Positioning a Mobile Subscriber in a Cellular Network System based on Signal Strength

Syed Asad Hussain, Muhammad Emran, Muhammad Salman, Usman Shakeel, Muhammad Naeem, Sharjeel Ahmed, Muhammad Azeem
Department of Computer Science
COMSATS Institute of Information Technology, Lahore, Pakistan
Ph: 0092-42-9203101 Ext: 261, Fax: 0092-42-9203100
asadhussain@ciitlahore.edu.pk, memran@ciitlahore.edu.pk, ms.salman@gmail.com, usman.s@gmail.com, naimaziz@gmail.com, sharjee@gmail.com, aazeemm@gmail.com

ABSTRACT

In this paper the study has been carried out for finding the position of a mobile subscriber from a network independent brokers' point of view. As each mobile device monitors signal strength, this helps in assisting the network to take timely handoff decisions. These signal strength measurements are referred to as NMR (Network Measurement Report). A detailed study was conducted to analyze the use of such parameters to locate a user under the coverage area of a BTS used in a cellular network. Use of these parameters implies that such a system work in a network independent manner. This paper discusses the issues in the implementation of such a system and includes the statistics collected using the simulation tool OPNET [1].

KEYWORDS

Positioning, Signal Strength, Network Measurement Report (NMR), Finger Printing, Multipath, Base Transceiver Station (BTS)

1. INTRODUCTION

In positioning a mobile subscriber (Location Tracking), a mobile user is provided with information pertaining to its current position. It is one of the popular areas of wireless computing research. Researchers paid attention to Positioning Systems after the Federal Communications Commission (FCC), mandated that all wireless carriers in the United States must provide a certain degree of accuracy in pinpointing location of mobile users who dial 911. The regulation was passed in 1996 and still most wireless carriers haven't implemented such a system [2]. The main reason behind this is the cost associated with the implementation of such a system. According to an estimate, a precise GSM based position system incurs a high cost (approx. U.S. $ 10,000) per base station.

The services offered by positioning system include navigation and routing (e.g. plotting a path for the user from point A to point B), finding point of interest which is also called POI (finding a certain business or a building within the user's vicinity), and geo-coding which means mapping the user to an actual geographic location. More sophisticated systems include assets management i.e. tracking a parcel or delivery truck and travel guides etc. The system in view here is an entry level system that handles proximity services and offers a geo-location to the users' based on signal strength. The system offers following facilities to the user:

(a) His/her current location,
(b) Direction (angle / bearing) from point A to point B,
(c) Distance (in kilometers) between point A and point B.

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2. RELATED WORK

So far the research includes facility location algorithms, which involve locating large scale wireless networks (WiMAX) and use of approximated radio maps algorithms [3]. A GPS receiver provides location estimation based on the time of arrival of four or more L-band signals from a network of 24 satellites. Commercial GPS receivers costing $150, accurately determine position within approximately 50 meters. The size and cost of GPS receivers will improve as the number of commercial GPS units increases [4]. Wireless service providers appear unwilling to adopt GPS as the principal location technology within the handset or car phone. This resistance may be attributed to cost, size, complexity, and power consumption associated with integrating a GPS receiver into a handset and to the vulnerability to radio frequency interference. Furthermore, reliability of GPS measurements is greatly reduced in urban environments, when satellite communication is masked by buildings, or when the mobile antenna is located inside a vehicle.

It is possible to locate the position of a mobile station by measuring the Time of Arrival (TOA) or angle of arrival (AOA) of a signal at multiple locations [2].

The transmitting mobile stations location is estimated by combining measurement from multiple base stations through triangulation method. An array of antenna elements is used for this purpose. The property of radio waves to travel at constant speed of light helps to use time of arrival (TOA) of a signal at multiple base stations for locating (pinpoint) a mobile station. In practice time difference of arrival (TDOA) measurements is utilized to eliminate need for accurate time deference at the mobile station.

Even though both AOA and TDOA appear to be technically viable solution, cost plays an important role in deployment AOA needs deployment, exact calibration and calibration maintenance of an antenna array at each base station. TDOA on the other-hand needs only time synchronization between each base station which can be achieved fairly economically using a GPS time reference.

An arrangement of both AOA and TDOA measurements may provide greater precision particularly in challenging environments. Moreover, few base stations are needed when both kinds of measurements are available [2].

3. THE METHOD

During the course of project, different techniques were studied that have been used in the past; in an effort to find a suitable method that would work, keeping in mind the technological and monetary constraints. One of the most renowned telecommunication companies of Pakistan was approached, in an effort to find out the details of the equipment they had used to set up the network. It was observed that most telecommunication companies currently in Pakistan have purchased only minimal equipment that is necessary to provide basic services of GSM to its users. Network providers in Pakistan were also reluctant to implement a location based system mainly due to their concerns regarding privacy of users' information. This motivated the team to search for a solution that makes use of the existing network parameters without incurring any additional cost of equipment to network providers. The proper hardware based solution is very costly as discussed earlier.

The proposed system is a handset based technique that uses Network Measurement Report (NMR). NMR contains cell information such as serving cell ID, signal strengths monitored by the handset and the Timing

Advance (TA) parameters (figure 1). The mobile device regularly forwards the NMR to the serving cell to assist the network to make handoff decisions. If the NMR can be retrieved, then on the basis of cell id's and received signal strengths from 3 or more BTS, it is possible to triangulate users' location. This can be done by approximating the user's distance from 3 or more locations on the basis of the signal strength received. [5]

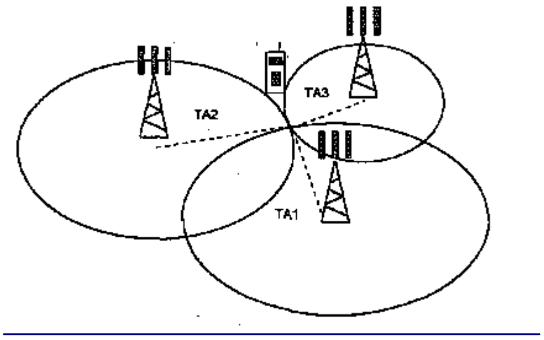

Figure 1: Triangulating a mobile device using Timing Advance [5]

Many researchers have tried to find a suitable relation between signal strength and distance. The main problem with signal strength is that it varies greatly according to terrain and changes drastically when a mobile device is present indoor due to multipath propagation[1]. There is no universal relation that can be used to calculate signal strengths for every location on the earth. For each location, site specific relations must be formulated. Okumara-Hata models [6, 7] are the most famous models for distance calculations using signal strengths but it is valid only for Japanese terrain.

Recently, signal fingerprinting has been adopted as another technique for locating a mobile device. This method implies that the received signal is extremely site-specific because of its dependence on the terrain and intervening obstacles. So the multipath structure of the channel is unique to every location and can be considered as a fingerprint or signature of the location if same RF signal is transmitted from that location. This property has been exploited in propriety systems to develop a *"signature database"* [3] of a location grid in specific service areas.

The received signal is measured along this grid and recorded in the signature database. When a mobile device moves in the same area, the signal received from it is compared with the entry in the database, and thus its location is determined. Such a scheme may also be useful for indoor applications where the multipath structure in an area can be exploited. A variation of this finger printing method was used for this project. Instead of a signature database, we used a constant '*k*' as a signature and derived different values of *k* at different locations using a GPS/OPNET.

More than 40 values of '*k*' are calculated for a desired area and an average is computed. This value is then stored in a database along with its corresponding calculated signal strength. The value of '*k*' remains constant as long as the network parameters are unchanged. A change in network parameters inevitably ensures a change in the values of '*k*', which must then be computed again. This is the drawback of finger-printing method, it requires that the covered area be continually monitored and the signature database be continually updated.

4. TRIANGULAING A MOBILE USER

Triangulating a mobile device involves three steps. The first step is to retrieve the signal strength values from the related BTS. The second step involves approximating the distances from the corresponding BTS with the help of the received signal strength. The final step is geo-coding which involves finding the

[1] Multipath means that a reflected wave reaches the mobile first before the actual wave one.

actual geographic location of the mobile device. This section discusses the last part.

Triangulation is defined as a process by which the location of a radio transmitter can be determined by measuring either the radial distance, or the direction, of the received signal from two or three different BTS points. Triangulation is used in cellular communications to pinpoint the geographic position of a mobile user.

An example of triangulation is now given to clarify the concepts. An object A sends out a RF signal. Three base stations pick up the signal, calculate the signal strengths and use calibrated data to calculate the approximate distance based on signal strength. A server then aggregates the values to triangulate the precise position of the object A. This is one way of triangulation, the other method involves three objects sending a signal and that signal is received at a single station.

To triangulate, one must know the trigonometric and the geographic formulas and their relationships so that one can perform transformation between these coordinates axis.

Intersection of two circles

The triangulation mechanism is an extension of the two circle intersection problem. The two circle intersection seems simple enough at first glance but in fact it is not. The major problem in two circle intersection is that both the circle can intersect at 2 points, at 1 point or do not intersect at all. A comprehensive solution is required that accounts for all the above mentioned scenarios. Let (a, b) and (c, d) be the centers of circles with radii r and s. These circles can be defined by the following equations:

$$(x-a)^2 + (y-b)^2 = r^2 \quad (1)$$

$$(x-c)^2 + (y-d)^2 = s^2 \quad (2)$$

These equations are in 2nd degree power, and hence difficult to be solved through programming techniques. In order to solve them, these equations must first be converted to linear form. Among many solutions, one of the most convenient solutions involves translation and rotation of the axis to find the intersection points. This algorithm is discussed as follows:

The points of intersections (x1, y1) and (x2, y2) of the two circles are calculated as follows:

$$e = c - a$$

$$f = d - b$$

$$p = \sqrt{e^2 + f^2}$$

$$k = \frac{p^2 + r^2 - s^2}{2p}$$

So now points are:

$$x1 = a + \frac{ek}{p} + \frac{f}{p} * \sqrt{r^2 - k^2} \quad (3)$$

$$y1 = b + \frac{fk}{p} + \frac{e}{p} * \sqrt{r^2 - k^2} \quad (4)$$

and

$$x2 = a + \frac{ek}{p} - \frac{f}{p} * \sqrt{r^2 - k^2} \quad (5)$$

$$y2 = b + \frac{fk}{p} - \frac{e}{p} * \sqrt{r^2 - k^2} \quad (6)$$

The three circle intersection is merely an extension of this problem and involves finding the intersection points of three circles and determining the most suitable point which is known as the epicenter.

5. ANALYSIS OF THE RESULTS

The general relationship between the received signal strength and distance is given below in figure 2.

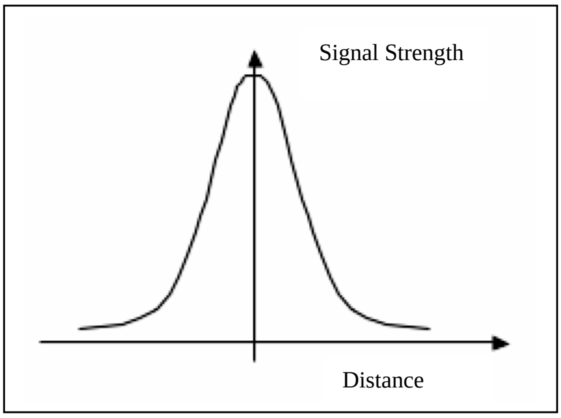

Figure 2- Relationship between distance and RX Levels [8]

We use the following equation [8] to calculate the value of '*k*'

$$k = v_i d_i^{\,2} \quad (7)$$

where k is a finger printing constant, v_i is the velocity of the signal and d is the distance between the sender and the receiver [8].

We use the above equation to determine values of k for different areas around the base stations. Generally the signal strengths around base stations follow the pattern shown in the figure 3.

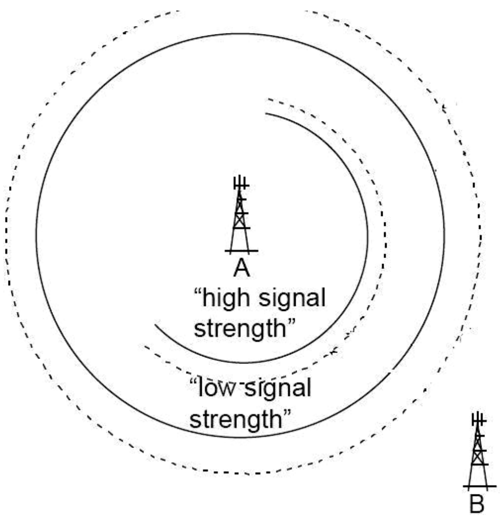

Figure 3: The signal strength value pattern

We found values of '*k*' which were effective for our terrain. Comparison of value of '*k*' with signal strengths and distances are given below in excel graphs of figure 4 & 5.

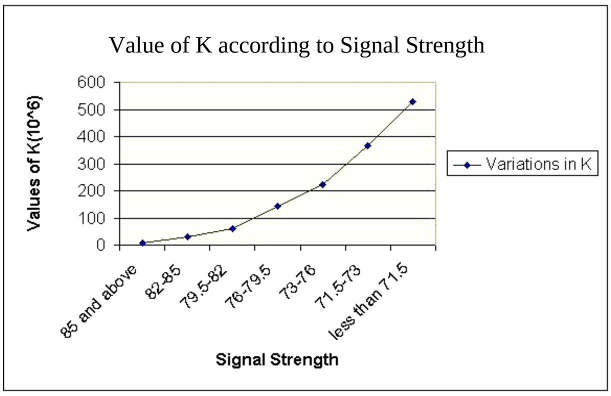

Figure 4: Comparison of value of k with signal strength

Figure 4 clearly shows that the values of '*k*' increase exponentially with the decrease in signal strength. However, the signal strength and distance variation is not that drastic.

Using these values of '*k*', the comparison between the distances and signal strengths is given below in figure 5.

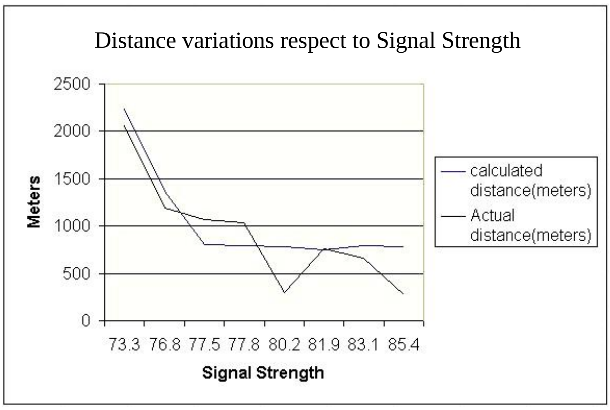

Figure 5: Comparison of distance with signal strength

6. CONCLUSION

We have presented an approach to approximate the location or position of a mobile user based upon signal strength of a mobile device by using different values of ‘*k*’. In addition we have shown that this approach provides better results in terms of accuracy as compared to signature database approach, which requires that the covered area be continuously monitored and the signature database be continuously updated.

Future research includes the provision of Location Based Services (LBS) in a region after approximating the location of cellular device.

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