Hybrid TOA-Based MIMO and DOA-Based Beamforming for Location and Positioning in WiMAX Networks

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Abstract— **This paper proposes on the development of a hybrid location and positioning (L&P) system by combining range measurements and angle measurements for a multiple input multiple output (MIMO) system. The proposed hybrid technique called as hybrid multiple linear lines of position (HMLLOP) algorithm extends the fundamental idea of using the multiple linear lines of position (MLLOP) scheme when extra information in the form of direction of arrival (DOA) measurements at a minimum of three base stations (BSs) is available. The technique explores the use of multiple linear lines of position (LOP) instead of circular LOP and determines new lower and upper bounds of DOA according to the measurements obtained from an MLLOP scheme which aims to minimize the DOA error caused by non-line of sight (NLOS) propagation. Simulation results have been provided that show that the proposed hybrid schemes outperform the range-only algorithm in terms of estimated location accuracy. It has been shown that time of arrival (TOA)-based location can be used as a baseline location estimation technique, with additional DOA measurements being used to further improve accuracy.**

Index Terms— **Direction of Arrival, Hybrid Location and Positioning, MIMO, WiMAX.**

I. INTRODUCTION

Hybrid L&P algorithms which use the combinations of available range, range-difference and angle of arrival (AOA) measurements to estimate the mobile station (MS) position in a wireless communication system. It is very helpful in certain application scenarios, especially when the number of BSs is limited.

MS position can be determined using various parameters such as signal strength (SS), AOA, TOA, time difference of arrival (TDOA), hybrid methods, etc. [1-3]. Among them, hybrid location systems are more popular because of their potential for estimating location with high accuracy. It is noted that a major problem that affects the accuracy of mobile location estimates is NLOS propagation, where the absence of a direct LOS path between BS and MS results in biased measurements and produces inaccurate positioning in the estimation of MS location, no matter which technique is utilized. NLOS propagation results in time and angle measurements that have large errors due to single or multiple reflections and diffraction of the signal between the MS and BS. For direction finding location systems, the angle from which the signal arrives at the MS does not represent the true direction of the BS. This can lead to a severe degradation in positioning accuracy if standard LOS-based location estimation algorithms are employed. In the last few years, several researchers have focused on mitigation techniques to deal with NLOS errors in measured times or angles of arrival [4, 5].

As described in [6] WiMAX technology supports several multiple-antenna technologies, such as smart antenna systems, beamforming and MIMO. Recently, combination of both beamforming and MIMO technologies have been utilized for mobile location scenario [7]. It has been mentioned that MIMO may be utilized when available at BSs and MS to improve location estimation accuracy [8]. MIMO can also be combined with beamforming to offer optimal estimation accuracy results [9]. By exploiting the multipath characteristics of MIMO and beamforming, it is possible to determine the position of the MS by considering the capability of MIMO to mitigate NLOS conditions. In a wireless system, parameters such as the TOA and DOA of multipath signals can be estimated by using advanced array signal processing techniques such as in [10].

In this paper, a hybrid L&P technique is proposed which determine the position of the MS based on a combination of a MLLOP range-based algorithm and DOA-based beamforming is proposed. As proposed in [11], the use of an MLLOP scheme increases the efficiency of the proposed scheme. The proposed hybrid technique augments the fundamental idea of using an MLLOP scheme when extra information in the form of DOA measurements at a minimum of three BSs is available. The technique explores the use of multiple LOP instead of circular LOP and determines new lower and upper bounds for DOA according to the measurements obtained from an MLLOP scheme which aims at minimizing the DOA error caused by NLOS propagation.

The remainder of this paper is organized as follows: Section II provides an introduction to beamforming in WiMAX. In

addition, we also present an L&P system using DOA-based beamforming and review the existing hybrid TOA-DOA algorithms. The proposed L&P technique, combining TOA and DOA-based beamforming for a MIMO system at several BSs has been proposed in Section III. Section IV discusses the performance of the proposed algorithm evaluated via computer simulations. Finally, our concluding remarks are given in section V.

II. LITERATURE REVIEW

A. Introduction to Beamforming in WiMAX

Beamforming is one of the WiMAX features commonly used to boost both capacity and coverage [9]. Beamforming is 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 DOA-based beamforming and eigenbeamforming – they differ from one another regarding the direction toward which energy is focused [6, 12].

DOA-based beamforming [6] is based on physical direction, where MSs are characterized in terms of DOA, or the physical angle from which the user energy arrives at the front of the beamformer antenna array. This technique determines in which direction, relative to the beamformer, the MS is located. After the DOA is obtained for each received signal, a weighting vector (consists of amplitude and phase shift information) of each antenna element is calculated, thus enhancing the desired signal in the physical direction of the specific user at the time of transition. On the other hand, eigenbeamforming (also known as intelligent beamforming) [6] is based on the mathematical direction in that it does not use a physical interpretation such as a geometric angle. The technique employs the channel impulse response at each beamformer antenna element to calculate the array weights that satisfy the desired criteria such as signal-to-interference-and-noise ratio (SINR) maximization. As long as the channel response is known at the beamformer, this technique focuses a beam in a mathematical direction, based on the mathematical decomposition of the channel array towards the desired user.

In this paper, our focus will be on the first technique, by using parameter measurements of TOA and DOA for a MIMO system. The DOA of MS signals at a BS can be obtained via antenna arrays and 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 at least two BSs, an estimate of the MS's position can be obtained, as described later in Section II (B).

B. DOA-Based Beamforming for L&P System

The use of AOA or DOA-based beamforming estimation at the MS, in addition to TOA based L&P, namely hybrid TOA/DOA-based beamforming techniques, can reduce the number of BSs required for a position fix or, if the number of BSs is kept constant, increase the redundancy and consequently the robustness and accuracy of the system.

The DOA of the MS signal can be estimated by measuring the phase difference between the antenna array elements or by measuring the power spectral density across the antenna array in what is known as beamforming, as explained in [13]. In other words, beamforming is the method used to create the radiation pattern of an antenna array. It can be applied in all antenna array systems as well as in MIMO systems. By combining the DOA estimates of at least two BSs, an estimate of the MS position can be obtained. The scenario is illustrated in Figure 1, below.
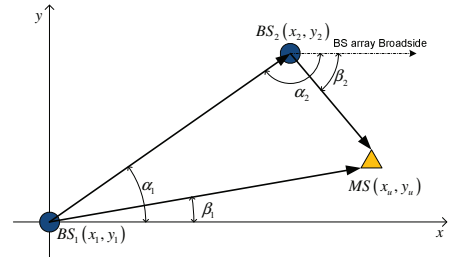

Figure 1: DOA-based beamforming data fusion with two BSs

One benefit of a DOA-based beamforming L&P method is that the number of BSs required for location estimation is fewer than that of TOA and TDOA methods. Another advantage of DOA location methods is that no clock synchronization is required between the BS and MS. On the other hand, in contrast with TOA/TDOA based location methods, a DOA based location algorithm does not need to consider timing synchronization problems. One disadvantage of the DOA method is, however, that the antenna array used at the BS is not available in 2G systems though it is planned for 3G cellular systems, such as UMTS and CDMA2000[14]. In addition, with the advent of WiMAX technology, this standard supports several smart antenna technologies, including MIMO and advanced (or adaptive) antenna systems (AAS) in both subscriber terminals and BSs [12]. Therefore, the parameters of DOA in WiMAX MIMO systems can be estimated by using advanced array signal processing, i.e combining TOA-based L&P; hence the integration of both techniques can further improve location estimation accuracy.

We assume that N BSs measure the DOA of the MS signal, and that the aim is to combine these measurements to calculate the MS position. As illustrated in Figure 1, let β_1 and β_2 denote the DOA of the MS signal at BS_1 and BS_2, respectively. Then, we have

$$\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} + \begin{bmatrix} R_1 \cos \beta_1 \\ R_1 \sin \beta_1 \end{bmatrix} \tag{1}$$

and:

$$\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} x_2 \\ y_2 \end{bmatrix} + \begin{bmatrix} R_2 \cos \beta_2 \\ R_2 \sin \beta_2 \end{bmatrix} \tag{2}$$

where:

$$R_1 = \sqrt{R_2^2 + R_{12}^2 - 2R_2 R_{12} \cos(\alpha_2 - \beta_2)}$$
$$= f(\alpha_2, \beta_2, R_2, R_{12})$$

(3)

Since $\alpha_1, \alpha_2, \beta_1, \beta_2, R_{12}$ are known, we simply denote R_1 as a function of R_2 as $R_1 = f_1(R_2)$, and correspondingly R_2 as a function of R_1 as $R_2 = f_2(R_1)$.

Likewise, for any other BS_i:

$$\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} x_i \\ y_i \end{bmatrix} + \begin{bmatrix} R_i \cos \beta_i \\ R_i \sin \beta_i \end{bmatrix}$$

(4)

In case if there are more than two BSs, a linear least square (LLS) formulation can be obtained by collecting together the relations in the above equations into a single equation as:

$$b = A\theta$$

(5)

where:

$$b = \begin{bmatrix} x_1 + R_1 \cos \beta_1 \\ y_1 + R_1 \sin \beta_1 \\ \hline x_2 + R_2 \cos \beta_2 \\ y_2 + R_2 \sin \beta_2 \\ \hline \vdots \\ \hline x_i + R_i \cos \beta_i \\ y_i + R_i \sin \beta_i \end{bmatrix}, \quad A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ \hline 1 & 0 \\ 0 & 1 \\ \hline \vdots & \vdots \\ \hline 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad \theta = \begin{bmatrix} x_u \\ y_u \end{bmatrix}$$

The least squares solution for θ is then:

$$\theta = (A^T A)^{-1} A^T b$$

(6)

Besides the regular sources of error in DOA measurements, such as noise and interference, DOA measurements can be corrupted by NLOS effects and errors in the angular orientation of the installed antenna arrays. Therefore, in our research, we will aim at improving the location accuracy by simultaneous utilizing of a variety of techniques.

C.   Review of Hybrid TOA-DOA Using LLS/NLLS (HTD)

The following is a two-step hybrid TOA/DOA-based beamforming procedure proposed by Sayed et al. [15] whereby a TOA procedure uses LLS and NLLS algorithms, and an AOA procedure applies an LLS algorithm. We assume that *N* BSs estimate the TOA and AOA of the MS. From the TOA equation, the LLS estimate of the MS position using TOA measurements is given by [16]:

$$\theta_{TOA} = (A^T{}_{TOA} A_{TOA})^{-1} A^T{}_{TOA} b_{TOA} + \beta_{TOA}$$

(7)

where:

(0.1)

$$\theta_{TOA} = \begin{bmatrix} x_u \\ y_u \end{bmatrix}$$

$$\beta_{TOA} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix}$$

$$A_{TOA} = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix}$$

$$b_{TOA} = \begin{bmatrix} b_{21} \\ b_{31} \\ b_{n1} \end{bmatrix}$$

$$b_{ij}{}_{TOA} = 0.5[r_j^2 - r_i^2 + d_{ij}^2]$$

Meanwhile, the NLLS estimate of the MS position using TOA measurement is then given by [16, 17]:

$$\theta_{\{k\}TOA} = \theta_{\{k\}TOA} - \left(J^T_{\{k\}TOA} J_{\{k\}TOA}\right)^{-1} J^T_{\{k\}TOA} f_{\{k\}TOA}$$

(8)

where:

$$\theta_{TOA} = \begin{bmatrix} x_u \\ y_u \end{bmatrix}$$

$$J^T J_{TOA} = \begin{bmatrix} \displaystyle\sum_{i=1}^{n} \frac{(x - x_i)^2}{(f_i + r_i)^2} & \displaystyle\sum_{i=1}^{n} \frac{(x - x_i)(y - y_i)}{(f_i + r_i)^2} \\ \displaystyle\sum_{i=1}^{n} \frac{(x - x_i)(y - y_i)}{(f_i + r_i)^2} & \displaystyle\sum_{i=1}^{n} \frac{(y - y_i)^2}{(f_i + r_i)^2} \end{bmatrix}$$

$$J^T f_{TOA} = \begin{bmatrix} \displaystyle\sum_{i=1}^{n} \frac{(x - x_i) f_i}{(f_i + r_i)} \\ \displaystyle\sum_{i=1}^{n} \frac{(y - y_i) f_i}{(f_i + r_i)} \end{bmatrix}$$

Similarly, the LLS estimate of the MS position using only DOA measurements is given by [16]:

$$\theta_{AOA} = (A^T{}_{AOA} A_{AOA})^{-1} A^T{}_{AOA} b_{AOA}$$

(9)

where:

$$\theta_{AOA} = \begin{bmatrix} x_u \\ y_u \end{bmatrix}$$

$$b_{AOA} = \begin{bmatrix} x_1 + R_1 \cos\beta_1 \\ y_1 + R_1 \sin\beta_1 \\ \hline x_2 + R_2 \cos\beta_2 \\ y_2 + R_2 \sin\beta_2 \\ \hline \vdots \\ \hline x_i + R_i \cos\beta_i \\ y_i + R_i \sin\beta_i \end{bmatrix}$$

$$A_{AOA} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ \hline 1 & 0 \\ 0 & 1 \\ \vdots & \vdots \\ \hline 1 & 0 \\ 0 & 1 \end{bmatrix}$$

The final location estimate can be taken as being a combination of the two estimates (TOA and DOA) as following:

$$\boldsymbol{\theta}_{Hybrid} = \gamma\boldsymbol{\theta}_{TOA} + (1-\gamma)\boldsymbol{\theta}_{AOA} \qquad (10)$$

where a parameter γ is selected depending on the corresponding accuracy of the TOA and DOA measurements. The value of γ is bounded by $0 \le \gamma \le 1$. In practical scenarios, the accuracy of TOA and DOA estimates normally depend on the environment. For instance, in rural coverage areas, TOA measurement can be less accurate than DOA measurement if a large antenna array is utilised. On the other hand, TOA measurements are much better than DOA measurements if the BS antenna array is surrounded by many scatterers. Therefore, the parameters of γ is must be carefully chosen in order to achieve high accuracy location estimation. However, it is quite challenging to select an optimum value for γ because different environments will result in varying accuracy for both TOA and DOA estimates. The selection of a wrong γ value will cause the estimated location to become worse. Therefore, the proposed algorithm, below, solves the problem without the need for γ value selection in any of the environment scenarios.

III. PROPOSED HYBRID MULTIPLE LINEAR LINES OF POSITION

The above hybrid method, assumes that TOA generates circular lines of position (CLOP) and combines these with additional information of DOA to determine MS. It has been described in [11], using MLLOP algorithms that generate multiple LOPs instead of CLOP for the MS by differencing pairs of squared range estimates and proceeding to solve the MS position using a geometric approach or least squares method, can further improve system accuracy.

In this section we propose a hybrid L&P technique by extending the basic idea of utilizing the MLLOP approach when additional information in the form of DOA-based beamforming measurements (as described in Section II (B)) at available BSs. This hybrid technique is called a HMLLOP algorithm. The proposed HMLLOP employs DOA measurements at *N* MIMO BSs, including the home BS, and attempts to emulate the methodology adopted for MLLOP using the TOA measurements [11] to calculate the MS position. We consider the case where the DOA measurements are available at *N* MIMO BSs in a macro-cellular environment. In this hybrid technique, besides employing MLLOP in TOA-based location estimation, errors in DOA can also be minimized by the estimation of new lower bound (LB) and upper bound (UB) values which are obtained from the

MLLOP scheme. Figure 2 shows the geometry of the proposed algorithm implemented in a MIMO2x1 antenna mode configuration at three BSs including the serving BS. For simplicity, we assume that all available BSs have the same MIMO antenna mode configurations.
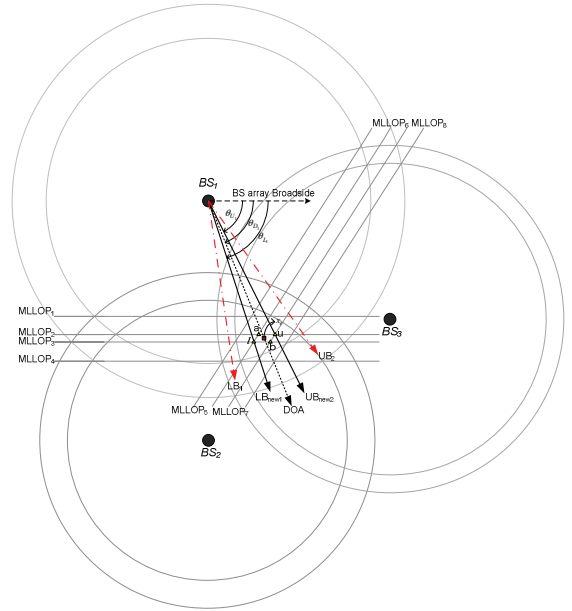

Figure 2: Geometry of HMLLOP-Based Location System

Let us assume *N* BSs with MIMO capability, positioned at $\left\{ x_i = [x_i, y_i]^T ; i = 1, 2, ..., N \right\}$, which acquire TOA and DOA measurements from a communication channel with an MS, and that each TOA measurement between each MIMO antenna at BS_i and MS is denoted by $\delta_{i,n}$ for $n = 1, 2, ..., N_t \times N_r$, where N_t is the number of transmitter antennae; N_r is the number of receiver antennae, and each DOA-based beamforming measurement between MIMO BS_i and the MS is denoted by θ_{D_i}. Recall that for a MIMO2x1 antenna system employing an MLLOP technique producing a total of 16 intersections points of estimation for MS by using TOA measurements, the possible estimates of the MS at the intersection points can be calculated as follows:

$$\hat{x} = \left(H^T H \right)^{-1} H^T B \qquad (11)$$

where:

$$H = \begin{bmatrix} C_1 & 0 \\ 0 & C_1 \\ \hline C_2 & 0 \\ 0 & C_2 \\ \hline \vdots & \vdots \\ \hline C_{N-1} & 0 \\ 0 & C_{N-1} \end{bmatrix}, \quad x = \begin{bmatrix} x_{e_n} \\ y_{e_n} \end{bmatrix},$$

$$B = \begin{bmatrix} B_1(y_1 - y_2) - A_1(y_1 - y_3) \\ A_1(x_1 - x_3) - B_1(x_1 - x_2) \\ \hline B_2(y_1 - y_3) - A_2(y_1 - y_4) \\ A_2(x_1 - x_4) - B_2(x_1 - x_3) \\ \hline \vdots \\ \hline B_{N-1}(y_1 - y_{N-1}) - A_{N-1}(y_1 - y_N) \\ A_{N-1}(x_1 - x_N) - B_{N-1}(x_1 - x_{N-1}) \end{bmatrix}$$

and:

$$A_k = \frac{1}{2}\left[r_{i,n}^2 - r_{1,n}^2 + \|BS_1\|^2 - \|BS_i\|^2 \right]$$

$$B_k = \frac{1}{2}\left[r_{(i+1),n}^2 - r_{1,n}^2 + \|BS_1\|^2 - \|BS_{(i+1)}\|^2 \right]$$

$$C_k = \left(x_1 - x_{(i+1)}\right)\left(y_1 - y_i\right) - \left(x_1 - x_i\right)\left(y_1 - y_{(i+1)}\right)$$

for $k = 1, 2, \ldots N - 1$.

However, it is shown that only 4 intersection points were selected as feasible intersection points to estimate the potential of MS positions which are marked as a, b, l and u points. These points will give the DOA measured relative to a known reference direction. The feasible range between MIMO BS_i and these points is denoted as $\delta_{i,p}$ for $p = 1, 2, \ldots, \varphi_{est}$, where φ_{est} represents the number of feasible intersection points for the estimated MS position.

A.   Upper and Lower Bounds of DOA

Figure 3 depicts an enlarged view of the geometry of an HMLLOP-based location which aims to find a new LB and UB for the measured DOA. As has been mentioned, beamforming is used to direct a signal in a particular direction. However, the DOA-based beamforming will be slightly biased due to NLOS errors. Dissimilar to range error, the error in DOA due to NLOS propagation can be either positive or negative. It can, therefore, be modeled as a Gaussian random variable with zero mean and variance. If the absolute maximum angular error on either side of the true line of position (DOA) is taken to be ψ, then the true DOA for BS_i,

θ_{D_i} is always pointing within $\pm\psi$ of the measured DOA-based beamforming, θ_{Dm_i}. The LB and UB for DOA error are given as follows:

$$\theta_{LB_i} = \theta_{D_i} - \psi; \quad \text{LB}$$
$$\theta_{UB_i} = \theta_{D_i} + \psi; \quad \text{UB} \tag{12}$$

Hence the measurement of DOA must lie between θ_{LB_i} and θ_{UB_i} and is given as follows:

$$\theta_{LB_i} \leq \theta_{Dm_i} \leq \theta_{UB_i} \tag{13}$$

and:

$$\theta_{Dm_i} = \arctan\left(\frac{y_i - y_e}{x_i - x_e}\right) \tag{14}$$

Note that the NLOS errors are included in θ_{Dm_i}. Therefore, this has introduced a non-linear equality constraint on MS location in the form of:

$$\theta_{LB_i} \leq \arctan\left(\frac{y_i - y_e}{x_i - x_e}\right) \leq \theta_{UB_i} \tag{15}$$
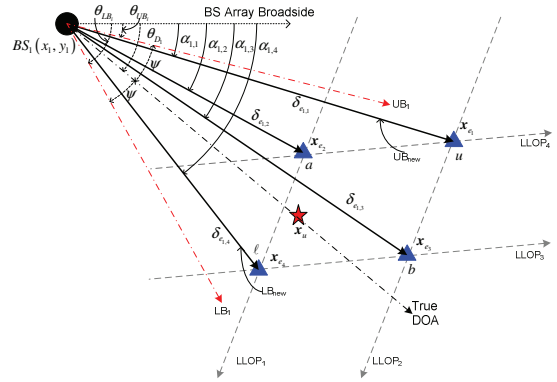

Figure 3 : Geometry of HMLLOP-Based Location for Determining Lower and Upper Bounds of DOA

Next we calculate the range between BS_i and each intersection point (feasible MS location):

$$\delta_{i,p} = \sqrt{\left(x_i - x_{e_p}\right)^T \left(x_i - x_{e_p}\right)} \tag{16}$$

where $x_i = [x_i, y_i]^T$ represents the location of the ith MIMO BS for $i = 1, 2, \ldots, N$ and $x_{e_p} = \left[x_{e_p}, y_{e_p}\right]^T$ denotes the location of the pth feasible estimate of the MS .

In general, if $\alpha_{i,p}$ represents the orientation of the line joining the reference BS and the feasible intersection point of the *i*th and *p*th range linear lines, then considering the geometry of the range linear lines in Figure 3, the angle, $\alpha_{i,p}$, between BS_i and the *p*th feasible MS location can be calculated as [13]:

$$\alpha_{i,p} = \tan^{-1}\left(\frac{y_{e_p} - y_i}{x_{e_p} - x_i}\right) \tag{17}$$

Then, we can calculate the new LB and UB based on the parameters obtained from the MLLOP algorithm. From (17), the LB and UB of the DOA can be determined as:

$$\alpha_{LB_i} = \arg\min\{\alpha_{i,p}\}; \quad LB$$
$$\alpha_{UB_i} = \arg\max\{\alpha_{i,p}\}; \quad UB \tag{18}$$

for $p = 1, 2, ..., \varphi_{est}$.

Finally, the LB and UB of the DOA in (18) are compared with (12), and the new DOA can be determined as per the following conditions shown in Table 1 below.

Table 1

Algorithm to Determine New θ_{D_i}

$$
\begin{array}{l}
if \ \theta_{D_i} \geq \alpha_{LB_i} \ \& \ \theta_{D_i} \leq \alpha_{UB_i} \\
\quad then \quad \theta_{D(new)_i} = \theta_{D_i} \\
elseif \ \theta_{D_i} < \alpha_{LB_i} \\
\quad then \quad \theta_{D(new)_i} = \alpha_{LB_i} \\
elseif \ \theta_{D_i} > \alpha_{UB_i} \\
\quad then \quad \theta_{D(new)_i} = \alpha_{UB_i} \\
end...
\end{array}
$$

Following a similar procedure for MLLOP TOA-based location in (11) and including the new DOA-based beamforming acquired from Table 1, the HMLLOP schemes can be expressed in matrix form as:

$$H_{HMLOP} x = B_{HMLOP} \tag{19}$$

where:

$$
H_{HMLOP} = \begin{bmatrix}
C_1 & 0 \\
0 & C_1 \\
\hline
C_2 & 0 \\
0 & C_2 \\
\hline
\vdots & \vdots \\
C_{N-1} & 0 \\
0 & C_{N-1} \\
-\sin(\theta_{new_1}) & \cos(\theta_{new_1}) \\
-\sin(\theta_{new_2}) & \cos(\theta_{new_2}) \\
\vdots & \vdots \\
-\sin(\theta_{new_N}) & \cos(\theta_{new_N})
\end{bmatrix}
$$

and:

$$
B_{MLOP} = \begin{bmatrix}
B_1(y_1 - y_2) - A_1(y_1 - y_3) \\
A_1(x_1 - x_3) - B_1(x_1 - x_2) \\
\hline
B_2(y_1 - y_3) - A_2(y_1 - y_4) \\
A_2(x_1 - x_4) - B_2(x_1 - x_3) \\
\hline
\vdots \\
\hline
B_{N-1}(y_1 - y_{N-1}) - A_{N-1}(y_1 - y_N) \\
A_{N-1}(x_1 - x_N) - B_{N-1}(x_1 - x_{N-1}) \\
y_1 \cos(\theta_{new_1}) - x_1 \sin(\theta_{new_1}) \\
y_2 \cos(\theta_{new_2}) - x_2 \sin(\theta_{new_2}) \\
\vdots \\
y_N \cos(\theta_{new_N}) - x_N \sin(\theta_{new_N})
\end{bmatrix}
$$

The solution is then given by:

$$\hat{x} = \left(H_{HMLOP}^T H_{HMLOP}\right)^{-1} H_{HMLOP}^T B_{HMLOP} \tag{20}$$

IV. PERFORMANCE AND SIMULATION OF RESULTS

Simulations were conducted to determine the performance of the hybrid HMLLOP location technique by computer simulation and to compare location accuracy with existing positioning algorithms at various types of antenna mode configurations. The available angular and range measurements are presented in degrees and metres, respectively. In practice, the number of available BSs, typically 3 – 6 BSs, can be overheard by the MS at any time [18]. In this simulation,

location estimation accuracy is checked for situations of up to 5 BSs and simulations are performed under the assumption of a macro cellular environment. In this environment, the BS antenna is assumed to be situated at a higher level relative to the MS. Hence, the angular and range errors are caused by local scatterers around the MS. The geometric coordinates of the BSs are selected as: $BS_1(x_1 = 500, y_1 = 3750)$, $BS_2(x_2 = 2250, y_2 = 4500)$, $BS_3(x_3 = 2250, y_3 = 3000)$, $BS_4(x_4 = 500, y_2 = 2500)$ and $BS_5(x_5 = 500, y_5 = 5550)$. The geometric coordinates of the true MS are $MS(x_u = 1500, y_u = 3750)$. BS_1 is assumed to be the serving BS.

The simulated system parameters have been selected to be similar to the IEEE802.16e downlink system, and the dispersive delay properties of the channel introduce range errors of up to 600m [19]. Therefore, the NLOS range errors are modelled as positive random variables having support over [0, 600m] and generated according to a CDSM model [20]. We assume that for a BS equipped with an antenna array, multiple transmit beams send different pilots to each beam. The receiving MS array can determine the scattered signal strength of each pilot and then recognize which transmit beam is employed. Therefore, the DOAs of multipaths are resolvable according to the different pilot signals from the MS. The DOA error caused by the channel is considered to be a Gaussian distributed variable with a zero mean, and standard deviation (SD) is set to 3, 5, 10 and 20 degrees [21]. The simulated location error has a total number of 1,000 different datasets and the estimation of MS position is obtained by averaging all 1,000 estimates. The TOA and DOA measurements are created by calculating the true distance from an MS position to a known BS with MIMO capability and each is corrupted by NLOS errors.

A. Effects of DOA-Based Beamforming

Firstly, a simulation is performed to investigate the effects of DOA-based beamforming on location estimation. In this simulation, only three BSs are considered. The range measurements are corrupted by NLOS errors with the CDSM model radius of scattering fixed at 100m for all available BSs. Four curves are presented for the DOA SD at 3, 5, 10 and 20 degrees, as shown in Figure 4. As can be observed, with an increasing number of antenna mode configurations, the accuracy of the location estimation improves consistently, especially when large DOA errors are present at the MIMO BSs. On the other hand, the smallest DOA SD error performed almost linearly, in spite of the number of antenna mode configurations.

Meanwhile Figure 5 depicts the proposed DOA-based beamforming by utilising the new LB and UB of the DOA. The simulation was performed to investigate the effectiveness of the proposed scheme at various degrees of DOA SD, i.e. 3, 5 and 10 degrees. The radius of the CDSM NLOS model is fixed at 100m. Basically, it is observed that the proposed DOA scheme performed better than the current measurement of DOA. It is noticed that the improvement is likely to be greater at lower antenna mode configurations and almost identical when a larger antenna mode configuration is employed. In addition, we can observe that the proposed scheme works very

well when the error in DOA SD is increased. For example, for a MIMO2x1 antenna mode, the difference in location error is about 10 metres when DOA SD is 3 degrees, then it rises dramatically to about 90 metres when DOA SD is increased to 10 degrees. In summary, the proposed DOA scheme supports the improvement of L&P estimation, especially when there are large errors in DOA SD.
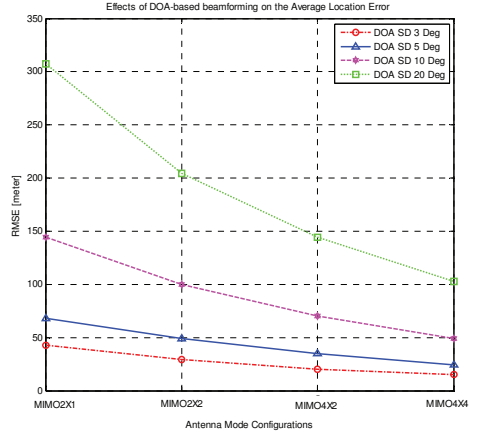

Figure 4: Effects of DOA Standard Deviation on location error with Various Numbers of MIMO Antenna Mode Configurations
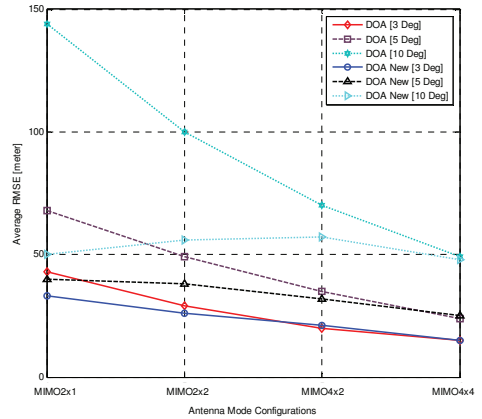

Figure 5 : Comparison of Average RMSE Location Error between Proposed DOA and Current DOA with several Antenna Mode Configurations

Further investigation was carried out to observe the effects of the proposed DOA due to different radii of the CDSM, R_d. It can be seen from the explanation in [20] that the maximum magnitude of the error in DOA is given by $arctan\left(\frac{R_d}{R}\right)$, where R denotes the true range between the MS and available BSs. Figure 6 shows the effects of the radius of CDSM on average RMSE performance between the proposed DOA and current DOA, utilizing MIMO2x1 and MIMO2x2 antenna mode configurations. It is observed that, as the radius of CDSM, R_d rises, the average magnitude of the NLOS range

and DOA increase as well, consequently leading to degradation of location estimation accuracy. This scenario is valid for both MIMO antenna mode configurations. For example, let $R_d = 300m$, the measured range error can increase to as high as about 600m, and the maximum magnitude of DOA error is about 15 degrees. It is also found that the proposed DOA performs better than direct DOA measurement for any radius of CDSM, R_d, for both the MIMO antennae considered. For instance, the gap in the average RMSE measured at an R_d of 300m between the proposed DOA and old DOA is about 90m and 30m, respectively. It is, however, noticed that the performance of the proposed DOA is nearly identical when the R_d value is less than 400m for both MIMO antennae considered.
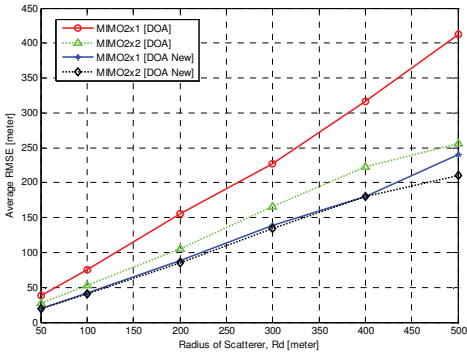

Figure 6 : Effect of the radius of CDSM on average RMSE performance between the proposed DOA and current DOA, utilizing several Antenna Mode Configurations

B.   *Performance Analysis for the HMLLOP Algorithm*

In this section we first carry out simulations to compare the performance of the proposed HMLLOP scheme with the MLLOP scheme proposed in [11] that utilised TOA-based location only. Two cases are tested in these simulations. In the first case, MS positions are varied at two different locations; the first when the MS's true position is located around the centre of all BSs in the region (MSC); the second, when the MS's true position is placed near the serving cell BS (MSN). Table 2 shows the location estimation errors in HMLLOP and MLLOP algorithms at various locations of the real MS for 5 available BSs with DOA SD of 5 degrees. Similarly, Figure 7 illustrates the same scenario results. Generally, the location estimation errors were affected by various locations of the MS. It is observed that the location estimation error when the MS position is at the centre of all BSs' coverage is better than when it is located near to the serving BS. Among the MIMO antenna mode configurations, monitoring the performance of location estimation is greatly improved with increasing numbers of MIMO antennae. As expected, the performance of the HMLLOP scheme is better than the MLLOP scheme, in spite of there being several antenna mode configurations and locations of the MS.

In the second case, a simulation was conducted to study the effect of location estimation accuracy with several numbers of BSs. In this scenario, the performance of location estimation is checked for 3 BSs, 4 BSs and 5 BSs, and the DOA SD is set to 5 degrees. The results of the simulation can be seen in Table 3 and Figure 8. As might be expected, with an increasing number of available BSs in the location estimation calculations, the accuracy of position estimation improves consistently, for both HMLLOP and MLLOP algorithms, especially when large MIMO antennas are present at the BSs. It can be observed that the proposed HMLLOP algorithm performed very much better than the MLLOP algorithm with any antenna mode configurations. In summary, by comparing the performance of HMLLOP and MLLOP, it is observed that the additional DOA information proves useful in minimizing location estimation error.

Table 2
Location Estimation Errors with HMLLOP and MLLOP Algorithms at Various Locations of True MS for 5 BSs

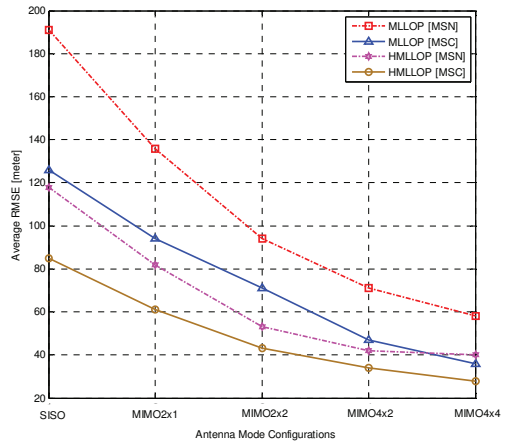| True MS Position	Antenna Configurations	MLLOP Mean RMSE [meter]	HMLLOP ($\sigma_{AOA} = 5^0$) Mean RMSE [meter]
MSN	SISO	191.0	118.4
	MIMO2 x 1	136.6	82.4
	MIMO2 x 2	94.0	52.6
	MIMO4 x 2	71.5	41.6
	MIMO4 x 4	57.8	40.2
MSC	SISO	126.6	85.3
	MIMO2 x 1	93.7	61.4
	MIMO2 x 2	71.1	43.2
	MIMO4 x 2	47.3	33.8
	MIMO4 x 4	35.9	27.5

Figure 7 : Average RMSE for HMLLOP and MLLOP for Different MS True Positions

Table 3
Location Estimation Errors for HMLLOP and MLLOP Algorithms with Number of BSs ($\sigma_{DOA} = 5^0$)

BS	SISO		MIMO2x1		MIMO2x2		MIMO4x2		MIMO4x4	
	Mean RMSE [meter]		Mean RMSE [meter]		Mean RMSE [meter]		Mean RMSE [meter]		Mean RMSE [meter]	
	MLLOP	HMLLOP	MLLOP	HMLLOP	MLLOP	HMLLOP	MLLOP	HMLLOP	MLLOP	HMLLOP
5	126.6	85.3	93.7	61.4	71.1	43.2	47.3	33.8	35.9	27.5
4	160.5	97.9	115.0	73.0	77.6	49.1	57.3	35.7	41.9	28.4
3	201.3	117.6	149.0	87.8	101.6	59.9	75.4	41.8	50.4	33.4
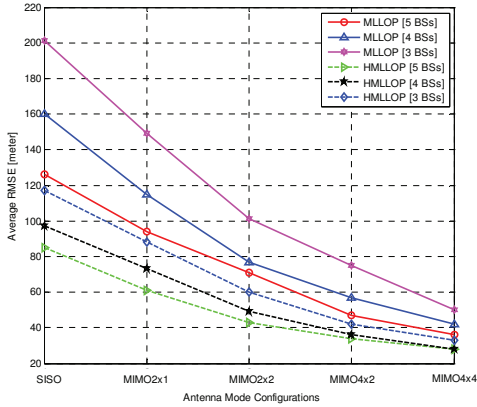
Figure 8 : Average RMSE for HMLLOP and MLLOP with Various Numbers of Base Stations

Figure 9 : CDF of Location Error of the HMLLOP and HTA algorithms for Various Antenna Mode Configurations (CDSM Radius: 200m, DOA SD: 5 Degrees)

Next, we examine the performance of L&P estimation among hybrid techniques. In this simulation we compare the HMLLOP algorithm with the HTD proposed by Sayed et al. [15], as described in Section II-C. The NLOS parameter errors, such as radius of CDSM, R_d, and DOA SD, are fixed at 200m and 5 degrees, respectively. The improvement in L&P estimation provided by the hybrid schemes can be observed in the cumulative distribution function (CDF) of average RMSE error, as illustrated in Figure 9. It can be seen that the proposed HMLLOP algorithm generates more accurate location estimates than the HTD algorithm for the MIMO antenna mode configurations considered. For example, in the case of a MIMO2x1 antenna, the location error of the HMLLOP algorithm is less than 100m for 78% of the time, whereas the HTD algorithm has the same location error for only 58% of the time. It is shown that the same scenario can be observed for the other MIMO antenna mode configurations, where the performance of the HMLLOP scheme is always better than the HTD scheme.
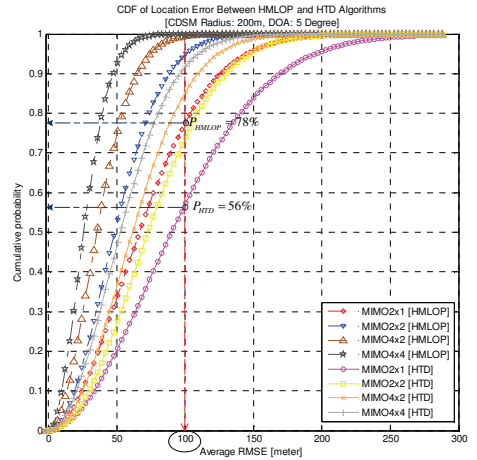
Finally, a simulation was carried out to observe the performance of the proposed HMLLOP algorithm with different radii of the CDSM, R_d, following the same procedure used in Section IV-A. Figure 10 depicts the effects of the radius of the CDSM, R_d, on location estimate performance between the HMLLOP and HTD schemes, utilising MIMO2x1 and MIMO2x2 antenna mode configurations. It can be observed that the performance of location estimates at any MIMO antenna considered becomes worse as the radius of CDSM, R_d, increases for both proposed HMLLOP and HTD algorithms. It is, however, the proposed HMLLOP that always outperforms the HTD scheme. For instance, in MIMO2x2 antenna mode, the average RMSE measured at an R_d of 200m between the proposed HMLLOP and HTD, is about 56m and 67m, respectively.
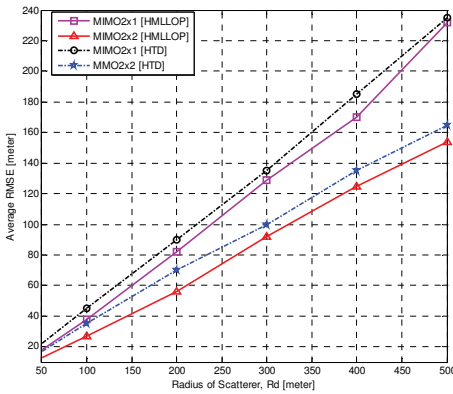
Figure 10 : Effects of the radius of the CDSM on average RMSE performance between the proposed HMLLOP and HTD Algorithms utilising several Antenna Mode Configurations

V. CONCLUSION

This paper has proposed on the development of a hybrid L&P system by combining range measurements and angle measurements for a MIMO system. The proposed hybrid scheme, called an HMLLOP algorithm, is proposed as a method to determine the position of the MS based on a combination of an MLLOP range-based algorithm and DOA-based beamforming. The hybrid technique extends the basic idea of using an MLLOP scheme with additional information about DOA measurements when available. The proposed technique involves the use of multiple LOP instead of circular LOP and utilizes the bounds on DOA errors due to NLOS to find a solution for location estimation. Simulations of the HMLLOP algorithm were carried out to represent its performance in an outdoor environment, where TOA and DOA measurements are combined. The first simulation was done to investigate the effect of DOA-based beamforming on location estimation. The results show that with the extra parameter of DOA, the proposed technique supports improved accuracy of location estimation, especially for large errors in DOA standard deviation. It was also shown through simulations that the hybrid HMLLOP algorithm provides better location accuracy than their range-based counterparts, in spite of any antenna mode configurations. The proposed algorithm is also more robust, regardless of whether the true MS location is located around the centre of the available BSs' coverage or is placed near the serving cell BS. In addition, compared to the existing hybrid HTD algorithm, the proposed technique achieved better performance when several MIMO antenna mode configurations were considered. More specifically, the results demonstrate that the average location error of the proposed algorithm is less than 85m for 67% of the time, whereas the HTD algorithm is less than 115m for the same error location, in the case of a MIMO 2x1 antenna mode configuration with NLOS parameter errors of radius of CDSM and DOA SD set to 200m and 5 degrees, respectively.

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