Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

An Empirical Study of Accuracy of Mobile Location Positioning in Cellular Networks

Sheung-On Choy, Man-Hok Wong, Kin-Yeung Wong, Chi-In Wong

***Abstract*—Mobile applications that provide location-based services need to retrieve the user's current location. It is well known that the location of a mobile device can be determined by using GPS. In addition to GPS, the use of network-based location estimation methods in today's mobile devices is common. This paper aims to study the accuracy of the network-based location estimation methods in cellular networks. An empirical study is carried out to find out the major factors that affect the accuracy of location estimation. Firstly, a number of measurement tools are developed and identified for the collection of location information of a mobile device. The information includes the actual location and those locations that are estimated by different external location providers. Secondly, a number of experiments are designed to collect location information in different situations and conditions. Thirdly, data are processed and analyzed to identify the major factors that affect the accuracy. Our experiment results show that the performance of location positioning in cellular networks in the urban area is better than that in the suburban and open areas.**

Keywords—Cellular, GPS, Positioning, Location Services

I. Introduction

The demand for mobile services is rising dramatically in recent years. Mobile phones play an important role in enhancing the living quality in human's daily life. Today, there are numerous mobile applications providing location-based services, which commonly require the retrieval of the user's current location.

There are two types of location providers for mobile phones.

GPS location provider: it determines device's location with the built-in GPS component.

Sheung-On Choy, Kin-Yeung Wong
Engineering Science Team, the Open University of Hong Kong
Hong Kong

Man-Hok Wong
Macao Polytechnic Institute
Macao

Chi-In Wong
Department of Electronic Engineering, City University of Hong Kong
Hong Kong

Network location provider: it determines device's location based on the signals and information of cellular towers and Wi-Fi access points. Results are retrieved by means of a network lookup.

In terms of location positioning, GPS is the most popular and widely applicable technique because its accuracy can fulfill the requirements of various kinds of applications (e.g., military, navigation and emergency). However, GPS cannot be used in the indoor environment and in the areas surrounded by tall buildings because the satellite signals will be reflected or blocked. On the other hand, the problem of Wi-Fi positioning is that the distribution of Access Points is very extreme (e.g. the coverage density of APs in rural areas is much lower than that in urban areas). For these reasons, the limitations of GPS and Wi-Fi based positioning lead to the development of cellular positioning techniques. Cellular positioning provides advantages of wide coverage and short latency of location estimation over GPS. However, its accuracy in terms of location estimation is commonly low. Thus, positioning based on only cellular signals is not suitable for the applications with higher requirement of location accuracy.

The main purpose of this study is to examine the accuracy of the network-based location estimation methods in cellular networks. This study is intended to:

Investigate the level of inaccuracy of network-based location estimation methods in cellular networks by recording data in different situations.

Determine what factors influence the accuracy of location estimation by an empirical study.

Make feasible suggestions on what the positioning method should be used for the location-based services in certain situations.

In this study, we wrote a mobile app using Android SDK to test the accuracy of different positioning technologies. The experiment was conducted in different areas of Macao from Dec 2013 to Feb 2014.

The organization of this paper is as follows. Section II provides a general overview of background information including the principle of mobile positioning technologies and some Wi-Fi positioning databases. Section III describes the design of a tool in Android in order to collect the location information and the approach to calculate the distance between the two locations. Section IV describes the experiment of collecting the location information using different methods. The results are shown in Section V. Section VI summarizes this paper and discuss on future work.

Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

TABLE I. CHARACTERISTICS OF GPS

Number of the space segment consists of satellites	24
Go around the Earth once (one orbit)	Around 12 hours
Incline	55 degrees with respect to the equatorial plane
Altitude	20200km above the earth

II. Background

In general, there are two main methods for determining mobile locations. They are handset-based and network-based. Handset-based methods use the internal GPS component of the mobile phone to collect the signals from the GPS satellites to identify a position. As GPS does not work indoors and consume much battery power, network-based location estimation methods become a promising alternative. They determine location based on wireless LAN or cellular network.

A. *Handset-based Positioning Technology*

Global Positioning System (GPS) is a satellite-based navigation system that was developed for the military purpose initially and is maintained by the United State Department of Defense. Since 1993, people can use GPS to determine location via satellites. Table I lists some characteristics of GPS and more information can be seen in [1-2].

Today, even lower-end smart phones are equipped with a GPS receiver. When users turn on the GPS function of a mobile phone, the GPS receiver receives the "Navigation Message" from four GPS satellites. Based on the messages, the phone can calculate the coordinates (X, Y, and Z) and estimates its location.

B. *Network-based Positioning Technologies*

1) Cellular based positioning

Mobile devices are connected to a mobile communication network, such as GSM. The radio frequency used in each cell tower will be different among the adjacent towers to avoid co-channel interference.

In a cellular network, each cell tower has its own cell ID. Cellular based positioning method determines locations based on Cell ID and signal strength from the cell towers in a cellular network. Location estimation in cellular networks was originally to support the 911 emergency services in America. It performs the position estimation via location parameters, which include:

Signal strength

Cell ID

Mobile Country Code

Mobile Network Code

Location Area Code

Figure 1. Simplified view of how cellular based positioning works

The Time of Difference of Arrival (TDOA) and the Enhanced Observed Time Difference (E-OTD) are two well-known methods [3] that mobile devices can retrieve the users' location in cellular network.

The TDOA positioning method requires at least three synchronized cell towers so as to estimate the time difference it takes to receive a signal from the mobile user. The E-OTD method is an improvement of the TDOA method. It estimates the time intervals of the radio signals between a cell tower and the mobile device and a known fixed spot (called location measurement unit). Three location measurement units are needed to determine the position. The mobile device actively participates in the positioning process in contrast to TDOA. E-OTD only works with mobile devices that include E-OTD technology.

Fig.1 illustrates the cellular-positioning operations. In the figure, mobile device A collects the parameters broadcasted from the cell towers (C1-C3). After that it sends these collected parameters to a location server, such as Google's location server. Based on the parameters, the server then estimates the location and sends it (latitude and longitude) back to the mobile device.

2) Wi-Fi based positioning

Wi-Fi based positioning method determines position based on Wi-Fi ID and the Wi-Fi signal. As shown in Fig. 2, when Wi-Fi is turned on, mobile devices will automatically scan for access points and send the Wi-Fi Access Points' Service Set Identifier (SSID) and Media Access Control (MAC address) data to Wi-Fi Positioning database which contains the information of Access Points. Afterwards, it compares these data in location database of mapped access points. Eventually, it uses this information to estimate the location.

There are many companies manage Wi-Fi positioning database, like Google and Apple. Wi-Fi positioning databases contain the MAC address of the access points, GPS coordinates and RSSI value [4]. In 2007, Google launched the Google street view project which was not only for making maps, but also for collecting the data of the Wi-Fi networks (e.g., SSID). Furthermore, Google uses crowd sourcing data to keep the database update. That is, Location Manager in Android phones will send the data of its known SSIDs and MACs to Google. These data would then be used by Google to update the database.

Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

Figure 2. Structure of Wi-Fi positioning system

3) Comparison of Different Positioning Technologies

Table II summarizes the performance and limitations among different technologies in determining the location of a mobile device.

TABLE II. COMPARISON OF DIFFERENT POSITION TECHNOLOGIES

	GPS	Cellular	Wi-Fi
	Performance		
Accuracy	High	Low	Medium
Latency	Slow	Fast	Fast
Extra power consumption	High	Low	Low
	Limitation		
The situation that it may not work	Indoor, around tall buildings	Areas without cellular network coverage	No Wi-Fi Access Point nearby.

III. Design Approach

In order to find out the factors that may affect the accuracy of cellular positioning method, we have the following methodology:

Develop a tool to record the estimated location of mobile device.

Obtain the actual location information of a selected location. Measure the accuracy of mobile location estimation in cellular networks (by comparing the estimated and the actual locations)

Analyze the collected data and find out the level of inaccuracy in different places

Find out the factors that affects the accuracy

A. Develop Tools for Recording Location Information

In order to find out the factors that affect the accuracy of cellular positioning method, a mobile app is developed to record the location and accuracy as given by the location providers of the phone.

The mobile app was developed by Android SDK. Developers can set up the criteria for switching the location providers by using the Android API. In this criterion, users can switch provider which is either GPS_Provideror or Network_Provider at any time, and switch out a fine provider with a coarse one to save battery life, for example. There is no limit to how often you can switch out providers. Users can also do this when a provider is unavailable, via a call to the registered location listener.

Users can get the location information using the Android API by the following steps:

A reference is acquired to the system Location Manager.

The app looks up the provider which is GPS_Provider or Network_Provider

Pass the parameters to the Location Listener and implement the callback methods in Location Listerner.

With RequestLocationUpdates, the mobile begins to locate user's position and return it to Location Manager.

B. Select Places for Experiments

In this study, we examined the accuracy of different positioning methods for different places in Macao. Three types of areas were examined: 1) urban area, 2) suburban area and 3) open area. And the places chosen to be examined in each area are shown in Table III.

C. Obtain the Actual Location Information

In order to evaluate the performance of location estimation in cellular networks, the actual coordinates of the places in the experiment have to be confirmed first. The latitudes and longitude of a location can be obtained in Google Map.

D. Measure the Accuracy of Location Estimation

When comparing the latitudes and longitudes as given by mobile and Google Map, the following formula can be applied for calculating the distance between the two latitude and longitude (lat/long) points [5].

TABLE III. PLACES IN MACAO WERE EXAMINED IN THE EXPERIMENT

Urban Area	Suburban Area	Open Area
China Civil Plaza	Seac Pai Van Park	Macao Tower
Macao Polytechnic Institute	Cheoc Van Park	Macau Fisherman's Wharf
Kam Pek Casino	Hac Sa Park	A-Ma temple
Three Lamps Square	Hac Sa Reservoir	MGM Macau
Ha Wan Street	Ka Ho BBQ Pavilion	StarWorld Hotel
Chun Pek Building		Ponte 16
Hoi Pan Building		Kun Iam Ecumenical Centre
		Lotus Square

Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

distance = acos(cos(rad(90-Lat1)) * cos(rad(90-Lat2)) + sin(RAD(90-Lat1)) * sin(rad(90-Lat2)) * cos(rad(Long1-Long2))) * 6371000

IV. Experiment

In order to find out what factors that would affect the accuracy, the experiments in different areas were performed. In each experiment, time and the information about the base station were also recorded down for later analysis.

For the study purpose, three different types of areas were selected in the experiment, namely, urban area, suburban area and open area. In the first part of experiment, the mobile app will be run to record the location information as estimated by the network-based location provider.

When we arrived at a place (e.g., Macao Tower), we conducted the following actions:

Switch on 3G, and then switch off the GPS and Wi-Fi functions of the mobile phone.

Switch on GPS, and then switch off the 3G and Wi-Fi capabilities

Switch on GPS, 3G and Wi-Fi capabilities

In the second part, we launched the RF Signal Tracker [6] to check what cell tower that the mobile phone was registering in. Normally, a mobile phone must register to enjoy the service from the nearest cell tower and each cell size is different. As shown in Fig. 3, it indicates that the Cell ID of the cell tower that the mobile was registered in is 20077. In this part of experiment, we can analyze whether the distance from the cell tower to the mobile phone is a factor to impact the location estimation.

Figure 3. The Serving Cell is shown in the Map

V. Results

A. *The Result of the Experiment*

Table IV lists the data of the estimated locations and the actual locations in urban, subur ban and open areas, respectively. The accuracy for the location estimations is also provided. As shown in the table, it is observed that the estimation errors in suburban area range from 162m to 645m. The average inaccuracy is nearly 400m. For urban area, the estimation errors range from 32m to 384m. The average inaccuracy is around 150m. Lastly, for open area, the estimation errors range from 96m to 633m, and the average value is around 250m.

Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

TABLE IV. LOCATION INFORMATION AND ACCURACY IN DIFFERENT AREAS

	Estimation		**Actual**		**Error (meter)**
	Latitude	***Longitude***	***Latitude***	***Longitude***	
Suburban Area					
Seac Pai Van Park	22.1297209	113.5569169	22.126693	113557997	354.596788
Cheoc Van Park	22.1149113	113.5602165	22.114358	113.562668	259.9265699
Hac Sa Park	22.1242327	113.5720605	22.118866	113.569351	658.7940319
Hac Sa Reservoir	22.1225111	113.5703394	22.12384	113.570983	161.9575593
Ka Ho BBQ Pavilion	22.1313939	113.5694418	22.129326	113.575296	645.3544029
				Average	416.1250486
Urban Area					
China Civil Plaza	22.1859377	113.548448	22.189086	113.549988	384.3096246
Three Lamps Square	22.2026608	113.5463735	22.202949	113.546088	43.48409739
Macao Polytechnic Institute	22.1944534	113.5519694	22.193341	113.551814	124.7237385
Kam Pek Casino	22.1951934	113.5384441	22.195621	113.53729	127.9809509
Ha Wan Street	22.189723	113.5356941	22.189258	113.546221	160.2413623
Chun Pek Building	22.211762	113.5502281	22.212949	113.549859	137.348641
Hoi Pan Building	22.2067954	113.5541519	22.206895	113.554451	32.72253229
				Average	144.4015639
Open Area					
Kun Iam Ecumenical Centre	22.1864511	113.5490548	22.186531	113.55183	285.8782736
MGM Macau	22.1818645	113.5457199	22.185182	113.548464	464.6615409
Macao Tower	22.1815712	113.5391742	22.180322	113.537949	187.6415797
A-Ma Temple	22.1815294	113.5319529	22.186918	113.530976	632.8149765
StarWorld Hotel	22.1874599	113.5466168	22.189586	113.547705	261.6175674
Lotus Square	22.1934359	113.5537819	22.19423	113.554156	96.33463174
Macau Fishermen's Wharf	22.1945047	113.5548424	22.19462	113.555177	47.27758775
Ponte 16	22.1948616	113.5377782	22.197289	113.536399	304.986231
				Average	285.1515486

B. *The Result of Level of Inaccuracy*

Fig. 4 shows the comparison of average accuracy for the three different areas. The average accuracy in urban areas is around 150 meters in Macao which is more accurate than suburban areas and open areas.

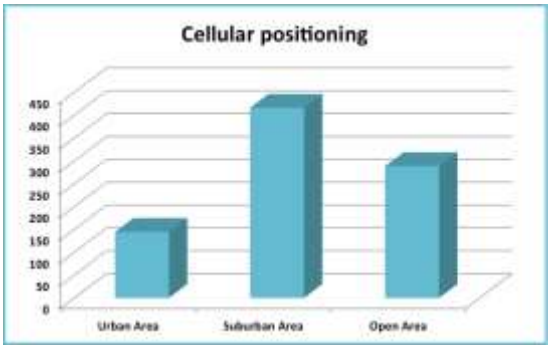

Figure 4. Average accuracy of different areas with cellular positioning

VI. Discussion and Conclusion

In this study, a number of experiments were performed and the level of inaccuracy was evaluated under the cellular based positioning method in Macao. It was found that using location based services by cellular positioning in urban areas is much more accurate than suburban areas and open areas since the density of the cell towers are extremely high in urban areas. That is, the processes of location estimation required the parameters as given by the mobile which is collected from cell towers. More signals it can collect, more accurate results will be returned. Moreover, the distance between the mobile and cell tower also influences the accuracy. Furthermore, multipath propagation is also one possible factor that impacts the accuracy. Reliable location-based services are now getting more and more important. Therefore, it is recommended to use pure cellular positioning in urban areas if the services require certain extent of accuracy. Otherwise, use GPS or Wi-Fi to assist the cellular positioning in suburban areas and open areas.

Proc. of the Intl. Conf. on Advances In Computer and Electronics Technology- ACET 2014.

ISBN: 978-1-63248-024-8 doi: 10.15224/ 978-1-63248-024-8-03

For the future work of this study, various approaches would be used to evaluate more factors. That is, performing the experiment between peak hours and normal hours. Furthermore, compare and measure the situation that the level of accuracy cell towers switching and non-switching. In addition, the study could be extended to be conducted in other cities.

References

[1] G. Blewitt, "Basics of the GPS Technique: Observation Equations," in Geodetic Applications of GPS, 1997.

[2] Global Positioning System. (1998). Retrieved 08 October, 2013, from http://www.phy.syr.edu/courses/PHY312.03Spring/GPS/GPS.html, access on 17 October, 2013.

[3] M. Samiei, M. Mehrjoo and B. Pirzade, "Advances of Positioning Methods in Cellular Networks," 1st International Conference on Communication Engineering, 2010, pp. 174-178.

[4] WiFi Positioning Databases , url: http://wlanbook.co m/wifi-positioning-databases/, Retrieved 18 October, 2013.

[5] Excel formula to calculate distance between 2 latitude, longitude (lat/lon) points (GPS positions), url: http://bluemm.blogspot.hk/2007/01/excel-formula-to-calculate-distance.html, Access on February 5, 2014.

[6] RF Signal Tracker on Google Play App Store, url: https://play.google.com/store/apps/details?id=com.hotrod.utility.rfsignaltrackereclair&hl=en, Access on February 5, 2014.

About Authors:

Sheung-On Choy received his B.Eng. and Ph.D degrees in electronic and information engineering from the Hong Kong Polytechnic University. Choy is currently an Assistant Professor in the Open University of Hong Kong. His research interests include Internet computing, Web technologies, and location-based services.

Man-Hok Wong received his B.Sc. degree in Computing from Macao Polytechnic Institute. He is currently an IT staff of Macau Millennium College. His research interests include location-based services and information systems.

Kin-Yeung Wong received his B.Sc. and Ph.D degrees in information technology from City University of Hong Kong. Wong is currently an Associate Professor in the Open University of Hong Kong. His research interests include Internet systems, network infrastructure security, and mobile computing. He is also an active industry consultant in the areas of computer networking and communication systems.

Kaze Chi-In Wong received his B.Sc. degree from Macao Polytechnic Institute. He is currently pursuing an MSc degree in Electronic and Information Engineering at City University of Hong Kong. He has finished a number of large-scale government-funded projects of Internet security. His research interests include network security, complex networks, queuing systems, Internet computing and mobile computing.