Localization in WiMAX Networks Depending on The Available RSS-based Measurements

Mussa Bshara, *Student Member, IEEE,* and Leo Van Biesen, *Senior Member, IEEE*

***Abstract*—Recently, localization in wireless networks has gained a lot of interest; especially after some of the most interesting positioning application areas have emerged in wireless communications. The most important are the Federal Communications Commission (FCC) and the European Recommendation E112, both of which require that wireless providers should be able to locate within tens of meters users of emergency calls.**

In this paper, fingerprinting-based localization depending on the available RSS-based measurements has been addressed in WiMAX networks. Fingerprinting is a good way to overcome signal propagation peculiarities caused by the propagation environment. And using the available RSS-based measurements is of great interest because of their availability during the normal operation of the standard modems, and the simplicity of obtaining them. The obtained results show that using the available RSS-based measurements to locate users in WiMAX networks is feasible and provides the required positioning accuracy for most of location-based services (LBS), if fingerprinting-based approaches are used to obtain localization. The available RSS-based measurement in the current WiMAX modems is called *SCORE*. The term SCORE is used by modem manufacturer to indicate the quality of the connection between the base station (BS) and the subscriber station (SS). However, using the actual received signal strength (RSS) values gives higher accuracy than using SCORE values, but obtaining them is more difficult and not feasible using the current modems.

***Keywords*-Fingerprinting, GPS, GSM, location-based services, localization, positioning, positioning accuracy, power maps , received signal strength, SCORE, WiMAX.**

I. Introduction

THERE are several ways to position a wireless network user. Global positioning system (GPS) is the most popular way, it provides positioning accuracy that meets all the known location-dependent applications requirements. The main problems with GPS -despite that the user's terminal must be GPS enabled- are the battery high consumption, the limited coverage and the latency. The battery high consumption means that the user can be positioned during a short period of time. Also GPS performs poorly in urban areas near the high risings and inside the tunnels, i.e. it has a poor performance when it is needed the most. And it needs about 4 minutes (cold start) before the first position fix is available. Another way to position a user, is to depend on the wireless network itself by using the available information such as SCORE information [1], or Cell-ID which has been used widely in global system for mobile communications (GSM) despite its limited accuracy [2]. One can also make measurements on the network to obtain localization, some of these measurements are hard to obtain such as time of arrival (TOA) which needs synchronization, and some are easy to obtain such as RSS measurements [3], [4]. Adding new hardware to the base stations (BSs) to improve the measurements accuracy (for example using array antennas or adding localization measurement unit (LMU) to each base station) can provide high localization accuracy, but this option suffers from the high roll-out cost. Some of the measurements can be conducted by the terminal itself, others can be only obtained by the network. From now on, we will refer to the measurements as network measurements regardless where these measurements have been conducted; in the network itself (network side), in the user terminal (terminal side) or in 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 TOA, time-difference of arrival (TDOA) and RSS observations, surveys [3], [5] and [6]. These approaches improved potentially the localization accuracy achieved by using the Cell-ID. The exponential path loss model which is known as the Okumura-Hata (OH) model [7], [8] was the first approach to be used to obtain positioning. In [9] the authors propose using statistical log-normal model of RSS measurements and the sequential Monte Carlo localization technique, to get better localization accuracy. In [10] an enhanced object tracking with RSS using Kalman Filter is proposed by obtaining velocity information of the mobile sensor node which is used to improve the accuracy of the tracking. The authors of [11] proposed using a grid-based centralized localization using RSS to locate a target using the maximum and minimum path loss exponents. The proposed method achieves higher localization accuracy than the conventional localization method using the same path loss exponent when the distribution of the path loss exponents over the field is uniform, and has worse performance when the distribution of the path loss exponents over the field is normal distribution. An indoor localization method based on received signal strength using discrete fourier transform has been proposed in [12]; the method provided satisfactory positioning accuracy if the environment stay consistent from the radio building phase. The fingerprinting approach which depends on comparing the on-line measurements obtained by the user with an already built database, proved to provide better performance than OH alternative [2]. In [13],[14] the authors used fingerprint approach to mitigate the effect of multipath components and the inconveniences related to OH approach to provide better positioning accuracy.

In this paper, we propose using fingerprinting-based local-

Mussa Bshara and Leo Van Biesen are with the Department of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel, Brussels, Belgium (e-mail: {mbshara,lvbiesen}@vub.ac.be).

ization depending on SCORE observations for positioning in WiMAX networks. The importance of the contributions of this paper can be summarized as follows:

- This paper provides a detailed description of all the RSS-based quantities that can be measured using the current WiMAX networks.
- The used RSS-based quantity, which is the SCORE, is new and has never been used before in any localization approach in wireless networks.
- Introducing an important enchantment to the classical fingerprinting approach based on the fact that the Cell-IDs are less affected by the propagation environment than RSS-based values.

We also argue that this approach meets the requirements of most of the known LBS such as discovering the nearby places, whereabouts of a friend, user tracking and many other services.

This paper is organized as follows: Section II discusses the positioning possibilities in WiMAX networks. Section III discusses the RSS-based measurements in the current WiMAX networks. The fingerprinting-based localization approach depending on RSS-based measurements is discussed in section IV, and we conclude in section V.

II. Positioning possibilities in WiMAX networks

The topology of WiMAX network is similar to GSM one; the two of them use base stations to establish a wireless connection with subscriber stations (GSM terminal or WiMAX enabled computer for example). And almost the same quantities can be measured using both networks. In WiMAX networks the following quantities can be used for possible localization application:

- *The Timing Adjust (TA):* This concept is similar to timing advance (TA) or time of arrival (TOA) concept in GSM networks [15].
- *The Time Difference of Timing Adjust (TDOTA):* This concept is similar to the time difference of arrival (TDOA) concept in GSM networks. The idea of this measurement is to compare more than one TA values measured to different base stations to eliminate the measurement error caused by the terminal clock synchronization as long as the network is synchronized.
- *The Angle of Arrival (AOA):* WiMAX uses directional antennas which allow the determination of the azimuth of a terminal seen by a certain base station. The current antennas used in Pre-WiMAX network in Brussels provide this information as sectors (60 , 90 and 120 degrees). WiMAX networks started to use advanced antenna arrays where *beamforming* allows rotating narrow beams. The narrow antenna patterns will increase the accuracy of the measured terminal azimuth.
- *The Base Station Identifier (BSID):* This concept is the same as Cell-ID in GSM networks. The position of a terminal can be determined depending on the serving base station coordinates. This value can be obtained -by the terminal- by obtaining the serving base station MAC address which is broadcasted over the control channel.
- *The Received Signal Strength Index (RSSI):* WiMAX terminals can measure the received power broadcasted by a base station (Extra software needed). This measurement gives information about the distance between the terminal and the corresponding base station. The RSSI values depend on the operating environment and a path loss model has to be developed for a certain environment.
- *The SCORE values:* The current standard WiMAX terminals measure the SCORE values of the available BSs. The SCORE values are related directly to the RSSI values. However, they can be considered -with some approximations- as rough RSSI measurements.

In addition, the support of short-range communications among the terminals (mesh networks) was proposed in WiMAX networks [15]. The rationale for introducing short-range communications is mainly due to three arguments:

1) The need to extend the coverage to places not covered by a base station.
2) Support peer-to-peer (P2P) high-speed wireless links between the terminals.
3) The need to enhance the communication between a terminal and the base station by fostering cooperative communication protocols among spatially proximate devices.

The accuracy of the location estimation can be enhanced by utilizing the additional information gained from measuring the relative distances between the terminals. The support of short-range communications is very attractive, but the practical implementation is very complicated and has a lot of complications. Therefore, the use of mesh networks could be avoided or be limited to security and emergency cases. For example, a police car (or an ambulance) can establish a direct connection to other cars; or in case of being outside the coverage area of the wireless network, a connection can be established to the main network backbone by using the available modems in its range.

Therefore, WiMAX networks have all the resources to locate their subscribers without relying on any external system. The most attractive resources for localization are the ones that are easy to obtain and already available during the normal terminal operation such as RSS-based values.

III. The RSS-based measurements in the current WiMAX networks

In this section, we consider the received power measurements. The received power is usually measured in watts (or dBm) and can be obtained by using special equipments such as power meters, base station analyzers or spectrum analyzers. In many applications the use of the mentioned equipments (or similar ones) is not possible due to many different reasons including the size and weight, the power consumption, the usage complications and the price. In real life, the choice of a certain measurement equipment depends on the application requirements, i.e., the received power could be measured using

Ch #	Signal dBm	Mod	LEDs	Total Symbols	Bad Symbols	RSSI	Viterbi	Reed Solomon	Mod	Total Symbols	Bad Symbols	Viterbi	Reed Solomon	Mod	Total Symbols	Bad Symbols	Viterbi	Reed Solomon
12	-107.0	4Q	0	1823	1823	21	329	9106	16Q	1311	1311	645	13094	64Q	1021	1021	980	15286
12	-106.0	4Q	0	3827	3827	21	329	19110	16Q	2705	2705	645	27005	64Q	1993	1993	981	29848
12	-105.0	4Q	0	5694	5693	21	329	28446	16Q	4162	4162	646	41560	64Q	3312	3312	981	49617
12	-104.0	4Q	0	9813	9814	22	329	48988	16Q	7463	7463	646	74520	64Q	5951	5951	983	89132
12	-103.0	4Q	0	10000	10000	22	329	49923	16Q	7947	7947	647	79341	64Q	6571	6571	983	98405
12	-102.0	4Q	0	10000	10000	22	329	49915	16Q	8440	8440	647	84284	64Q	7315	7315	982	109565
12	-101.0	4Q	0	10000	10000	22	330	49930	16Q	8739	8739	647	87258	64Q	7926	7926	984	118709
12	-100.0	4Q	0	10000	10000	22	329	49917	16Q	8920	8920	647	89061	64Q	8375	8375	984	125420
12	-99.0	4Q	0	10000	10000	19	325	49928	16Q	8978	8978	635	89672	64Q	8325	8325	976	124685
12	-98.0	4Q	0	10000	10000	22	327	49927	16Q	8766	8766	647	87532	64Q	8375	8375	985	125428
12	-97.0	4Q	0	10000	10000	22	318	49918	16Q	8736	8736	645	87235	64Q	8208	8208	985	122939
12	-96.0	4Q	0	10000	10000	22	296	49905	16Q	8965	8965	642	89479	64Q	8454	8454	986	126611
12	-95.0	4Q	0	10000	9496	22	254	49096	16Q	8986	8986	633	89702	64Q	8680	8680	986	130019
12	-94.0	4Q	0	10000	1685	24	150	20505	16Q	9921	9921	600	99069	64Q	9906	9906	986	148338
12	-93.0	4Q	1	10000	12	25	107	1751	16Q	9981	9981	559	99659	64Q	9982	9982	986	149481
12	-92.0	4Q	1	10000	1	27	79	120	16Q	9983	9983	511	99666	64Q	9983	9983	987	149545
12	-91.0	4Q	2	10000	0	29	52	3	16Q	9982	9982	453	99656	64Q	9981	9981	984	149486
12	-90.0	4Q	2	10000	0	29	32	0	16Q	9981	9981	394	99621	64Q	9982	9982	979	149496
12	-89.0	4Q	3	10000	0	30	19	1	16Q	9981	9785	334	96122	64Q	9982	9982	966	149496
12	-88.0	4Q	3	10000	0	30	9	0	16Q	9983	4038	271	57716	64Q	9983	9983	926	149504
12	-87.0	4Q	3	10000	0	30	4	0	16Q	9984	209	218	15094	64Q	9984	9984	848	149527
12	-86.0	4Q	3	10000	0	30	1	0	16Q	9982	1	171	2363	64Q	9981	9981	733	149368
12	-85.0	4Q	3	10000	0	32	0	0	16Q	9981	0	130	286	64Q	9982	9918	614	141079
12	-84.0	4Q	3	10000	0	30	0	0	16Q	9984	0	104	70	64Q	9984	8120	534	105972
12	-83.0	4Q	4	10000	0	36	0	0	16Q	9982	0	65	8	64Q	9981	753	441	26514
12	-82.0	4Q	4	10000	0	36	0	0	16Q	9984	0	43	0	64Q	9984	37	380	5875
12	-81.0	4Q	4	10000	0	36	0	0	16Q	9982	0	27	1	64Q	9981	0	323	986
12	-80.0	4Q	4	10000	0	36	0	0	16Q	9982	0	16	0	64Q	9981	0	272	202
12	-79.0	4Q	4	10000	0	37	0	0	16Q	9982	0	8	0	64Q	9981	0	222	38
12	-78.0	4Q	5	10000	0	41	0	0	16Q	9983	0	4	0	64Q	9983	0	181	16
12	-77.0	4Q	5	10000	0	42	0	0	16Q	9981	0	2	0	64Q	9982	0	147	6
12	-76.0	4Q	5	10000	0	42	0	0	16Q	9981	0	1	0	64Q	9982	0	119	1
12	-75.0	4Q	5	10000	0	42	0	0	16Q	9983	0	0	0	64Q	9983	0	94	0
12	-74.0	4Q	5	10000	0	42	0	0	16Q	9981	0	1	0	64Q	9982	0	90	4
12	-73.0	4Q	5	10000	0	43	0	0	16Q	9983	0	0	0	64Q	9983	0	59	0
12	-72.0	4Q	5	10000	0	47	0	0	16Q	9982	0	0	0	64Q	9981	0	49	0
12	-71.0	4Q	5	10000	0	43	0	0	16Q	9983	0	0	0	64Q	9983	0	49	0
12	-70.0	4Q	5	10000	0	48	0	0	16Q	9983	0	0	0	64Q	9983	0	35	1
12	-65.0	4Q	5	10000	0	53	0	0	16Q	9984	0	0	0	64Q	9984	0	19	0
12	-60.0	4Q	5	10000	0	58	0	0	16Q	9981	0	0	0	64Q	9982	0	14	0
12	-55.0	4Q	5	10000	0	60	0	0	16Q	9983	0	0	0	64Q	9983	0	13	0
12	-50.0	4Q	5	10000	0	66	0	0	16Q	9981	0	0	0	64Q	9982	0	13	0
12	-45.0	4Q	5	10000	0	72	0	0	16Q	9983	0	0	0	64Q	9983	0	13	0
12	-40.0	4Q	5	10000	0	77	0	0	16Q	9982	0	0	0	64Q	9981	0	13	0
12	-35.0	4Q	5	10000	0	83	0	0	16Q	9982	0	0	0	64Q	9981	0	13	0

Fig. 1: The modem calibration table (used to convert the RSSI values to RSS ones measured in dBm).

different equipments for different purposes or applications. For example it could be measured using a small sized and simple equipment, if the measurement accuracy is enough for a certain decision or application. Take for example a GSM terminal, it continuously measures the received power from the neighboring base stations. It is true that the measurement accuracy is not that high, but it is certainly enough to decide the best base station. The same thing applies to WiMAX modems, they also measure the received power and they use this measurement to decide the quality of the connection between the modem and the neighboring base stations. In this research, we distinguish between three types of RSS-based measurements:

1) *The Received Signal Strength* (RSS): The RSS values represent the actual measured power (in dBm). Usually they are presented as real values with 2 decimal digits resolution, however they can be found as integer values depending on the used measurement equipment. These values are measured using dedicated equipments such as spectrum analyzers.
2) *The Received Signal Strength Index* (RSSI): The RSSI values are presented as positive integer values. They are

obtained by WiMAX modems and are presented only for the serving BS.

3) *SCORE :* The SCORE values are obtained by the standard WiMAX modems simultaneously for all the available base stations and presented as positive integer values.

In this research, only the quantities that can be measured by WiMAX modems are used; i.e, RSSI and SCORE values. And all the used values were converted to RSS values measured in dBm as explained in sections III-A and III-B.

A. Converting RSSI values to RSS values

To obtain the actual received power measured in dBm from RSSI measurements, a calibration table has to be used. For each used modem (in measurements), a calibration table is generated. Figure 1 shows the used calibration table in our measurements (only channel 12 can be found in the provided table, but in the original table channels 2 and 27 can be also found). The table contains information about the measured WiMAX signals, such as channel number (frequency), coding, *Viterbi* decoder information etc ..., and it also contains the equivalent RSS values to a set of RSSI ones. The conversion from RSSI to RSS is done by searching the calibration table for the equivalent RSS value to a certain RSSI one.

B. Converting SCORE values to RSS values

There are no available calibration tables that give the equivalent RSS values to SCORE measurements. Therefore, the solution is to convert the SCORE values to RSSI ones using the equation 1, and then using the calibration tables to obtain the equivalent RSS values in dbm. The relation between SCORE and RSSI values according to the information provided by the modem manufacturer is given by the following equation:

$$SCORE = (RSSI - 22) - (0.08 \times AvgViterbi) \quad (1)$$

Where, *AvgViterbi* is a value generated by the modem decoder.

C. Practical issues on obtaining RSS from RSSI and SCORE values

Using calibration tables directly to convert RSSI values to RSS is not practical due to the following reasons:

1) Converting a large number of values needs relatively long time to look up the tables to find the equivalent RSS values to the measured RSSI ones. The processing power is an issue in portable devices solutions.
2) Finding the exact RSSI values in the calibration table is not guaranteed. The calibration table is generated for a set of RSSI values, so it is not guaranteed to find all the measured values in the table. In many cases, only close values to the exact ones can be found.
3) It is possible - in few cases- to find more than one equivalent RSS value to the same RSSI measurement. For example, in the table shown in figure 1, the equivalent RSS values to the RSSI value of 21, are: -107 dBm, -106 dBm and -105 dBm. And for the RSSI value of 22, the equivalent RSS values are: -104 dBm, -103 dBm, -102 dBm, -101 dBm and -100 dBm.

TABLE I: The fitting curves coefficients for channels 2, 12 and 27.

	Channel 2	Channel 12	Channel 27
p1	-6.434e-006	-8.381e-006	-8.744e-006
p2	0.001493	0.001817	0.001879
p3	-0.1252	-0.1426	-0.144
p4	5.537	5.803	5.639
p5	-181.3	-175.8	-166.7
R-square	0.9888	0.9817	0.9884
RMSE	1.978	2.533	2.019

Therefore, to generalize (to take all the possible values into account) and for the sake of simplicity, a fit curve has been generated for each channel (i.e., for each curve of the three conversion table curves shown in figure 2).

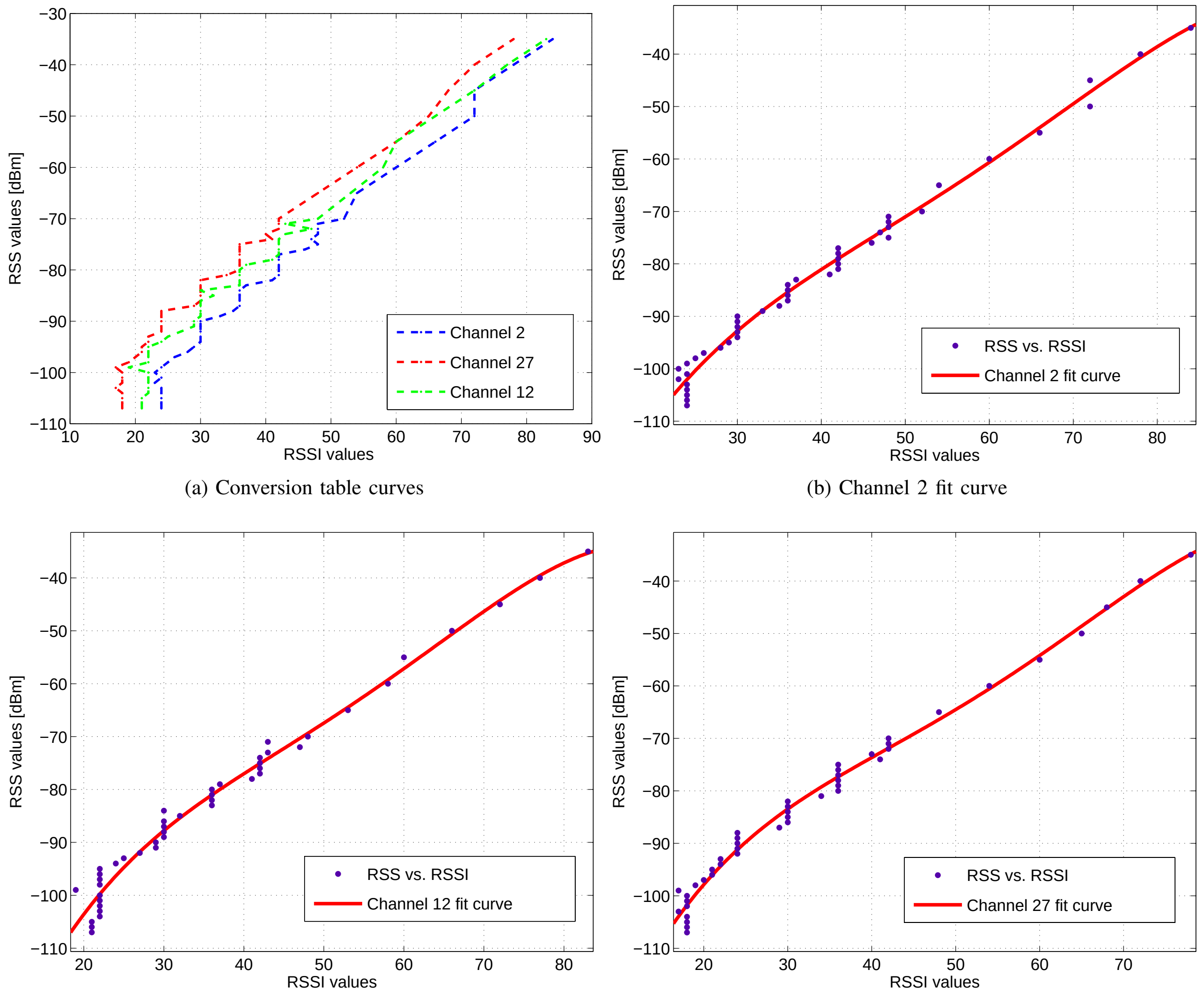
The modem has been calibrated only for three channels: channel 2, channel 12 and channel 27. The channels have been chosen to cover the used frequency range, channel 2 is the lower frequency bound, channel 12 is the middle frequency and channel 27 is the higher frequency bound. If the number of the observed (measured) channel does not exist in the calibration table, the closest channel is to be chosen.

Three curves have been generated depending on the calibration table, one curve for each channel. The fitting equation is given by:

$$\begin{aligned} RSS &= p1 \times RSSI^4 + p2 \times RSSI^3 + p3 \times RSSI^2 \\ &\quad + p4 \times RSSI + p5 \end{aligned} \quad (2)$$

The Coefficients p1, p2, p3, p4 and p5 differ from one channel to another as shown in table I. Therefore, it is enough to store only the coefficients instead of storing the complete calibration table. *R-square* measures how successful the fit is in explaining the variation of the data; a value closer to 1 indicates a better fit; and RMSE is the root mean squared error, a value closer to 0 indicates a better fit. One can choose a less complicated fitting curve (linear curve), but the 4^{th} degree polynomial curve was chosen, because it gives the highest *R-square* value and the lowest root mean squared error, with a price of only storing few numbers (coefficients) more.

Obtaining RSS values from SCORE ones requires knowing *AvgViterbi* information (refer to equation 1). Unfortunately this information is not available for all the measured BSs (It is only available for the serving BS). The available calibration tables show that the value of *AvgViterbi* takes considerable values only for weak signals, and takes the value of zero (or very small) for strong signals. Thus, setting *AvgViterbi* to zero will affect the most the accuracy of low signals. However, this will make the overall SCORE measurements accuracy lower than RSSI one.



(a) Conversion table curves

(b) Channel 2 fit curve

(c) Channel 12 fit curve

(d) Channel 27 fit curve

Fig. 2: The calibration table fitting curves. These curves are used to convert RSSI to RSS values measured in dBm.

D. Measurement accuracy

Measuring RSS values directly using advanced measurement equipments (such as spectrum analyzers) is the most accurate way, it gives the values directly in dBm as real values. These values will be considered as our reference values to evaluate the accuracy of the other types of measurements.

1) RSSI measurements accuracy: The RSSI values are less accurate than RSS values due to the following reasons:

- The RSSI values are integer numbers, i.e., each of the original values is rounded to the closest integer.
- Using the modem calibration table will produce an additional error due to calibration table production and the conversion error.
- The modem is calibrated only for three channels, for the lower, medium and high frequency bands, and the closest channel to the measured one will be used. This approximation will affect the accuracy of the obtained values.
- The fitting curves are also approximations to real values, thus using these fitting curves to convert RSSI to RSS will affect also the accuracy of the final values.

However, the real RSS values (measured directly in dBm by dedicated equipments) are not used in this research; and from now until the end of this paper the term RSS will be used to indicate the RSS values obtained using RSSI measurements.

2) SCORE measurements accuracy: SCORE values are less accurate than RSSI measurements due to the lack of *AvgViterbi* information. Setting this information to any constant value (such as zero) will affect negatively the conversion accuracy of some values and keep the accuracy unchanged for the rest of the values. Thus, some obtained values will keep their accuracy unchanged and some will lose some accuracy due to this assumption. This approximation will produce an additional error in addition to the error resulting from converting RSSI to RSS. Equation 1 shows that the minimum obtained RSSI value from SCORE measurements is 22. But when RSSI values are obtained by direct measurements, values such as 17, 18, 19, 20, 21 can be found, refer to calibration table shown in figure 1 (recall that the provided calibration table in 1 is only a sample and doesn't show all the values and channels).

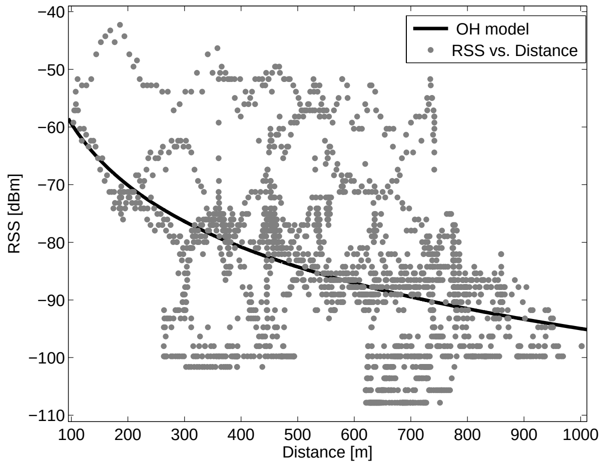


Fig. 3: The actual RSS measurements and the related OH model.

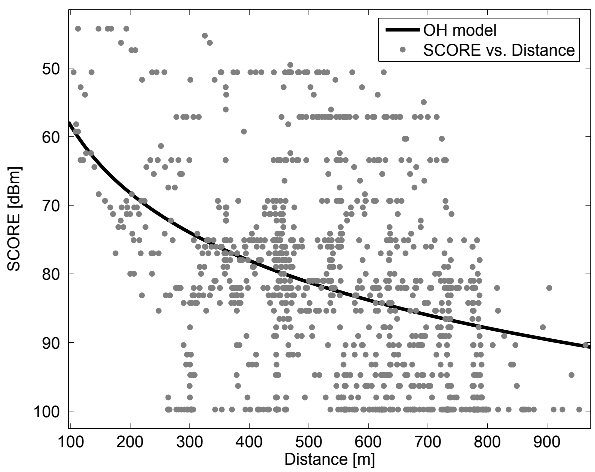


Fig. 4: The actual SCORE measurements and the related OH model.

E. The relation between the measured SCORE and RSS values in the area under study

The relation between the measured SCORE and RSS values in the area under study has been studied by computing the average error and the covariance between the two quantities. The results show good correlation between SCORE and RSS values which means that using SCORE values instead of RSS values is possible, but lower positioning accuracy is expected. Some antennas (BSs) have better correlation between the SCORE and RSS values comparing to other antennas. This is because these antennas have a stronger signal in the area under study. For example antennas 1,2,3 and 4 have better correlation than antennas 6 and 7 (refer to figure 5). Indeed the BSs 6 and 7 are experimental BSs and have lower transmission power than the rest of the BSs in the area under study. Also, the correlation is bad for low signals in all the antennas. This is due to the approximation made about *AvgViterbi* value. This value was set to zero while for low signals *AvgViterbi* takes large values refer to figure 1. Figure 3 and figure 4 depict the actual RSS and SCORE values along with the related OH model. The two obtained OH models show good correlation between the two quantities and proves that using SCORE values to obtain localization is plausible.

In this research, the focus is on using the practically available RSS-based measurements for localization. In fact the only practically available RSS-based measurements for localization is the SCORE measurements. Because they are the only RSS-based measurements that can be obtained simultaneously for all the available BSs, which is indeed a vital condition for realistic applications.

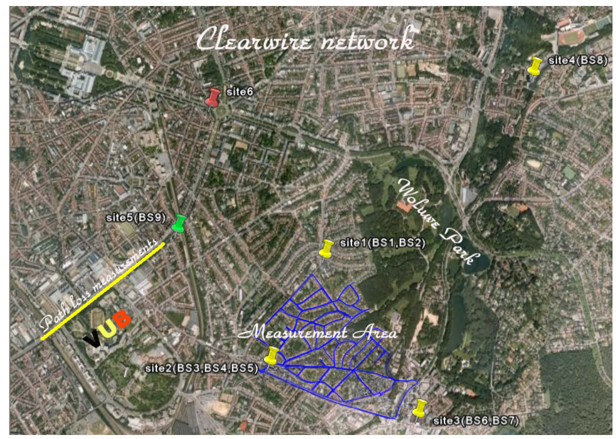


Fig. 5: The area under study, the measurement area is the blue roads.

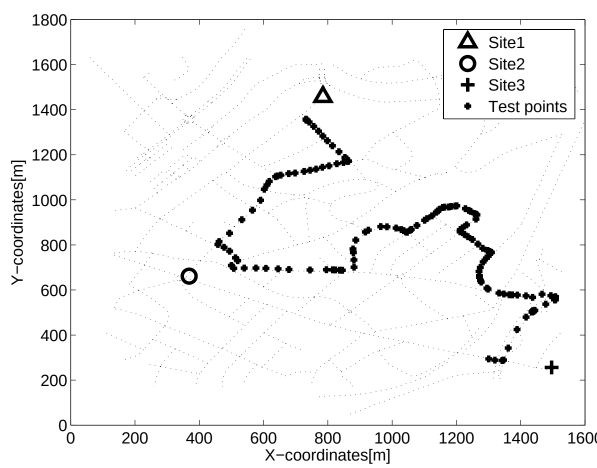


Fig. 6: The used test points. Note that the test points were chosen to cover almost the whole area.

IV. Fingerprinting-based Localization depending on RSS-based measurements

Localization depending on RSS measurements suffers from the high variations in signal strength due to the propagation environment effect on the traveling signal from the transmitter to the receiver. Therefore, the focus is on finding localization approaches that can cope with these variations and minimize their effect on positioning accuracy. one of the most known

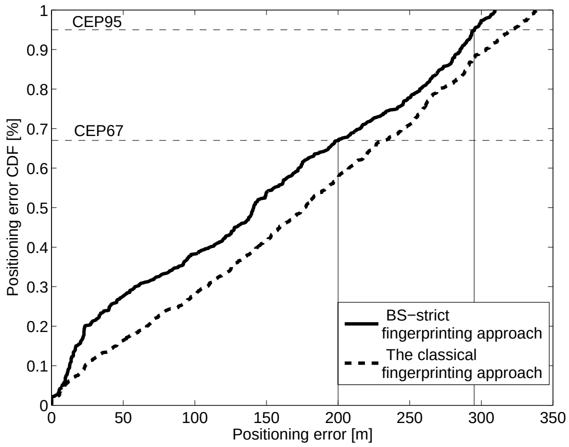


Fig. 7: The positioning error CDFs. The two fingerprinting approaches were used, the classical and the BS-strict.

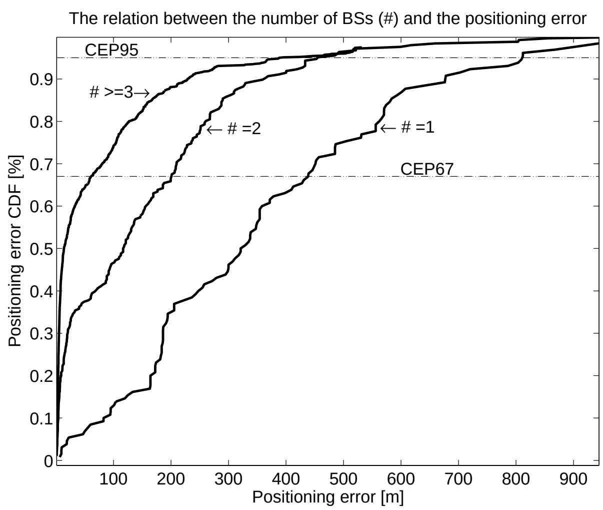


Fig. 8: The relation between the number of the detected BSs and the positioning error.

and effective approach is the *Fingerprinting*.

In general, The received power can be expressed as

$$P_r = \frac{a_t P_t}{R^2} + n_t. \quad (3)$$

Where, P_r is the received power, P_t denotes the transmitted power, a_t is a constant related to the signal frequency and the gain of the receiver and transmitter antennas, R is the distance between the transmitter and the receiver and n_t is the noise component. The previous equation shows that the transmitted power decades with the distance between the transmitter and the receiver. This fact has been used to estimate the distance between the receivers (SSs) and the transmitters (BSs) to obtain localization. The classical model of RSS measurements is based on the so-called Okumura-Hata model [7], [8] which is given as

$$\text{OH model:} \quad y = P_{BS} - 10\alpha \log_{10}(\|p_{BS} - p_{SS}\|_2) + n. \quad (4)$$

where P_{BS} is transmitted signal power (in dB); α is the path loss exponent; n is the measurement noise, p_{BS} is the position of the BS and p_{SS} the position of SS; the standard $\|\cdot\|_2$ norm is used. This model has been used in many proposed localization algorithms [3], [16], but it suffers from the following shortcomings:

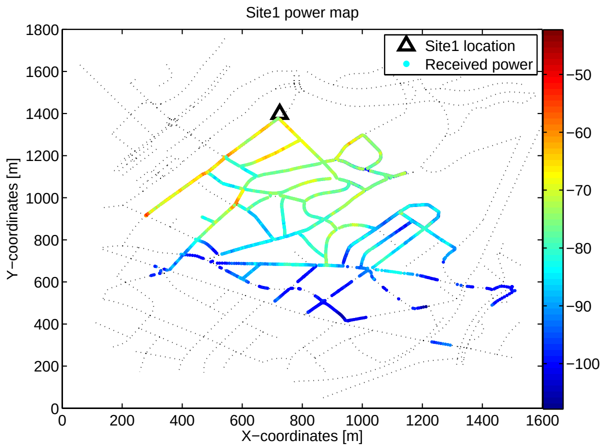
1) It is global, this means that the used path loss exponent is not accurate, because it is related directly to the local environment.
2) The position of the transmitters needs to be known.
3) The transmitted power also needs to be known.

And, the most important is the high signal variations due to the fading, especially is urban environments where the multipath phenomena is strongly present. Figure 3 depicts the actual RSS measurements for one of the base stations in the area under study and the related OH model. It is clear that the difference between the actual measured values and the ones obtained depending on theoretical models (such as OH) is relatively big and plays an opposing role on localization accuracy. Therefore, obtaining localization depending on a certain model will be strongly affected by the difference between the actual measured values and the values obtained by using this model. And the more the model can minimize this difference, the best localization accuracy can be obtained depending on this model such as in fingerprinting localization.

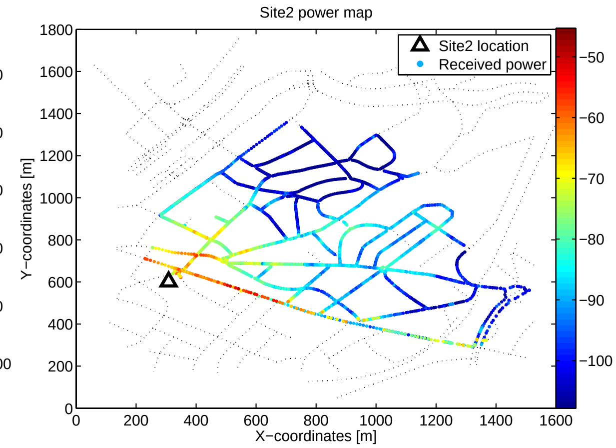
Currently, fingerprinting-based positioning in wireless networks is a new and very active field. The key idea of fingerprinting -as the name says- is that each location has a set of unique features, and this set of features or the “fingerprints” will be used to identify a specific location in the same way a person’s fingerprint is used to identify him / her. To be able to use this methodology a database of all the fingerprints has to be ready and stored on the system as vectors $[(x, y), F_v]$ where, (x, y) is the location coordinates and F_v is the set of the considered features in the said location. The features could be any wireless network related values like: TA, AOA, RSS or a combination of them. This database implicitly takes care of the line of sight (LOS) and non-line of sight (NLOS) problems that are difficult to handle [17]; and partially includes the effects of slow and fast fading. The total effect can be approximated as a gain in SNR with a factor of ten compared to the OH model, see [3]. The mentioned database can be built using two approaches:

1) Collect the “fingerprints” by using direct measurements. This method gives the most accurate database but it is time consuming.
2) Predict the “fingerprints” to avoid the time consuming job by using the radio propagation formulas to predict the RSS values. This method is not accurate as the first one because it is not possible to model all the propagation effects.

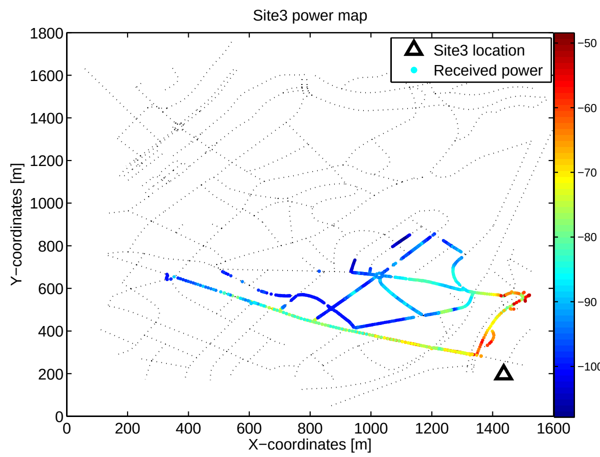
In this research, the first method was adopted, and the RSS values (the used feature) have been collected from all the possible roads in the area under study, we assume that the target or the user is using the public road network (in fact this assumption has no value in our case as we obtain localization



(a) Site No. 1



(b) Site No. 2



(c) Site No. 3

Fig. 9: The power maps of the available WiMAX sites in area under study.

in the static case). The RSS values were collected by using a special calibrated modem with extra software installed on (provided by Clearwire, Belgium). The measurements have been manipulated and stored in a database for later use. The area under study is the measurement area shown in figure 5.

The power maps of all the available sites in the measurement area have been generated and plotted, see figure 9. The mentioned power maps were manipulated and stored in a database in forms of vectors (RSS vectors). Each vector contains all the RSS values in a specific location (x, y); i.e. the database contains a set of vectors (fingerprints) of the form $[(x, y), RSS_1, RSS_2, ...RSS_n]$, where n is the number of the received base stations in the location (x, y).

The localization is obtained during the fingerprinting on-line phase by finding the best match between the target's (user's) vector (RSS vector) and the vectors stored in the database or, in other words, compare the target's "fingerprint" with all the database "fingerprints" and choose the best match. The matching process is based on calculating the distance between the target's fingerprint with all the fingerprints stored in the database, and choosing the fingerprint with the minimum distance. The current WiMAX modems don't measure RSS values, but instead they measure *RSS-based* values called SCORE values; therefore, the target's fingerprint will contain the set of the received SCORE values, and the online measurement vector is of the form $[SCORE_1, SCORE_2, ...SCORE_m]$, where m is the number of the received base stations.

A. Fingerprinting-based localization using SCORE measurements

The on-line target's fingerprint contains all the received SCORE values in the target's current location. A distance metric approach was used to compare all the "fingerprints" stored in the database with the target's fingerprint . In case of comparing vectors with different lengths (this happens when some BSs are not received by the target but they already exist in the database's vector or the vise versa, when the database's vector doesn't contain some BSs that have been received by the target); the missing information is considered as not a number value (NaN) and two approaches were followed:

1) *The classical fingerprinting approach*: Ignore the NaN values and compute the distance between the two vectors.

2) *The BS-strict fingerprinting approach*: Hard punishment to be applied on the points that have NaN values by excluding them (the distance between the two vectors is considered to be infinite). It is called *"BS-strict"* because the two vectors must have the same BSs to be considered.

The SCORE values were obtained using the test points shown in figure 6. While choosing the test points, a special attention has been paid to considering all the possible situations; i.e., in some points only one BS can be measured (one SCORE value), in others 2 or more BSs can be measured, etc.... Building the off-line database is the main concern in fingerprinting localization. It requires extensive measurement campaigns, and once it is built, it has to be updated continuously to stay consistent with the changing environment (new BSs, new constructions etc...). More convenient solution than conducting measurements is to use radio planing programs. This solution produces less accurate databases but it is preferred in some cases. Another alternative is to allow users with positioning capabilities (such as GPS) to contribute on-line to the database. Some users could be stationary (at home, in the office), others could be mobile users (for example a taxi driver). This option is a good way to keep the database accuracy and consistency, and to overcome the direct measurements difficulties. In this research, the off-line database was built using direct measurements, and the RSS values were chosen to build the database due to the following reasons:

1) Using radio planning tools produces RSS databases only.
2) Some RSS databases are already available and provided by some specialized companies for all the available wireless networks.
3) SCORE values are subject to higher variations than RSS ones. Because they depend on the signal strength and the output of the *Viterbi* decoder.

The two mentioned fingerprinting approaches were applied, the classical and the BS-strict approach. The obtained results show that the BS-strict approach performance is slightly better than the classical one. This is due to the fact that the BSID values (Cell-IDs values) are more robust against the noise than the RSS-based values; i.e. the same Cell-ID will be read regardless the presence of a strong noise or not, but different RSS-based values will be read.

B. The relation between the positioning accuracy and the number of the detected base stations

The relation between the positioning accuracy and the number of the detected BSs has been studied using RSS values. Four positioning accuracy intervals have been considered as shown in table II. The percentage of the points that have one BS (type 1), two BSs (type 2)...etc, has been calculated for each accuracy interval. It has been found that for high accuracy intervals, most of the points have 3 BSs or more; and for low positioning accuracy, most of the points have only one BS. Figure 8 plots the relation between the number of the detected BSs and the positioning accuracy.

TABLE II: The relation between the positioning accuracy and the number of the detected BSs. The percentage of each type has been calculated in each accuracy interval. The table has to be read column by column.

Number of BSs	1	2	3 (or more)
Positioning error is $<$10m	17%	34%	49%
Positioning error is from 10 to 50m	8%	19%	18%
Positioning error is from 51 to 350m	38%	37%	31%
Positioning error is $>$ 350m	37%	10%	2%

Table II gives detailed results about the percentage of each type in each positioning accuracy interval. For example, consider type 1 (i.e., the fingerprint vector contains only one BS), we found that only 25% (17% + 8%) of the points were positioned in an accuracy less or equal to 50 m against 75% of the points that were positioned with low accuracy . On the other hand, 67% (49% +18 %) of the points that have 3 or more BSs were positioned with high accuracy ($\leq$ 50 m) against 33% of the points that were positioned with low accuracy. In fact increasing the length of the fingerprints increases their diversity (higher distinction between the points); and therefore, increases the possibility of making the right match between the on-line fingerprint and the stored ones (database). Therefore, the localization accuracy will be improved by increasing the network density as more BSs will be available.

V. Conclusion

This paper has discussed using fingerprinting-based positioning to locate users in WiMAX networks depending on SCORE measurements. A novel fingerprinting approach was introduced depending on the fact that base stations identifications numbers (Cell-IDs) are more robust against the multipath and fading than RSS-based values. The new approach is called BS-strict because the compared vectors (i.e., fingerprints) must have the same BS values to match. The relation between the number of the detected base stations and the positioning accuracy has been investigated and it has been found that increasing the network density will increase the positioning accuracy.

The obtained results show that using SCORE values to position users in WiMAX networks is feasible with enough positioning accuracy to satisfy most of the known LBS requirements. The achieved accuracy is obtained in the static case (static positioning) and the target's motion information was not used. In dynamic positioning, the target's motion information will be used and better positioning accuracy is expected. Moreover, using the public road network information (assuming that the user is always on the road) will produce additional positioning accuracy improvement [18]. The future work will focus on improving the accuracy by using the motion model information in addition to the public road network information.

References

[1] M. Bshara and L. V. Biesen, "Fingerprinting-Based Localization in WiMAX Networks Depending on SCORE Measurements," *AICT 2009 conference proceedings*, pp. 9–14, May 2009.

[2] Cello consortium report. [Online]. Available: http://www.telecom.ntua.gr/cello/documents/CELLO-WP2-VTT-D03-007-Int.pdf

[3] F. Gustafsson and F. Gunnarsson, "Possibilities and fundamental limitations of positioning using wireless communication networks measurements," *IEEE Signal Process. Mag.*, vol. 22, pp. 41–53, 2005.

[4] G. Sun, J. Chen, W. Guo, and K. Liu, "Signal processing techniques in network-aided positioning: A survey of state-of-the-art positioning designs," *IEEE Signal Process. Mag.*, vol. 22, no. 4, pp. 12–23, July 2005.

[5] S. Gezici, Z. Tian, B. Giannakis, H. Kobayashi, and A. Molisch, "Localization via ultra-wideband radios," *IEEE Signal Process. Mag.*, vol. 22, pp. 70–84, 2005.

[6] D. Li and Y. Hu, "Energy-based collaborative source localization using acoustic microsensor array," *Journal of Applied Signal Processing*, pp. 321–337, 2003.

[7] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, "Field strength and its variability in VHF and UHF land-mobile radio service," *Rev. Elec. Commun. Lab.*, vol. 16, pp. 9–10, 1968.

[8] M. Hata, "Empirical formula for propagation loss in land mobile radio services," *IEEE Trans. Veh. Technol.*, vol. 29, no. 3, pp. 317–325, Aug. 1980.

[9] W. D. Wang and Q. X. Zhu, "RSS-based Monte Carlo localisation for mobile sensor networks," *IET Communications*, pp. 673–681, 2008.

[10] M. Nabaee, A. Pooyafard, and A. Olfat, "Enhanced object tracking with received signal strength using Kalman filter in sensor networks," *Internatioal Symposium on Telecommunications*, pp. 318–323, 2008.

[11] J. Shirahama and T. Ohtsuki, "RSS-based localization in environments with different path loss exponent for each link," *Vehicular Technology Conference*, pp. 1509–1513, 2008.

[12] M. Zhang, S. Zhang, J. Cao, and H. Mei, "A novel indoor localization method based on received signal strength using discrete Fourier transform," *Communications and Networking in China*, pp. 1–5, 2006.

[13] O. Sallent, R. Agusi, and X. Cavlo, "A mobile location service demonstrator based on power measurements," *Vehicular Technology Conference*, vol. 6, no. 1, pp. 4096–4099, Sep. 2004.

[14] A. Taok, N. Kandil, S. Affes, and S. Georges, "Fingerprinting localization using ultra-wideband and neural networks," *Signals, Systems and Electronics*, vol. 54, no. 4, pp. 529–532, Aug. 2007.

[15] *Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband wireless Access Systems*, IEEE Std. 802.16, 2004.

[16] A. Heinrich, M. Majdoub, J. Steuer, and K. Jobmann, "Real-time path-loss position estimation in cellular networks," in *Proceedings of International Conference on Wireless Networks (ICWN'02)*, Jun. 2002.

[17] K.-T. Feng, C.-L. Chen, and C.-H. Chen, "GALE: an enhanced geometry-assisted location estimation algorithm for NLOS environments," *IEEE Trans. Mobile Comput.*, vol. 7, no. 2, pp. 199–213, Feb. 2008.

[18] U. Orguner, T. B. Schön, and F. Gustafsson, "Improved target tracking with road network information," *Proceedings of IEEE Aerospace Conference*, March 2009.