Enhancing Location Estimation Accuracy in WiMAX Networks

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Abstract—Mobile location technologies have attracted significant attention as a mean to deal with the ever increasing demand of wireless communication services. With the availability of WiMAX systems, the technology becomes a feasible solution to support location services in wireless broadband networks. In this paper, we utilise some of the WiMAX offered features namely multiple input multiple output (MIMO), adaptive modulation and coding (AMC), beamforming, and relay station (RS) for enhancing the location estimation accuracy in location services. Simulation results show that in term of location estimation accuracy, the proposed solution adheres to Federal Communications Commission (FCC) requirements.

I. INTRODUCTION

As the wireless technologies develop further, many useful and promising applications have been brought into our daily life. In recent years, location and positioning (L&P) based services are among the most promising applications which provided great convenience to users. For instance, by knowing a mobile station (MS) position many new applications often called as Location Based Services (LBS) can be enabled. These include, but not limited to tracking, location sensitive billing, public safety and enhanced emergency services, monitoring, and etc [1].

Due to high demand on unlimited services and applications, wireless broadband communications are becoming more popular since the users are provided with “anywhere and at any time” kind of service. With the existence of WiMAX, the provision of mobile broadband connectivity together with other essential applications (e.g L&P of MS) is becoming reality. WiMAX is a wireless standard to enable mobile broadband services at a vehicular speed of up to 120 km/h [2, 3]. WiMAX complements and competes with Wi-Fi and the third generation (3G) wireless standards in terms of 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 and do not require line of sight (LOS) for a connection between the MS and a Base Station (BS). It is also 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. Furthermore, WiMAX has some unique features that can be employed for enhancing the positioning accuracy [4, 5].

With the introduction of new Position Computation Service (PCS) in the mobile WiMAX market, increased competition is expected between service providers to attract consumers. However, to the best our knowledge, there is no feasible solution for mobile WiMAX positioning which is not dependent upon GPS. In this paper we propose a novel mobile WiMAX positioning scheme by utilizing some of the WiMAX offered features in order to enhance the accuracy of location estimation in location services.

The remainder of this paper is organized as follows. Section II explains briefly literature review about existing L&P techniques. Section III discusses proposed techniques to enhance L&P in WiMAX networks. Section IV presents preliminary results and finally section V concludes the paper.

II. EXISTING LOCATION AND POSITIONING TECHNIQUES

There are many different location-estimation schemes that have been proposed to acquire the MS’s position. The MS’s position can be determined using various parameters such as signal strength (SS), angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA), hybrid methods, and etc [1, 6]. The SS is a technique in which the distance from base station (BS) to MS is estimated using the received power. The power at the MS depends on the average path loss, shadowing conditions and the small scale fading effects. The AOA estimations can be obtained if the network infrastructure provides antenna arrays, with the restriction that the accuracy is highly dependent on the LOS conditions.  Time based method (TOA and TDOA approach) is the most widely used technique in positioning technology. The TOA approach determines the distance between an MS and a BS by measuring the propagation time (absolute time) of radio wave between them. Using the concept of trilateration, at least three BSs are required to determine MS’s position. Meanwhile, the TDOA is a hyperbolic position determining technique. At two BSs, the TDOA of the signal from an MS is measured. Then the possible solutions where the time difference is constant lie on a hyperbola with each BS located in one of its foci. Forming those hyperbolas between different pairs of BSs, the position of the MS is determined by intersection of all hyperbolas.

III. PROPOSED LOCATION AND POSITIONING IN WiMAX

There are many approaches in determining a MS’s position – some of which are explained in [6-10], however, L&P technologies based on WiMAX is not widely investigated yet although there exist some proposal such as in [11, 12]. WiMAX has some useful features that can be employed to enhance the positioning accuracy including MIMO, AMC,
beamforming and RS. Based on the concept of ‘trilateration’ that are employed in many existing L&P technologies, we proposed an idea to determine WiMAX MS’s position as illustrated in Fig. 1. The following sub-sections will discuss the proposed techniques based on WiMAX offered features.

**A. Positioning Using MIMO Features**

As illustrated in Fig. 1, in the MIMO features, an individual 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, \( N_r \) different signals are transmitted simultaneously over minimum of \( N_t \times N_r \) 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 hand, multiple numbers 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 improve the accuracy of a MS’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 MS’s location. Note that at this stage we consider the MIMO antenna is diversity antenna, so that only TOA measurements are taken into account. In the WiMAX downlink, there is a preamble consist of a known OFDM(A) symbol that can be used to attain initial synchronization between the BSs and the MS [13]. Therefore, under the assumption that the transmitter and the receiver are perfectly synchronized, the MS is able to identify the TOA signals from each MIMO antenna based on detection of downlink preamble signals that are transmitted by each WiMAX MIMO BS as shown in Fig. 2 which was obtained as a result of WiMAX simulation.

According to the conventional linear least squares (LLS) estimation [14], the MIMO TOA based method with \( M \) BSs estimates

\[
\hat{x}_{MIMO} = \arg \min_x \sum_{i=1}^{M} \sum_{l=1}^{L} \sum_{j=1}^{J} |\delta_{i,n}^l - \|x - x_i^l\|^2
\]

where \( x \) is the true position of MS, \( x_i^l \) and \( \delta_{i,n}^l \) denote the coordinates of \( i \)th BS and the range measurement between the \( i \)th BS and the MS with \( i \)th pilot (preamble) signal, respectively, \( i = 1, 2, ..., M \) and \( n = 1, 2, ..., N_i \times N_r \).

**B. Proposed MIMO Positioning with Virtual BS**

In addition to the MIMO system, we propose a novel location estimation algorithm with virtual BS (VirBS). In this work, we deal with MIMO2x1 antenna mode configurations where 2 TOA signals are measured between each BS and MS. Since the simultaneous signals transmitted from the same location of BS (by assuming that antenna spacing is negligible), the improvement of location estimation accuracy is not so good. In addition, it can be expected that the performance of the location estimation will be a function of the number of BSs and the addition of measurements from more BSs, if available, should result in improved accuracy. However, taking into account the constraint on hearability when power control is employed in a wireless cellular system to reduce interference, the number of BSs considered in positioning should be limited. On the other hand, in reality, it is not practical to arbitrarily install additional BSs. Therefore, with MIMO system in the case of MIMO2x1, one of TOA signals measured between particular BS and MS can be used in designing VirBS. Therefore the number of BS will increase virtually without any influence to the interferences. In order to determine the suitable location of VirBS, a good geometric topology must be chosen. The geometry topology is based on geometric dilution of precision (GDOP) [15]. A large GDOP value corresponds to poor geometry topology, which will
result in inferior performance by adopting most of the existing location algorithms. Conversely, the smaller GDOP value, the more accurate of location estimation can be achieved. Therefore, the proposed location estimation algorithm with VirBS will reduce the GDOP effect by incorporating the assisted VirBS. The proposed VirBS algorithm can be formulated by solving any existing location algorithms (in this case LLS algorithm has been chosen) with the additional geometric constraints, which are determined by the locations of the VirBS. The solution is obtained by minimizing NLOS errors among the larger TOA measurements for each MIMO BSs.

Fig. 3 illustrates the schematic diagram of the proposed VirBS formulation including iterative processes for VirBS location estimation and VirBS scheme namely VirBS-COG. During the initial stage, the MS’s position is estimated using VirBS location estimation scheme with the measurement input only from the physical MIMO BS, i.e using the LLS algorithm based on TOA measurements and the location of VirBS is chosen to be located opposite to the physical BS and initial MS. The concept of the proposed VirBS algorithm is to design a mathematically formulated VirBS such that the previously estimated MS will be situated in a better virtual layout without adjusting the location of existing BSs. The virtual range measurement of the VirBS, $R_V$ is determined based on the initial location of MS and by minimizing the NLOS errors. In the VirBS-COG scheme, the VirBS is assigned such that the initial MS is located at the center of gravity of the extended virtual layout, meaning that the initial MS will possess the minimal GDOP value. In order hand, the iteration process in determining the location VirBS at different angles (degree-of-freedom) will be terminated until the initial MS obtain the lowest value of GDOP. After obtaining the location of VirBS, a new location estimate MS can be acquired by applying the VirBS Location Estimation algorithms.

C. Positioning Using Beamforming Features

Beamforming as one of WiMAX features commonly used to boosts both capacity and coverage. However in this feature, the beamforming will be employed to improve the location estimation accuracy. Beamforming is the method used to create the radiation pattern of an antenna array. Beamforming utilizes multiple antenna elements, or arrays, as is the case with diversity and MIMO techniques. There are two prevalent beamforming techniques namely Direction of Arrival (DOA)-based beamforming and eigenbeamforming – differ from one another regarding the direction toward which energy is focused [3].

DOA-based beamforming is based on physical direction, while eigenbeamforming (also known as intelligent beamforming) is based on mathematical direction. In this paper, our focus will be the first technique by using parameter measurements of TOA and DOA for MIMO system. The DOA of MS signals at a BS can be obtained by antenna arrays. The DOA of the MS signal can be calculated by measuring the phase difference between the antenna array elements or by measuring the power spectral density across the antenna array.

By combining the DOA estimates of the at least two BSs, an estimate of the MS’s position can be obtained as illustrated in Fig. 4.

More generally, assume $M$ BSs estimate the DOA of the MS signal, and the goal is to combine these measurements to estimate the MS location. As indicated in Fig. 4, let $\beta_1$ and $\beta_2$ denote the AOA of the MS signal at $BS_1$ and $BS_2$, respectively. Then we have

$$
\begin{bmatrix}
x_u \\
y_u
\end{bmatrix} = \begin{bmatrix}
x_1 \\
y_1
\end{bmatrix} + \begin{bmatrix}
R_1 \cos \beta_1 \\
R_1 \sin \beta_1
\end{bmatrix}
$$

and

$$
\begin{bmatrix}
x_u \\
y_u
\end{bmatrix} = \begin{bmatrix}
x_2 \\
y_2
\end{bmatrix} + \begin{bmatrix}
R_2 \cos \beta_2 \\
R_2 \sin \beta_2
\end{bmatrix}
$$

where
\[
R_1 = \sqrt{R_x^2 + R_y^2 - 2R_xR_y\cos(\alpha_x - \beta_x)} = f(\alpha_x, \beta_x, R_x, R_y)
\]
\[
R_2 = \sqrt{R_x^2 + R_y^2 - 2R_xR_y\cos(\alpha_y - \beta_y)} = f(\alpha_y, \beta_y, R_x, R_y)
\]

Since \(\alpha_x, \alpha_y, \beta_x, \beta_y, R_x, R_y\) is known, we simply denote \(R_1\) as a function of \(R_2\) as \(R_1 = f(R_2)\), and so on \(R_2\) as a function of \(R_1\) as \(R_2 = f(R_1)\).

Likewise, for any other BS:\
\[
\begin{bmatrix}
  x_u \\
  y_u
\end{bmatrix} = \begin{bmatrix}
  x_l \\
  y_l
\end{bmatrix} + \begin{bmatrix}
  R_1 \cos \beta_l \\
  R_1 \sin \beta_l
\end{bmatrix}
\]

(4)

In a case there are more than two BSs, a LLS formulation can be obtained by collecting the relations in above equation into a single equation as
\[
\hat{b} = A\hat{\theta}
\]

(5)

where
\[
\begin{bmatrix}
  x_1 + R_x\cos \beta_1 \\
  y_1 + R_x\sin \beta_1 \\
  x_2 + R_x\cos \beta_2 \\
  y_2 + R_x\sin \beta_2 \\
  \vdots \\
  x_l + R_x\cos \beta_l \\
  y_l + R_x\sin \beta_l
\end{bmatrix},
A = \begin{bmatrix}
  1 & 0 & 1 & \vdots & 1 & 0 \\
  0 & 1 & 0 & \vdots & 0 & 1 \\
\end{bmatrix},
\hat{\theta} = \begin{bmatrix}
  x_u \\
  y_u
\end{bmatrix}
\]

The least squares solution for \(\theta\) is then
\[
\hat{\theta} = (A^T A)^{-1} A^T \hat{b}
\]

(6)

**D. Positioning Using AMC Features**

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 Fig. 1. In each region, users have the same modulation and coding scheme (MCS). In order to determine the area covered by each modulation scheme, the maximal distance, \(R_e\) 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 MCS have been calculated in [16] and are shown in Table I. Then, \(R_e\) can be calculated using information in Table I. 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 [3]:

\[
PL_i[\text{dB}] = -10\log \left( \frac{\lambda^2 G_t G_r}{(4\pi R_e^2)} \right)
\]

(7)

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

\[
PL_i[\text{dB}] = P_t[\text{dBm}] - \text{SNR}[\text{dB}] - N[\text{dBm}]
\]

(8)

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

\[
N[\text{dBm}] = 10\log (\tau T W)
\]

(9)

where \(\tau = 1.38 \times 10^{-23} K^{-1}\) 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:

\[
R_e = \frac{\lambda \times 10^{(P_t[\text{dBm}]+10\log \log (G_t)+10\log \log (G_r)-\text{SNR}[\text{dB}]+N[\text{dBm}])/20}}{4\pi}
\]

(10)

**TABLE I READER SNR ASSUMPTIONS**

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Coding Rate</th>
<th>Receiver SNR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>½</td>
<td>3.0</td>
</tr>
<tr>
<td>QPSK</td>
<td>¼</td>
<td>6.0</td>
</tr>
<tr>
<td>16-QAM</td>
<td>½</td>
<td>11.5</td>
</tr>
<tr>
<td>64-QAM</td>
<td>¼</td>
<td>15.0</td>
</tr>
<tr>
<td>2/3</td>
<td>¼</td>
<td>21.0</td>
</tr>
</tbody>
</table>

**E. Positioning Using RS Features**

Wireless relay has been proposed as a solution to extend the coverage of a single BS. 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 [17]. The MMR-BS provides the primary area of coverage. It also has a backhaul connection, such as leased copper or fiber optics. The RS extends the BS coverage. A MS can connect to BS, an MMR-BS or a RS. Therefore, multiple RSs, 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’s position is the same with other positioning methods by applying trilateration method based on at least three number of BS. However, in the case of WiMAX positioning, only one BS with assistance of RSs is proposed which means that the MS can be estimated within a cell by using the serving BS with assisted of RSs as shown in Fig. 1.
been shown that the performance of the positioning algorithms lack behind as compared to the MIMO performance. It has shows improvement with the number of BSs however it is accuracy can be achieved. Besides, the accuracy in SISO also increase number of MIMO antenna at BS, the better range accuracy of location estimation. It is observed that with the increasing number of BS leads to the increasing of the error decreases with an increasing of BSs. On the other hand, BSs. Generally, it was shown that the mean of the location be seen in Fig. 5. In this scenario, the location estimation sets and the MS’s position is obtained by averaging over all the 1000 estimates. In the TOA measurements, the range data are created by calculating the distance from a true MS’s position to the known BS positions and the measurement noise and NLOS are added to the true calculated range to get the measured range data. Then the estimate of MS’s position can be determined by using trilateration method based on the LLS and non linear least square (NLLS) algorithms [14, 18].

We performed simulation at the various numbers of SISO and MIMO BS when true position of MS is located at the centre of the all BSs coverage and the simulation results can be seen in Fig. 5. In this scenario, the location estimation accuracy is checked for the situations of 3 BSs, 4 BSs and 5 BSs. Generally, it was shown that the mean of the location error decreases with an increasing of BSs. On the other hand, the increasing number of BS leads to the increasing of the accuracy of location estimation. It is observed that with the increase number of MIMO antenna at BS, the better range accuracy can be achieved. Besides, the accuracy in SISO also shows improvement with the number of BSs however it is lack behind as compared to the MIMO performance. It has been shown that the performance of the positioning algorithms will be a function of the number of BSs and with the addition of measurement from more BSs, if available improved distance accuracy should be obtained. However, taking into consideration the constraint on ability when power control is employed in wireless cellular systems to minimize interference, the number of BS involved in positioning should be limited. Nonetheless, the BS is equipped MIMO antenna configurations will no be effected by this constraint because their capability to double up the signals.

In order to evaluate the degree of improvement for all the antenna mode configurations, the cumulative probability for the squared value of location error under LLS and NLLS algorithms is shown in Fig. 6. It can be observed that the average RMSE for the NLLS algorithm is better compared to LLS algorithm for all the antenna mode configurations. It can be seen that an average MIMO antenna configurations brings down the average location error below the FCC requirements, much more than the case for SISO.

Simulation is performed to show the effectiveness of the proposed VirBS algorithms under various number of virtual BS. The noise models and simulation parameters are the same as above MIMO simulation. However the MIMO BS will be fixed at three BS. The performance is compared between the proposed VirBS scheme at different number of VirBS with MIMO2x1 system and the result as shown in Fig. 7. Generally, we can see that the accuracy of location estimation for MIMO with VirBS is better than the MIMO without additional VirBS. It is observed in Fig. 7 that the estimation errors are reduced as the numbers of VirBS are augmented. For an example, the mean location errors is 130m, 116m, 110m and 93m for 3 MIMO BS only, 3 MIMO BS with 1 VirBS, 3 MIMO BS with 2 VirBS and 3 MIMO BS with 3 VirBS, respectively. It is shown that the improvement of location estimation with additional VirBS can achieve around 30 percent by selecting the suitable location of VirBS that possess lowest GDOP.

Next, simulation in beamforming is performed with the same parameters in MIMO simulation with additional DOA-based beamforming measurements where DOA caused by channel is considered to be Gaussian distributed with a zero mean and standard deviation is set to 5 degree. Fig. 8 shows the average RMSE for the proposed TOA/DOA-based beamforming as compared with that TOA only location at various numbers of BSs. It can be seen that the combination of TOA and DOA-based beamforming perform well than TOA for any antenna mode configurations. As expected, it is observed that with an increasing number of BSs, the accuracy of the position estimation improves consistently, especially when large MIMO antennas are present at the BSs.

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 I, we run 500 samples for different SNR values and the result can be seen in Fig. 9. From the figure, we can see that a particular 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.

Finally, in order to study the performance of location estimation in RS features, we perform simulation under the propagation scenario in typical urban macro-cell [19] and used channel models proposed in [20]. The TOA estimation between BS/RS and MS is determined by delay spread that measured from power delay profiles in [20]. Simulations are performed in three cases. In the Case#1, we determine the location estimation errors between three BSs. Then, for the Case#2, three BSs with $n$ assisted RSs $(n = 1, 2)$ is used to estimate the position of MS. Finally, the Case#3, MR-BS with
two assistance RSs is used to estimate the position of MS. The channels between BSs/RSs and MS are corrupted with NLOS noises, generated using circular disk scatterer model (CDSM) model [21]. Note that only SISO antenna mode configuration is considered in this simulation and the result can be seen in Fig. 10. It can be observed that the performance of location estimation accuracy for BS with the assistance RS(Case#2 and Case#3) is better than BS without RS assisted(Case#1) for the error model considered. The mean of the location error decreases with an increasing of RSs. In addition, Case#3 performs very well than the Case#1 and Case#2 due to small NLOS errors between RS and MS.

V. CONCLUSIONS

In this paper we presented the potential of wireless broadband communications usage in particular the WiMAX for location estimation. We have proposed a L&P service for WiMAX based on trilateration concept by taking into consideration the offered features of WiMAX so it can enhance the accuracy of MS’s position. Preliminary simulations for MIMO, VirBS, beamforming, RS and AMC have been carried out. The MIMO results showed that the positioning accuracy of the MIMO antenna modes is better than that of SISO antenna modes which meets the FCC requirements. It has been validated that the proposed VirBS scheme provides better accuracy for location estimation compared with existing MIMO based positioning method. Simulation results also demonstrated that the proposed hybrid TOA/DOA-based beamforming location scheme generally performs better than TOA only location schemes while the AMC could be used to approximate the distance of MS from BS. Finally, the performance evaluation results showed that the RS can be used as the solution to improve the location estimation accuracy without additional of BS.

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Fig. 9 Received SNR Function as Distance

Fig. 10 The CDF location error Using LLS Algorithm for SISO antenna mode configurations with Assistance of RSs

REFERENCES


