Localization in WiMAX Networks Based on Signal Strength Observations

Applications in Location-based Services

Mussa Bshara, Nico Deblauwe, Leo Van Biesen
Department of Electricity and Instrumentation
Vrije Universiteit Brussel
Brussels, Belgium
{mbshara, ndeblauw, lvbiesen}@vub.ac.be

***Abstract*— Wireless operators have realized the value and potential to provide location-based services (LBS) to their customers in a convenient and seamless way without imposing extra hardware or extra fees. Recently, localization in wireless networks has gained a lot of interest and the researchers are continuously seeking new methods and techniques aiming at improving the localization accuracy which plays the main role in improving the quality of service as well as providing new services. WiMAX is a promising wireless technology which started to be widely adopted and, it provides high data rates, i.e. new services are in the horizon.**

In this paper, we consider the problem of positioning in WiMAX networks depending on the received signal strength (RSS) observations to support LBS.

***Keywords*- GPS, GSM, mesh networks, navigation, LBS, positioning, path loss model, received signal strength, timing adjust, timing advance, WiMAX.**

I. Introduction

There are several ways to know a wireless network user's location. Global Positioning System (GPS) is the most popular way, it provides an accuracy which allows providing LBS with excellent quality of service including navigation and mapping; the main problem with GPS -despite that the user's terminal must be GPS enabled- is the battery high consumption which means that the user can use GPS and profits LBS for a short period of time. Also GPS performs poorly in urban areas near the high rising and inside tunnels, i.e. it has a poor performance when it is needed the most. Another way to know where a user is located is to depend on the wireless network itself by using the available information like Cell-ID, the only disadvantage of using Cell-ID is the poor accuracy, but still useful for a bunch of services [4]. One can also make measurements on the network to obtain localization; from now on we will refer to these measurements as network measurements regardless where these measurements have been conducted, in the network itself (network side), in the user terminal (terminal side) or both. Many localization approaches depending on network measurements have been proposed in GSM networks and sensor networks; most of the work focused on range measurements depending on time of arrival (TOA) and time-difference of arrival (TDOA) observations and RSS observations, surveys[1,2,3]. These approaches improved potentially the localization accuracy achieved by using the Cell-ID.

In this paper, we propose using RSS observations for positioning and tracking in WiMAX networks. We argue that this approach provides sufficient accuracy for the most of LBS provided by the service providers.

The rest of this paper is organized as follows: in section 2 we discuss the positioning possibilities in WiMAX networks using the current modems; in section 3 we provide WiMAX RSS measurements, in section 4 estimating user's path depending on RSS observations is provided and the conclusion is provided in section 5.

II. Positioning possibilities in WiMAX networks using the current modems

WiMAX networks are very similar to GSM networks from topology point of view; the two of them use base stations (BS) to connect wirelessly to subscriber stations (SS); therefore, the positioning techniques which can be applied on GSM networks like triangulation, trilateration…etc, could also be applied on WiMAX networks taking into account the different technology aspects for each of the two technologies. Using range measurements between BS and SS to position a network user has been discussed for GSM networks, surveys [1,2,3]. In WiMAX networks range measurements can be obtained by:

- Observing the Timing Adjust values; this concept is similar to Timing Advance in GSM networks.
- Observing the RSS values.

The timing adjust value is determined by the serving base station and measuring this value is not achievable using the current modems; but observing RSS values -despite its low accuracy comparing to timing adjust - is possible and can be done in two ways:

1- Reading the already available "RSS index" values in the modem and obtain the RSS values: these values are called "scores" and they are related directly to RSS values. The main advantage of reading the "score" values is the possibility of measuring this value for all the available base stations simultaneously. The only drawback shows up in measurement's accuracy; it is slightly less accurate to obtain RSS values from score values than measuring the RSS values directly.
2- Measuring directly the RSS values and this has to be done for each channel (BS) separately.

Also, WiMAX has the ability to build mesh networks by supporting short-range communications among the terminals. The IEEE 802.16-2004 WiMAX standard [10] provides a mechanism for creating a multi-hop mesh network which can be deployed as a high speed wide-area wireless network. Supporting short-range communications between the terminals gives more localization possibilities and improves the localization accuracy by measuring the relative distances between the terminals.

III. WIMAX RSS MEASUREMENTS

All the measurements were conducted in Brussels capitol city using the already available pre-WiMAX network operated by Clearwire at frequency of 3.5 GHz. The measurements were collected in different places and times; the places have relatively dense buildings with heights between 4 and 7 floors and also, some high glass buildings can be found. The base stations are located at a height of 5 to 7 floors and the subscriber station's antenna was positioned on top of a vehicle with a GPS receiver. Two types of measurements were conducted, the first type was conducted using a spectrum analyzer and was dedicated to study the relation between the received signal strength and the distance from the serving BS, which led to a path loss model development. The second type of measurements was conducted using the modem readings. Two readings were collected simultaneously every one second while the vehicle was moving: the received signal strength measured by dBm if the spectrum analyzer was used or the "score" values measured by dB if the modem was used, and the measurement precise location obtained from GPS readings. An Omni-directional antenna was used; therefore there was no need to change its bearing to adjust to the point in the direction with highest received power. The data was captured on the hard disk of a computer for later processing. Fig. 1 shows the obtained path loss model. We can notice clearly that the effect of the multi-path component is stronger near the high glass buildings (between 550 and 700 m).The collected data is modeled by the following logarithmic curve:

$$Y = -22.98 \log_{10}(X) - 23.89 \quad (1)$$

Where,

Y: is the received signal strength.

X : is the distance between the BS and SS.

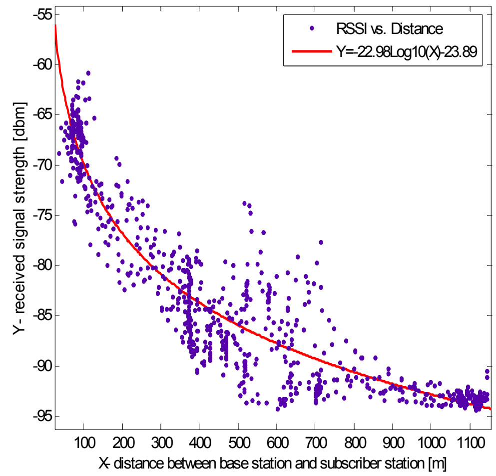

Figure 1: The obtained path loss model

The root mean square error (RMSE) is 3.061and the r-squared value is 0.8958 .i.e. there is a good matching between the model obtained and the collected data.

The RSS values measured by the modem were collected in the area between the three base stations shown in Fig 2. and they have been used to plot the power map for each of the mentioned BSs. See figures 3 to 5.

The power maps can be used to improve the localization accuracy, the signal to noise ratio (SNR) improvement is expected to be a factor of 10 comparing to the crude logarithmic distance relation, obtained in Fig. 1, see [1].

Figure 2: The measurements area (between the three BSs) and the driven path (yellow line) which will be estimated later in this paper(Google earth map)

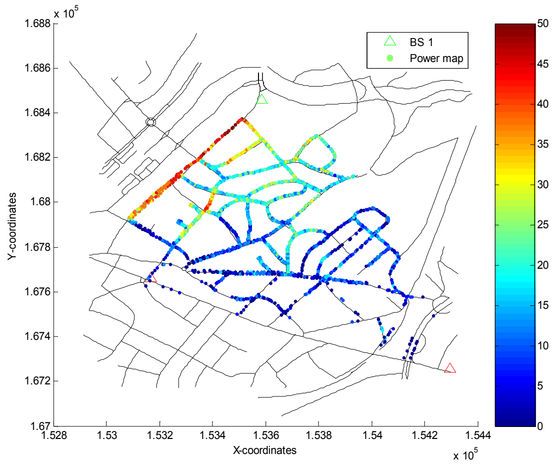

Figure 3: Base station 1 power map

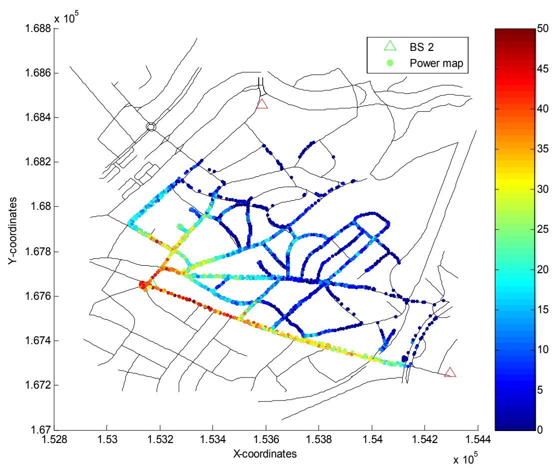

Figure 4: Base station 2 power map

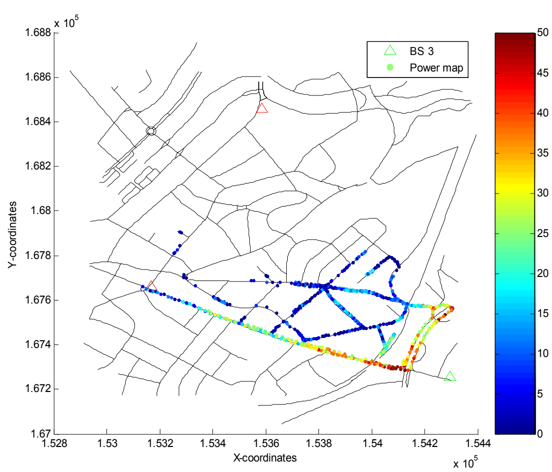

Figure 5: Base station 3 power map

IV. ESTIMATING USER'S PATH DEPENDING ON RSS OBSERVATIONS

In this section, the crude RSS measurements will be used to estimate a user's path assuming that the user is using the public road network (car). The same measurement's setup was used to measure the signal strength along the driven path shown in Fig. 2; the collected data showed that the maximum number of base stations could be detected simultaneously (the modem can receive signals from them at the same time instant) is three; but it was not possible to detect three base stations simultaneously all the time (at all the driven path's points) which is going to affect negatively the positioning accuracy.

The received signal strength can be written as a function of user's position and the base station position as follows [1]:

$$RSS = h(X, S_i) \tag{2}$$

Where,

$X(x, y)$: is the user's position.

$S_i(S_{i,x}, S_{i,y})$: is the position of the base station i .

To calculate the function h , we calculate its gradients:

$$\frac{\partial h}{dx} = \frac{10\alpha}{\log(10)} \frac{x - S_{i,x}}{d_i^2}$$

$$\frac{\partial h}{dy} = \frac{10\alpha}{\log(10)} \frac{y - S_{i,y}}{d_i^2} \tag{4}$$

Where d_i is the distance or the range between the user and the base station i .

A sigma-point particle filter was used to estimate the user's path taking into account that the distance between two base stations is about 1200m. The true and the estimated trajectories are shown in Fig. 6; the estimated ranges from the base stations are shown in Fig. 7, the positioning estimation instant error is shown in Fig. 8 and the cumulative distribution function of the positioning error is shown in Fig 9.

The results show that 67% of the positioning errors are smaller than 220m and 95% of the errors are smaller than 320m, that means that the circular error probability (CEP) doesn't comply with the FCC requirements for mobile and network-centric positioning, but the accuracy still enough for most of LBS provided by the service providers (for example, it is enough to know the closest petrol station). For navigation purposes, more information is needed to achieve higher localization accuracy.

V. CONCLUSION

Localization depending on the available network information plays an important role in providing LBS, and the localization accuracy is very important to determine the services that can be provided; While some services require relatively low localization accuracy others can't be delivered effectively without high localization accuracy (providing information about the nearest petrol station is not the same as providing information about the highway next exit).

Providing LBS in WiMAX networks depending on network measurements is expected to gain a lot of interest during the coming years, because of:

1- The availability: WiMAX networks started to be widely deployed.
2- Positioning accuracy: positioning in WiMAX networks is expected to have better – or the same in worst case- accuracy as GSM networks. This is due to:
    a. The timing adjust value in WiMAX networks is more accurate than the timing advance value in GSM networks, which leads to more accurate range measurements.
    b. Measuring the relative distances in WiMAX mesh networks – where the distances are relatively short- will help in improving the localization accuracy.
    c. Relying on RSS measurements for localization showed good results (the example provided in this paper).
3- High data rates: WiMAX networks provide high data rates which will open the road wide in front of new services and applications.
4- Power consumption: no extra power is needed to provide LBS if the network resources are used for positioning.

In addition, the ability to build WiMAX mesh networks is important for localization, it can help in locating users who are out of BS coverage, and it is also important for LBS by enabling the users to profit LBS even when they don't have direct connection to a BS; this could be particularly important in emergency and security cases.

The example provided in this paper was a real scenario which has been applied on the pre_WiMAX network in Brussels. Depending on the results obtained, we conclude that WiMAX networks are capable of locating and tracking users with sufficient accuracy for some LBS applications depending only on RSS observations. The obtained localization accuracy can be improved by using the power maps, figures 3 to 5; but still not enough for some services like navigation; using extra information (like road maps) will become a must if services that require high localization accuracy are provided.

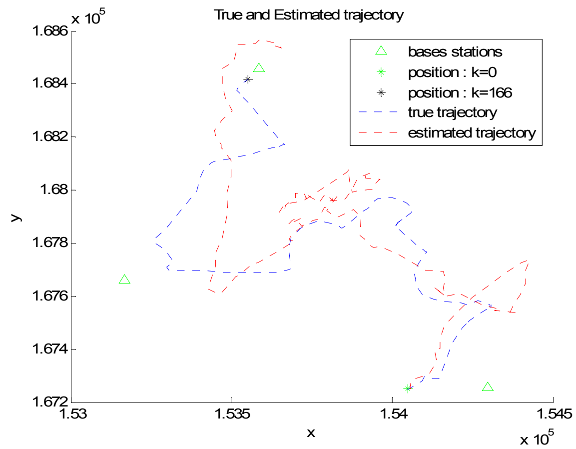

Figure 6: The true and estimated trajectories

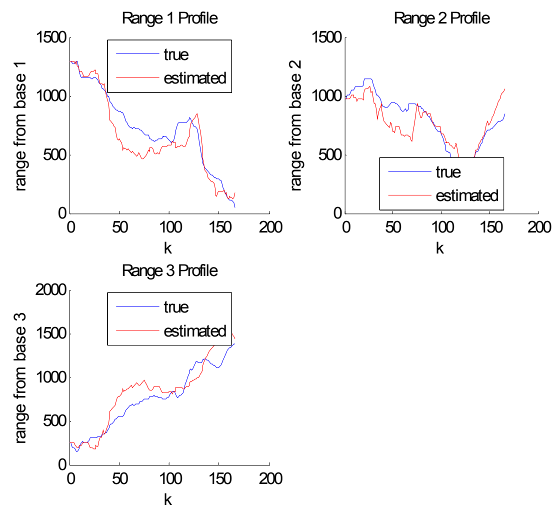

Figure 7: The true and estimated ranges

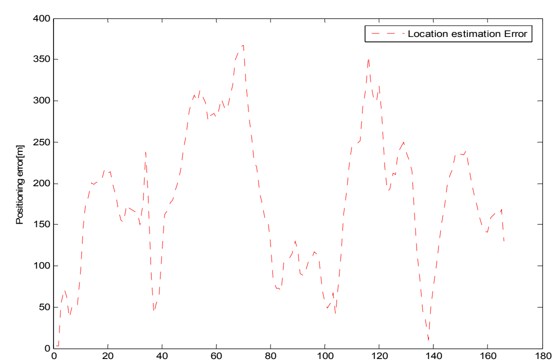

Figure 8: The instant positioning error

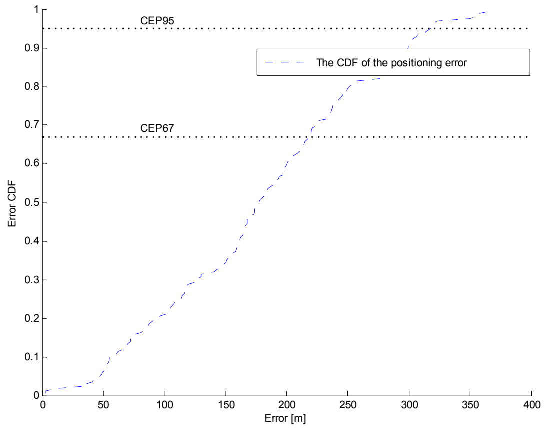

Figure 9: The error cumulative distribution function

REFERENCES

[1] Fredrik Gustafsson, Fredrik Gunnarsson,"Possibilities and fundamental Limitations of positioning using wireless communication networks measurements", IEEE Signal Processing Magazine, vol. 22, pp. 41–53,2005.
[2] S. Gezici, Z. Tian, B. Giannakis, H. Kobayashi, and A. Molisch, "Loca-Lization via ultra-wideband radios," IEEE Signal Processing Magazine, vol. 22, no. 4, pp. 70–84, 2005.
[3] D. Li and Y. Hu, "Energy-based collaborative source localization using acoustic microsensor array," Journal of Applied Signal Processing, pp. 321–337, 2003.
[4] Nico Deblauwe, Leo Van Biesen: "Public transport LBS: Combining GPS and GSM positioning
[5] Christof Olivier, PhD thesis: Characterisation of Electromagnetic Radiation Close to Broadcast and wireless Communications Antennas.
[6] C L Hong, I J Wassell, G E Athanasiadou, S Greaves, and M Sellars: "Wideband Channel Measurements and Characterisation for Broadband Wireless Access"
[7] Fredrik Gustafsson, Adaptive Filtering and change detection.
[8] Sebastian Thrun, Probabilistic Robotics.
[9] Jeffrey G. Andrews, Arunabha Ghosh, Rias Muhamed, Fundamentals Of Wimax.
[10] IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems, October 2004.