Wireless Location Positioning Based on WiMAX Features - A Preliminary Study

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Abstract. In this paper, we exploit the potential of positioning technologies in wireless broadband communications, which are based on worldwide interoperability for microwave access (WiMAX), in particular the IEEE802.16* standards. By utilizing the additional features in WiMAX including multiple input multiple output (MIMO), adaptive modulation and coding (AMC), beamforming, relay station and power control, we believe that the features can be used for enhancing the location estimation accuracy in location services.

Keywords: WiMAX features, positioning.

1 Introduction

As the wireless technologies develop further, many useful and promising applications come into our lives. In the recent years, location and positioning based services are among the most promising applications which have brought us with great convenience. For instance, by knowing a user's location many new applications often called as Location Based Services (LBS) can be enabled. However, one of the current key issues for LBS is the positioning technologies in wireless broadband communications.

Most current positioning systems are not functioning properly where people spend much of their time, meaning that coverage in these systems is either constrained to outdoor environments or limited to a particular building or campus with installed location infrastructure. For an example, the most popular positioning system, Global Positioning System (GPS) operates worldwide, but it requires a clear view of the skies and signals from at least four satellites. It does not work indoors and operates poorly in many cities where the so called "urban canyons" formed by buildings prevent GPS receiver units from seeing enough satellites to get a position lock [1]. Meanwhile, purpose-built systems such as Active Badge, Cricket, The Bat etc., can be used in indoor environments [2]. However, for cost reasons, people prefer to use existing infrastructure such as mobile phone networks, and wireless LAN (WLAN).

Predictions regarding wireless broadband communications and wireless internet services are cultivating visions of unlimited services and applications that will be available to the user "anywhere and at anytime" [3]. Users expect to surf the Web, access e-mail, download files, have several multimedia applications, such as real-time audio and video streaming, multimedia conferencing, interactive gaming and perform

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a variety of other tasks through a wireless communication link. The user further expects a uniform user interface that will provide access to the wireless link whether shopping at the mall, waiting at the airport, walking around town, or even driving in the car. Current wireless infrastructures, however, as well as next-generation proposals cannot furnish the necessary bandwidth and capacity to provide these services to mobile stations (MSs) [4]. Unfortunately, mobile users will likely be the most demanding of bandwidth and wireless services. Clearly, a broadband wireless solution is needed to provide MSs the high-bandwidth mobile service they demand at a low cost.

Of these, WLAN (also known as 'Wi-Fi') that supports wireless broadband communications can be implemented with the least effort, as its associated consumer hardware is the most readily available. However, Wi-Fi works within a limited range of an access point and suitable only for fixed wireless broadband. Besides that, to ensure the success of delivering high bandwidth and less interference from Base Station (BS) to users especially for MSs, the system depends on accurate positioning systems.

With the arrival of WiMAX recently, the technology is able to fullfill the criteria of the next generation wireless systems. WiMAX is a wireless standard to enable mobile broadband services at a vehicular speed of up to 120 km/h [5]. WiMAX complements and competes with Wi-Fi and the third generation (3G) wireless standards in terms on coverage and data rate. More specifically, WiMAX supports a much larger coverage area than WLAN. On the other hand, it operates at both outdoor and indoor environments as well, does not require line of sight (LOS) for a connection, and is significantly less costly and provides higher data rate as compared to the current 3G cellular standards. Although the WiMAX standard supports both fixed and mobile broadband data services, the latter have a much larger market. In addition, WiMAX supports additional features that can be used for enhancing location and positioning technologies, such as MIMO, AMC, power control, relay station and Beamforming.

The remainder of this paper is organized as follows. Section 2 explains briefly literature review about existing location and positioning techniques. Section 3 discusses proposed techniques to enhance location and positioning in WiMAX. Finally section 4 concludes the paper.

2 Existing Location and Positioning Techniques

The location of the mobile users can be determined in several different ways. Generally, there are three main groups of location and positioning technologies available in the market, namely Satellite based Positioning, Network-based Positioning and Indoor Positioning [6].

The most popular satellite-based positioning is Global Positioning System (GPS). The positioning technique used in GPS is known as *Trilateration* (distance measurement) by which the user's position is calculated using the intersection of the spheres determined by the distances between the each satellite and the GPS receiver. Having signals from at least three or four satellites, it is sufficient to compute the physical location of a device equipped with a GPS receiver with the location error varies from a couple of meters to several tens of meters depending on the propagation environment.

An example for Network-based Positioning is Global System for Mobile Communications (GSM). The most common positioning methods for GSM are Cell ID, Angle of Arrival (AOA), Received Signal Strength (RSS), Time of Arrival (TOA), and Time Difference of Arrival (TDOA).The Cell ID is used to determine the serving Base Station (BS) and then use the position of the BS as an estimate of the mobile's position. Its accuracy is directly proportional to the cell size in the network. For many location-based services, the accuracy of the Cell ID technique is not sufficient. The AOA involves measuring the angle of arrival of a signal from a BS at mobile phone or vice versa. In either case, a measurement produces a straight-line locus from a BS to a mobile phone. Another AOA measurement will yield a second straight line; the intersection gives the estimation of the mobile's position. The RSS method determines the user's position by signal strength received based on the known mathematical model for the relation of the signal strength and the distance between the mobile phone and the BS.

The TOA technique on the other hand determines the distance between mobile phone and BS by measuring the propagation time (absolute time) of radio wave between them. Using the same concept of trilateration, at least three BS are required to determine mobile user's position. The TDOA is a hyperbolic position determining technique. At two base stations, the time difference of arrival of the signal from a mobile unit is measured. Then the possible solutions where the time difference is constant lie on a hyperbola with each base station located in one of its foci. Forming those hyperbolas between different pairs of base stations, the position of the mobile unit is determined by intersection of all hyperbolas.

Finally, the common positioning technology used in indoor environment is Wireless Fidelity (Wi-Fi). Wi-Fi is based on the IEEE802.11 family of standards and is primarily a local area networking (LAN) technology designed to provide in-building broadband coverage [9]. In general, current Wi-Fi systems based on IEEE802.11a/g support a peak physical layer data rate of 54 Mbps and typically provide indoor coverage over a distance of 100 feet. Obviously, Wi-Fi is not designed and deployed for the purpose of positioning. However, it has found that the most current solutions to determine the location of any mobile users are based on the utilisation of signal strength. The signal strength values from the reference stations (access points (APs)) are measured by the positioning device. And based on the use of signal information (signal quality, signal strength, SNR and so on), there have been two possible implementations – the fingerprinting approach and the propagation approach.

3 Proposed Location and Positioning Based on WiMAX

There are many approaches in determining a user's location – some of which are explained in [1, 2, 6-8] – however, location and positioning (L&P) technologies based on WiMAX is not widely investigated yet although there exist some proposal such as in [10, 11]. WiMAX has some useful features that can be employed to enhance the positioning accurracy including MIMO, AMC, Beamforming, Relay Station and power control.

Based on the concept of 'Trilateration' that are used in many existing L&P technologies, we proposed an idea to determine WiMAX user's location as illustrated in figure

1. According to figure 1, each MIMO BS and MS are equipped with MIMO antennas that consist of multiple transmitters and receivers (multiple antennas) on both sides which is N_t transmit antenna on the BS and N_r receive antenna on the MS. In this case, N_t different signals are transmitted simultaneously over minimum of N_t x N_r transmission paths and each of those N_r received signals is a combination of all the N_t transmitted signals and distorting noise. Hence, the multiple of transmission path may be achieved by adopting MIMO systems as compared to conventional 1 x 1 systems that use single antenna at both ends of the link with the same requirement of power and bandwidth. On the other hands, multiple number of simultaneous signals can be transmitted from a MIMO BS, and by applying trilateration method, more signals will be detected by MS. Therefore, we believe that MIMO will not only improve the capacity and the throughput of a wireless link significantly but can also be used to enhance the accuracy of a user's location. Furthermore, each MIMO BS will transmit the signals to the Network Management Systems (NMS) which in turn monitors the network accurately and provides L&P services for updating the user's location.

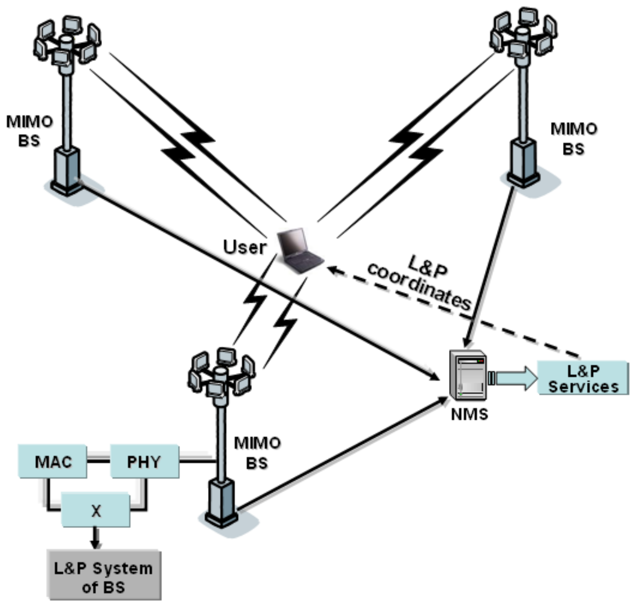

Fig. 1. Proposed System Architecture of Location and Positioning in WiMAX Services

Meanwhile, AMC allows WiMAX system to adjust the signal modulation scheme (64QAM, 16QAM, QPSK or BPSK) depending on the signal-to-noise (SNR) condition of the radio link. The idea behind the AMC is to dynamically adapt the modulation and coding scheme to the channel condition so as to achieve highest spectral efficiency at all times. However, this causes the signal level to be almost the same throughout a BS coverage area, so that the signal level measurement cannot be used to estimate the location of mobile users. In addition, WiMAX uses power control to adjust the signal quality based on SNR. As a result, the same scenario as above can be seen in the signal level. Nonetheless, by taking the information from both the physical layer (the type of modulation scheme used and power control reading) and MAC layer at WiMAX BS, the data can be used to determine the MS's location as shown in figure 2.

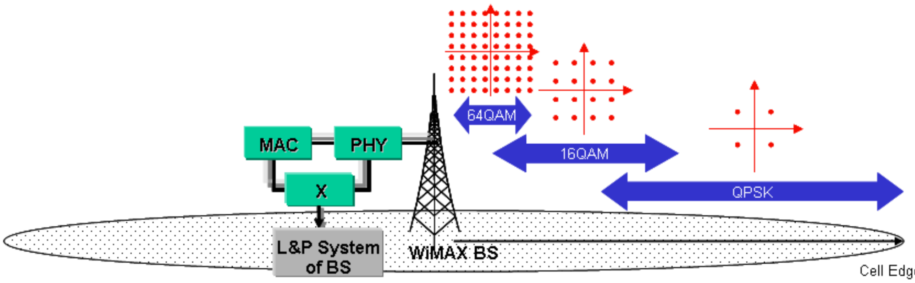

Fig. 2. Scheme for the Utilization of AMC

In order to determine the area covered by each modulation scheme, the maximal distance, R_i between BS and MS must be calculated first using a corresponding modulation. This distance is determined using the maximal SNR a user should received without data loss. Different values of received SNR for different modulation/coding scheme have been calculated in [13] and are shown in Table 1. Then, R_i can be calculated using information in Table 1. Without loss of generality, we study AMC in the presence of path loss for free space only (other sources of interference are negligible) and the model is given by [9]:

$$PL_i[dB] = -10log\left[\frac{\lambda^2 G_t G_r}{(4\pi R_i)^2}\right] \quad (1)$$

where λ is the wavelength, G_t and G_r is tranmitter and receiver antenna gain, respectively and R_i is the distance between the transmitter and the receiver. Equation (1) is also equal to:

$$PL_i[dB] = P_t[dBm] - SNR[dBm] - N[dBm] \quad (2)$$

where P_t is the transmitter power and N is the thermal noise which is given by:

$$N[dBm] = 10log(\tau TW) \quad (3)$$

where $\tau = 1.38 \times 10^{-23} JK^{-1}$ is the Boltzman constant, T is the temperature in Kelvin ($T = 290$) and W is the transmission bandwidth in Hz.

Using the above equations, we can calculate the relationship between the distance and the SNR as follows:

$$R_i = \frac{\lambda \times 10^{\frac{P_t[dBm]+10\log(G_t)+10log(G_r)-SNR[dB]-N[dm]}{20}}}{4\pi} \quad (4)$$

Table 1. Receiver SNR Assumptions

Modulation	Coding Rate	Receiver SNR (dB)
BPSK	½	3.0
QPSK	½	6.0
	¾	8.5
16-QAM	½	11.5
	¾	15.0
64-QAM	2/3	19.0
	¾	21.0

And the area of each region for each modulation is given by:

$$S_i = \pi \times \left(R_i{}^2 - R_{i-1}^2\right) \tag{5}$$

It is worth noting that wireless relay has been proposed as a solution to extend the coverage of a single base station. In 2006, the IEEE approved a project called P802.16j (802.16j), for a mobile multihop relay (MMR) specification to extend BS reach and coverage without the backhaul requirement [13]. The MMR-BS provides the primary area of coverage. It also has a backhaul connection, such as leased copper or fiber optics. The relay station (RS) extends the BS coverage. A MS can connect to BS, an MMR-BS or a RS. Therefore, multiple relay stations, in addition to a BS are not only to be used for enhancing the throughput and improving the range of the BS, but they can be used for positioning purpose. In this feature, the concept to determine MS position is the same with other positioning methods by applying trilateration method based on at least three number of base station. However, in the case of Wi-MAX positioning, we propose to use only one BS with assisted relay stations which means that the MS can be estimated within a cell by using the serving BS with assisted of relay stations as shown in figure 3.

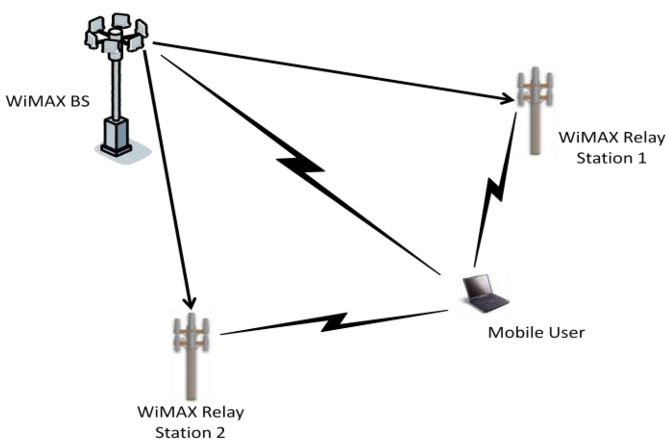

Fig. 3. WiMAX BS with Assisted Relay Stations

4 A Simulation Example

This section presents preliminary results from the simulation of a simple MIMO communication system and the effect of AMC on coverage area. In the case of MIMO simulation, we compare the location estimation accuracy at different types of base antenna mode between SISO and MIMO antennas. We consider the antenna as a diversity antenna, so that only the time of arrival (TOA) measurements are taken into account. For simplicity, we make assumption that transmitter and receiver are perfectly synchronized.

In the TOA measurements, the range data are created by calculating the true distance from an MS position to known BS positions and measurement noise are added to the true calculated range to get the measured range data. The measurement noise is assumed to be Gaussian distribution with standard deviation of $\sigma = 100m$. Then the estimate of an MS position can be determined by using trilateration method as shown in Figure 1. The scenario consists of three synchronized BSs, organized in a cell with radius of about 500m and the true position of an MS is located near the center of the all BSs coverage. Table 2 compares the estimated error of the location between SISO and MIMO antenna. From the results, we can see that the MS location can be estimated with high accuracy as the number of antenna increases.

Table 2. Comparison of Average RMSE with Different Antenna Mode Configurations

Antenna Mode Configurations	Mean Distance Error [meter]	Standard Deviation [meter]
SISO	105.73	64.14
2x1 MIMO	87.32	49.89
2x2 MIMO	75.67	40.13
4x2 MIMO	71.73	35.45
4x4 MIMO	66.21	31.23

To illustrate the effect of coverage area from the BS upon the usage of AMC, let us consider the following example based on the licensed band for WiMAX outdoor environment which has carrier frequency and system bandwidth equal to 3.4GHz and 20 MHz, respectively. At this transmission bandwidth, the thermal noise can be equal to -100.97 dBm. According to the maximum allowed Effective Isotropic Radiated Power (EIRP) of 1W, the transmitters are assumed to have transmission power P_t of 1W which equals 30 dBm. We consider the case of antennas in BS and MS without gain. Based on Table 1, we run 500 samples for different SNR values and the result can be seen in figure 4. From the figure, we can see that a particular modulation and coding scheme (MCS) will be employed if the MS is within a certain distance from the BS. Therefore by using this logic, we can say that if an MS is using a particular MCS, we can approximate its distance from the BS. This is achieved by assuming that the selection of the MCS is based solely on the distance from the BS and other factors such as channel condition do not influence the selection of that particular MCS.

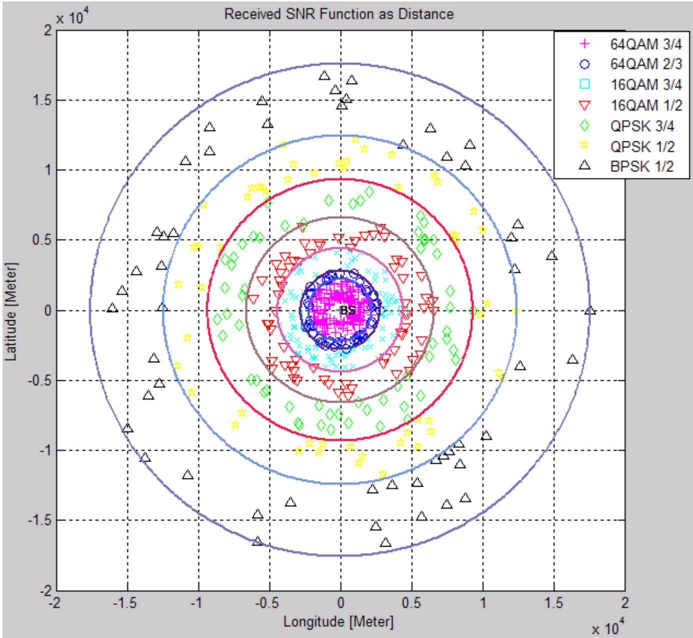

Fig. 4. Received SNR Function as Distance

5 Conclusion

In this paper, we presented the potential of wireless broadband communications usage in particular the WiMAX or the IEEE 802.16* standards for positioning technologies. Depending on the required accuracy and network topology, different positioning methods such as trilateration/triangulation, round trip delay, Cell ID, fingerprinting etc can be employed for WiMAX [14]. We have proposed a location and positioning service for WiMAX based on trilateration concept by taking into consideration the offered features of WiMAX so it can enhance the accuracy of user's location. Preliminary simulations for MIMO and AMC have been carried out. The MIMO results validate that the positioning accuracy of the MIMO antenna modes is better than that of SISO antenna modes, while the AMC could be used to approximate the distance of MS from BS. Our next step shall be on employing more accurate channel model to replace the gaussian channel model used in this work. Furthermore, we will include the parameters from the features of WiMAX such as relay, beamforming and power control in the calculation of the location of the MS.

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