the logarithm of the ratio between the received power (P_r) at the receiving point and the reference power (P_{ref}). Based on propagation mode, the received power is inversely proportional to the square of distance (d). The equations below summarize this relationship:

$$RSSI \propto -10\log\left(\frac{P_r}{P_{ref}}\right) \quad (4)$$

$$RSSI \propto -10\log\left(\frac{1}{d^2 \times P_{ref}}\right) \quad (5)$$

Then, using k and α to represent all uncertain factors in Eq.5, the equation can be simplified to:

$$RSSI = -klog(d) - \alpha \tag{6}$$

Figure 7 demonstrates an ideal relationship between RSSI and distance. A linear curve makes the RSSI-based positioning possible if the factors k and α wasdetermined.

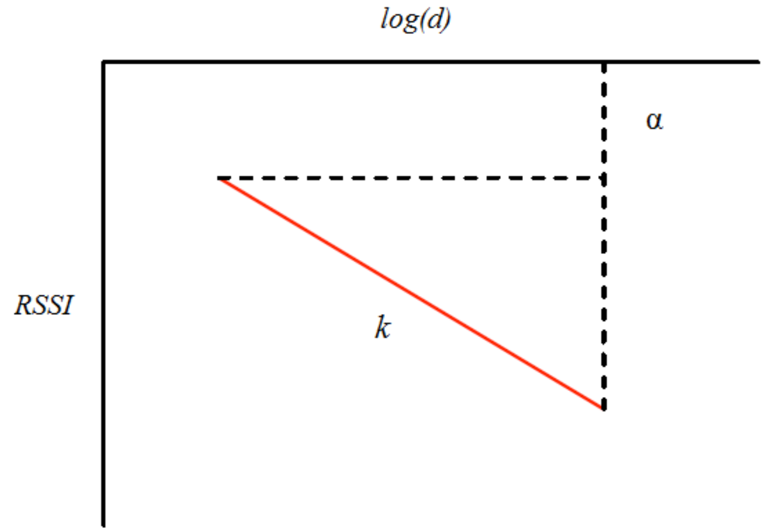


Figure 7: Ideal relationship between RSSI and distance

However, outdoor environment is dynamic and the radio signal is affected by many factors in this kind of environment such as slow fading and fast fading. Therefore, it seems to be hard to find a realistic curve.

Empirical Mode Decomposition (EMD) is an adaptive signal processing method which is highly efficient to analyze complex and non-linear signal. This method decomposes a signal (S_n) into a series of Intrinsic Mode Functions (*IMFs*) and one residue (r_n), which can be represented as the following equation [10]:

$$S_n = \sum_{k=1}^{N} imf_{k,n} + r_n \tag{7}$$

As EMD decomposes signal based on signal's own characteristics, each IMF contains different oscillation feature which is displayed as frequency from original signal. In other words, each IMF has different frequency from each other. Therefore, the noise can be filtered by selecting related IMF to reconstruct signal.

An improved EMD method is called Ensemble Empirical Mode Decomposition (EEMD) which adds white noise into original signal before using EMD to process. Some research works show that when the added white noise distributed evenly it can offset the noise in the signal [11]. The process of EEMD is:

- Add a white noise series to the signal;
- Decompose the data with added white noise into IMFs;
- Repeat step 1 and step 2, but with different white noise series
- Obtain the means of corresponding IMFs of the decompositions as the final result.

The signal strength in wireless system is affected by many factors such as: path loss, shadowing and fading. The shadowing and fading is the natural behaviour of amplitude changes in high frequency and low frequency respectively. In this case, the EMD/EEMD can be applied to remove those signal changes from the received signal and retrieve the distance related data. The process demonstrated in Figure 8.

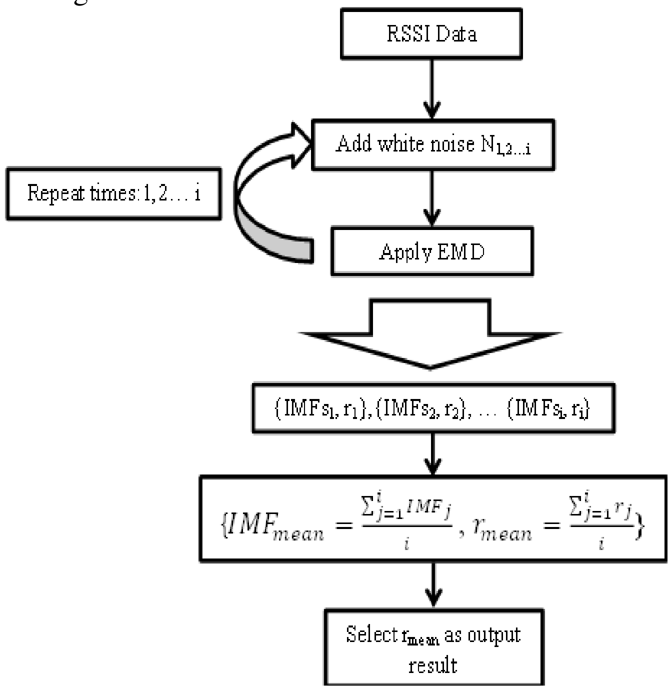


Figure 8 : The data processing using EMD method

5. LOCALIZATION

Two experiments were set up in different outdoor conditions to determine the factors k and α in Eq.6. The first Experiment A was carried out in a street at midnight which is quiet enough to avoid pedestrians' and vehicles' effects with one sniffing stations. During this experiment, 27 points in a straight line with 1m gap were measured and at each distance. 50 signal strengths were collected, and then the EMD/EEMD with i equals to 500 is used to process each point. The result is shown in Figure 9 below.

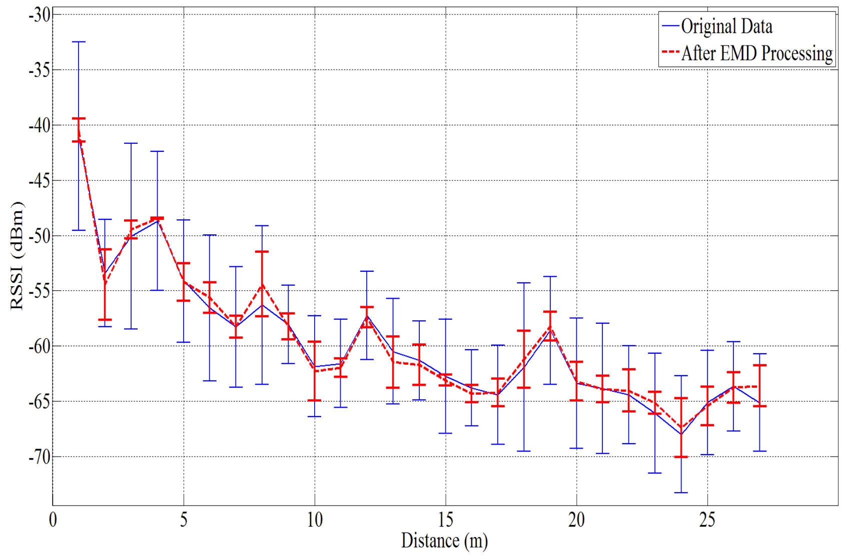


Figure9: Experiment A result

In Figure9 Figure, the solid line connects the mean values of each point's data and the dash line connects the mean value of processed data at each point. It is obviously that, the blue line (data) has a larger error or standard deviation and after using EMD method, the mean value does not change too much but the error is reduced. Besides, the data energy (received signal strength) does not change during adding white noise and keeping the residue only as result. Therefore, the EMD/EEMD method does not distort signal which shows this method not only reduce the oscillation but also increase the accuracy.

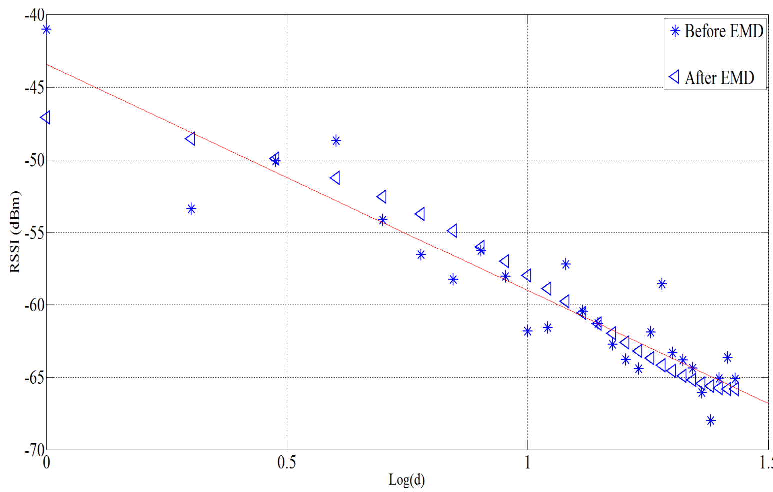


Figure10: RSSI vsLog(d) in Experiment A

Figure 10 demonstrates the relationship between RSSI and logarithm of distance. The star marks present the mean value of original data, the triangle marks are the results of applying EMD/EEMD to the mean value of original data and the line is the optimal fitting line for these data. From the figure, it can be seen that the triangle marks in Figure 10 are closer to the fitting line, which means these data will provide smaller error when calculating the distance. The fitting line shows an equation which is:

$$RSSI = -15.31\log(d) - 41.05 \quad (8)$$

where 15.31 and 41.05 arethe value of factors k and α.

The Experiment B was carried out on the street with high traffic load and high signal interference. And repeat the steps in Experiment A. The result is shown in Figure 11.

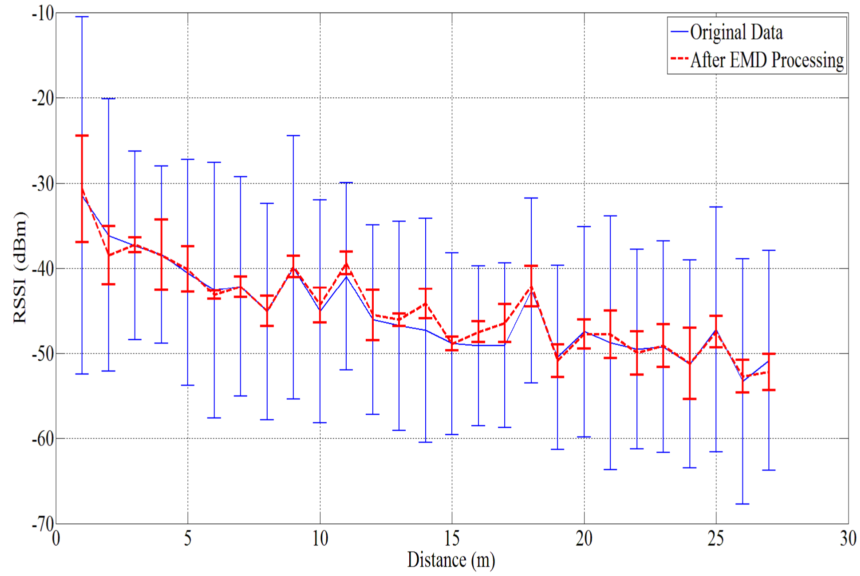


Figure 11: Experiment B result

Due to the dynamic environment condition, a larger standard deviation than Experiment A is shown in Figure 11. However, the standard deviation is reduced significantly after applying EMD/EEMD method.

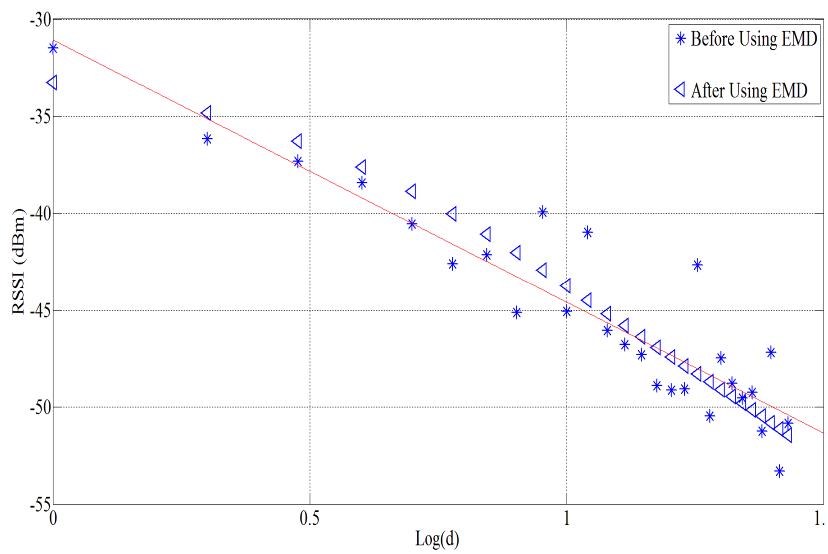


Figure 12: RSSI vsLog(d) in Experiment B

Similar to Experiment A, the line in Figure 12 is the fitting line for these data. It follows the equation below:

$$RSSI = -14.85log(d) - 35.45 \quad (9)$$

where 14.85 and 35.45 arethe value of factors k and α.

Experiment A and B arethe two extreme situations for an urban condition. Hence, the results from these two experiments can be regarded as upper and lower boundary. To obtain the average value of two results and set the factor k to 15.08 and the factor α to 38.45. Therefore, the relationship between RSSI and distance is:

$$RSSI = -15.08\log(d) - 38.45 \quad (10)$$

In order to examine Eq.10, Experiment C was carried out with the setting which is shown in Figure 13. The line is the movement path of mobile device and the points are the sniffing stations' locations.

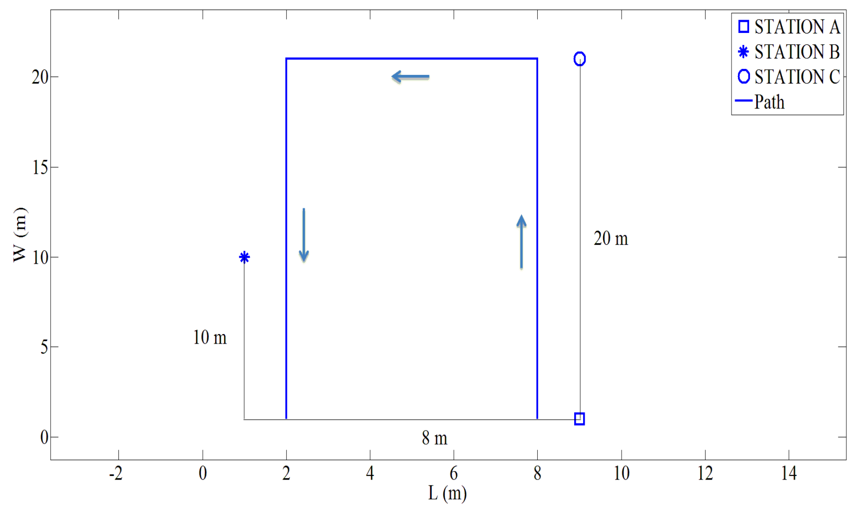


Figure 13: Experiment C set up

Figure 14 presents the collected data in test run C. The points present the original data collected by each station and the lines present the processed data by using EMD/EEMD. The results from station A and station C match with the movement path.

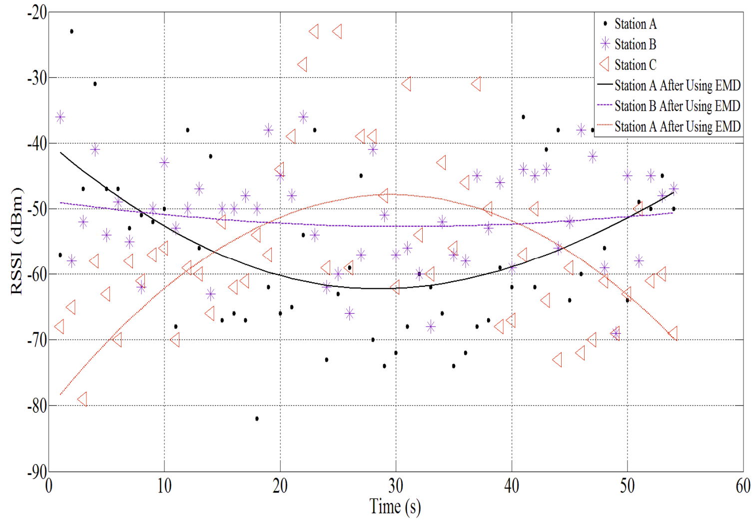


Figure 14: Experiment C result

Then, we use triangulation method to do localization based on the data collected by these three stations.

1. Use the station position as center, calculated distance as the radius to draw a circle.
2. The intersection point of three circles is the location.
3. If there are more than one or no intersection point, the center of the smallest triangle can be constructed as the location.

The result is demonstrated in Figure 15. The dash line presents the reverted path by using Eq.10 and processed data. The solid line is the real path. The movement can be observed by comparing the solid line and dash line.

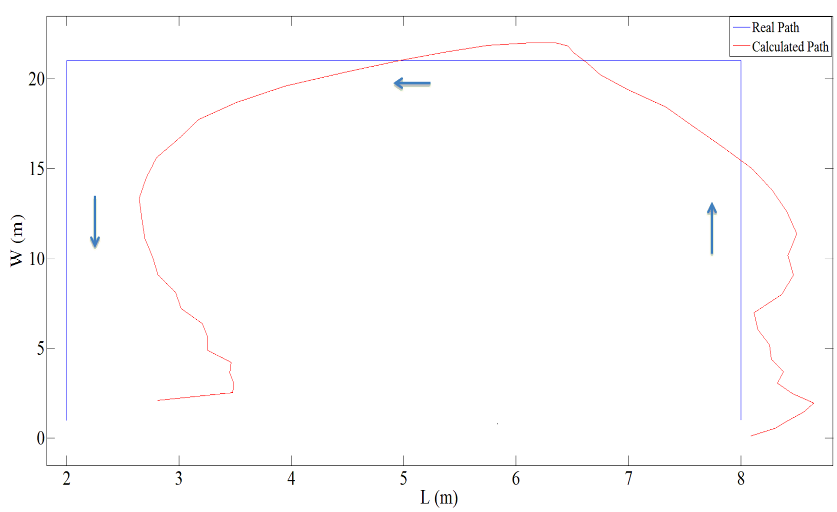


Figure 15: Normalized localization result

The position calculation error is shown in Figure 16 with maximum error of 3.13m and minimum error of 0.08m and average error of 0.998m. This error is caused by the selection of factors k and α, and the environment interference. The selected factor in this paper is an average value for different environment quality in the investigation area. It presents a general relationship between

RSSI and distance. In other hand, some distortion still remains in the RSSI signal after processing.

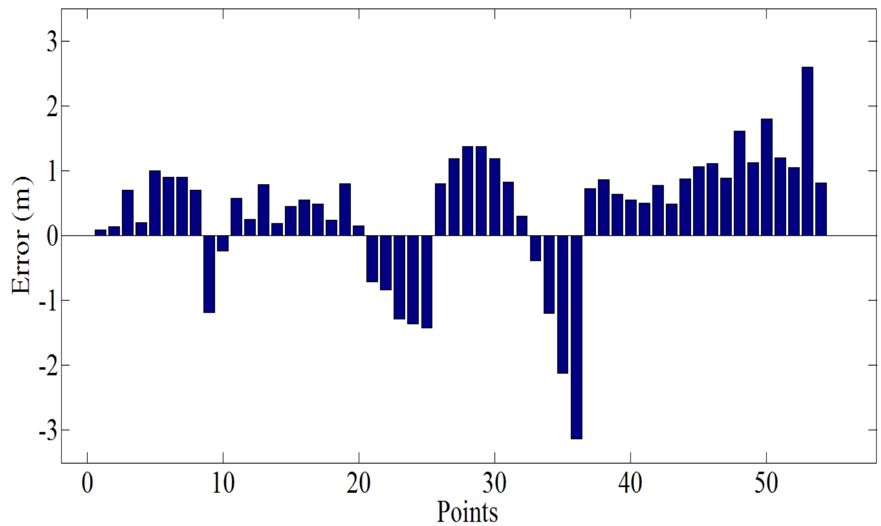


Figure 16: Localization error

6. CONCLUSION

In this paper, an outdoor large-scale mobile tracking system and a data processing method arepresented. A pair of scanning and hopping time is discovered to avoid packet loss and increase measurement accuracy.

After a series of experiments, the EMD/EEMD method has been proved that it is suitable for RSSI based localization, as it can remove the noise effect from original signal. Based on the positioning result, the mobile tracking system can be used to detect the wireless user movement with medium-precision localization with 0.998m average error. In future research thismobile tracking system will be deployed in streets using a mesh network to achieve sniffing station data exchange and centralized data collection.

REFERENCES

[1] L. YanXia, C. Liting, and S. Yuqiu, "Application of WiFi Communication in Mobile Monitor," in *Information Engineering and Electronic Commerce, 2009. IEEC '09. International Symposium on*, 2009, pp. 313-317.

[2] U. Bandara, M. Hasegawa, M. Inoue, H. Morikawa, and T. Aoyama, "Design and implementation of a Bluetooth signal strength based location sensing system," in *Radio and Wireless Conference, 2004 IEEE*, 2004, pp. 319-322.

[3] A.Bensky. Wireless positioning technologies and applications. Artech House, Inc., 2007.

[4] Z. Vasileios, B. Honary, and M. Darnell. "Indoor 802.1 x based location determination and real-time tracking." Wireless, Mobile and Multimedia Networks, 2006 IET International Conference on. IET, 2006.

[5] S. Ronni, and T. Berglund. "Location tracking on smartphone using IEEE802. 11b/g based WLAN infrastructure at ITU of Copenhagen."

[6] Ndoye, Mandoye. "Vehicle detector signature processing and vehicle reidentification for travel time estimation." Transportation Research Board 87th Annual Meeting. No. 08-0497. 2008.

[7] Anagnostopoulos, C-NE. "License plate recognition from still images and video sequences: A survey." Intelligent Transportation Systems, IEEE Transactions on 9.3 (2008): 377-391.

[8] P. AmbiliThottam, M. Iftekhar Husain, and S.Upadhyaya. "Is RSSI a reliable parameter in sensor localization algorithms-an experimental study." Proceedings of the field failure data analysis workshop, Niagara Falls, New York, USA. 2009.

[9] D. Park; J. Park, "An Enhanced Ranging Scheme Using WiFi RSSI Measurements for Ubiquitous Location," Computers, Networks, Systems and Industrial Engineering (CNSI), 2011 First ACIS/JNU International Conference on , vol., no., pp.296,301, 23-25 May 2011

[10] Huang, Norden E. "Applications of Hilbert–Huang transform to non-stationary financial time series analysis." Applied Stochastic Models in Business and Industry 19.3 (2003): 245-268.

[11] Z. Wu and H. Norden E. "Ensemble empirical mode decomposition: a noise-assisted data analysis method." Advances in Adaptive Data Analysis 1.01 (2009): 1-41.

[12] I. J. Q. Binghao Li, Andrew G. Dempster,, "On outdoor positioning with Wi-Fi," *Journal of Global Positioning System,* vol. 7, pp. 18-26, 2008.

[13] S. Saha, K. Chaudhuri, D. Sanghi, and P. Bhagwat, "Location determination of a mobile device using IEEE 802.11b access point signals," in *Wireless Communications and Networking, 2003. WCNC 2003. 2003 IEEE*, 2003, pp. 1987-1992 vol.3.

[14] X. C. Yuan Song, Yoo-Ah Kim, Bing Wang, Hieu Dinha, Guanling Chen, "Sniffer channel selection for monitoring wireless LANs," *Computer Communications,* vol. 35, pp. 1994–2003, 2012.

[15] U. Deshpande, T. Henderson, and D. Kotz, "Channel Sampling Strategies for Monitoring Wireless Networks," in *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, 2006 4th International Symposium on*, 2006, pp. 1-7.

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