Performance Analysis of TOA-based Positioning in LTE by utilizing MIMO Feature

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Abstract—**This paper presents the performance analysis of a TOA-based positioning in LTE by utilizing MIMO feature. In this work, the wireless channels between the mobile terminal (MT) and eNodeBs are modeled by using a geometric-based stochastic channel models in WINNER II to measure the propagation delay. Then, the location of the MT is estimated by using the geometric-based multiple linear line of position (MLLOP) technique. We focus the analysis on the typical urban microcell scenario (B1 Hotspot) with three fixed-located eNodeBs and a randomly located mobile terminal. The simulation works are executed in both LOS and NLOS conditions. We compare the performance of MIMO feature utilization to SISO antenna configuration system based on root mean square error. The results show that utilizing MIMO feature enhances the estimation accuracy. The number of antenna elements at the receiver and transmitter greatly influence the estimation accuracy of MT's position. The best performance is achieved by utilizing MIMO 4x4 configuration that gives the estimation error of less than 18m and 25m for 67% and 90% of the time respectively.**

Index Terms— **LTE Positioning; MIMO Antenna Configuration; TOA; Urban Microcell.**

I. INTRODUCTION

The most accessible location & positioning (L&P) systems for mobile communication networks is the global navigation satellite system (GNSS) or normally called as Global Positioning System (GPS). The weakness of GPS is that it provides high estimation accuracy only when the mobile terminal (MT) has clear connection or line of sight (LOS) condition which requires the access to at least four satellites [1]. Unfortunately, under ill conditions like indoor, urban and dense environments, the access to the satellites is very limited, making the GPS-assisted (L&P) techniques less reliable.

To accommodate the increasing demand of location based services (LBSs), the potential of terrestrial signals is widely explored through the development of mobile communication network-based L&P techniques. Even though the enhancement of estimation accuracy in network-based L&P techniques have been extensively carried out through out the years, mitigating the multipath and non-line-of-sight (NLOS) propagation remain the main research issue especially in the time-based positioning. In the time-based positioning techniques, multipath propagation causes bias in the propagation delay [2] or normally called as time of arrival (TOA) measurements. The multipath effect is intensified in an NLOS condition where the direct path between eNBs and MT is absent due to the presence of obstructions and scatterers in the surrounding.

To mitigate the effect of multipath and NLOS propagations, many researches have been carried out to enhance the estimation accuracy through the manipulation of the special features available in the systems. For example, the authors in [2] exploited device-to-device (D2D) communication feature which is newly introduced in LTE systems by proposing cooperative L&P technique. The authors in [3] utilize beam forming capability of the antenna used in the systems, while in [4], the availability of relay stations is manipulated. Basically, the techniques proposed in the previously mentioned works rely on the same concept which is reducing estimation error by using multiple sources of radio signal. Another feature that is very interesting to explore is the multiple input multiple output (MIMO) antenna configuration.

As defined in the 3GPP Technical Specification Release 11 [5], MIMO technology is one of the special features supported by the LTE systems. The MIMO feature has been expansively exploited in geometric-based L&P techniques [6]–[9] by taking the consideration of the WiMAX systems specification. This feature is still open to be explored in LTE system. Based on the promising results obtained in the previous studies [6]–[8], in this paper, we investigate the potential of MIMO feature in mitigating multipath and NLOS propagation errors in LTE systems. Firstly, we investigate the effect of NLOS propagation to the TOA measurements in WINNER B1 [10] propagation scenario. Then, we use the multiple linear line of position (MLLOP) technique proposed in [9] to calculate the estimated position.

The remainder of this paper is organized as follows: Section II provides the background study of TOA-based positioning technique. Section III reviews the geometric L&P techniques TOA-based positioning. Then, we describe the simulation set up and discuss the results in Section IV. Finally, the findings are concluded in Section V.

II. BACKGROUND STUDY

Among the measurement parameters that have been used in network-based L&P techniques are time of arrival (TOA) [6], time difference of arrival (TDOA)[11], received signal strength indicator (RSSI)[12], angle of arrival (AOA)[13] and hybrid of those parameters methods [7]. In this paper, we focus on TOA measurement since this parameter is used in the MLLOP.

A. TOA-based Positioning

In the TOA-based positioning techniques, the estimated position of the MT is determined by using the trilateration method as depicted in Figure 1. As seen in the figure, the radius of the circles, r_1, r_2, r_3 which correspond to the time taken by the signal from the MT to reach each of the eNBs (TOA) form three circular line of positions (CLOPs). The position of the MT is at the intersection of the CLOPs.

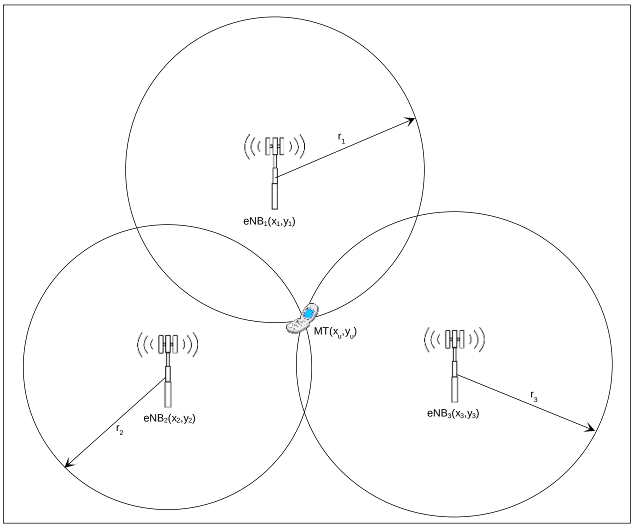

Figure 1: Trilateration method in TOA-based Positioning

In the case of error free condition, the measurement of TOA can be obtained by using Equation (1), where r_i is the distance between eNB and MT, Δ_{TOA} is the difference TOA received by an eNB and the reference eNB, and c is the speed of light.

$$r_i = \Delta_{TOA} \times c \tag{1}$$

However, in the presence of multipath signals, the TOA measurement is subject to noise error as described in Equation (2). The term $L_i(t_i)$represents the true distance between the MT and eNBi, $n_i(t_i)$ is the Gaussian measurement noise. The term $NLOS_i(t_i)$ represents the NLOS error at time sample t_i where i=1,2,3,…M and M is the number of available eNBs.

$$r_i(t_i) = L_i(t_i) + n_i(t_i) + NLOS_i(t_i) \tag{2}$$

The true distance, $L_i(t_i)$ is calculated as in Equation (3), where (x_i,y_i) is the coordinate of eNB$_i$ and (x_u,y_u) is the true location of the MT.

$$L_i(t_i) = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2} \tag{3}$$

Then, the estimated position of the MT can be calculated by expanding Equation (4) to find the estimated position of the MT (x_e,y_e), where (x_i,y_i) ~~in~~ is the coordinate of eNB$_i$.

$$r_{i,n} = \sqrt{(x_i - x_e)^2 + (y_i - y_e)^2} \tag{4}$$

The simplest method to estimate the MT's position is by using the linear least square (LLS) method. The estimated position can be solved based on matrix form equations as in Equation (5) – (9):

$$\boldsymbol{Ax} = \boldsymbol{b} \tag{5}$$

where:

$$\boldsymbol{A} = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix}, \boldsymbol{x} = \begin{bmatrix} x - x_1 \\ y - y_1 \end{bmatrix}, \boldsymbol{b} = \begin{bmatrix} b_{21} \\ b_{31} \\ \vdots \\ b_{n1} \end{bmatrix} \tag{6}$$

with:

$$b_{ij} = 0.5\left[r_j^2 - r_i^2 + d_{ij}^2\right] \tag{7}$$

and:

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 - \left(y_i - y_j\right)^2} \tag{8}$$

where i=1,2,…,n and n represents the number of available eNBs. The term d_{ij} denotes the distance between eNB$_i$ and eNB$_j$. Then, the estimated position of MT is obtained from Equation (9), where $\boldsymbol{X}$ is the coordinate of reference eNB denoted by $(x_1,y_1)^T$.

$$\boldsymbol{x} = (\boldsymbol{A}^T\boldsymbol{A})^{-1}\boldsymbol{A}^T\boldsymbol{b} + \boldsymbol{X} \tag{9}$$

LLS is less accurate since it does not consider the effect of multipath and NLOS errors where the CLOPs may intersect at more than one point.

B. LTE Channel Model

The performance of time-based L&P techniques is highly dependent on the propagation of the signals through the wireless channel between the MT and eNBs which determines NLOS error. Therefore, the channel model is an essential tool for simulation, performance evaluation and testing the L&P schemes. For LTE systems, there are two channel models that can be used which are tapped-delay line (TDL) and Geometric-based Stochastic Channel Models (GSCM) [14]. In this paper, we use a type of GSCM namely WINNER II channel model [10] to model the wireless link between the MT and eNBs. WINNER II calculates the channel impulse response based on the geometric properties of the stations and scatterers in a stochastic manner.

As summarized in Table 2-1 of [10], a wide range of propagation scenarios is supported by WINNER II including indoor office, typical urban microcell, bad urban, suburban, typical urban macrocell and rural macrocell. We limit the work of this paper to considering only typical urban microcell (B1 Hotspot). WINNER B1 is a grid-based scenario where the location of eNBs can be set by using Cartesian coordinates. The details about the channel model can be found in [10].

III. REVIEW OF GEOMETRIC ESTIMATION TECHNIQUES

A. Linear Line of Position Method

The linear line of position (LLOP) method was proposed in [15] to enhance the estimation accuracy by introducing linear lines that connect the intersections of the corresponding CLOPs. As depicted in Figure 2, for a three eNBs layout, there are three LLOP introduced to connect the intersections between eNB$_1$-eNB$_2$, eNB$_1$-eNB$_3$ and eNB$_2$-eNB$_3$. The position of the MT is estimated at the intersection of the three LLOPs.

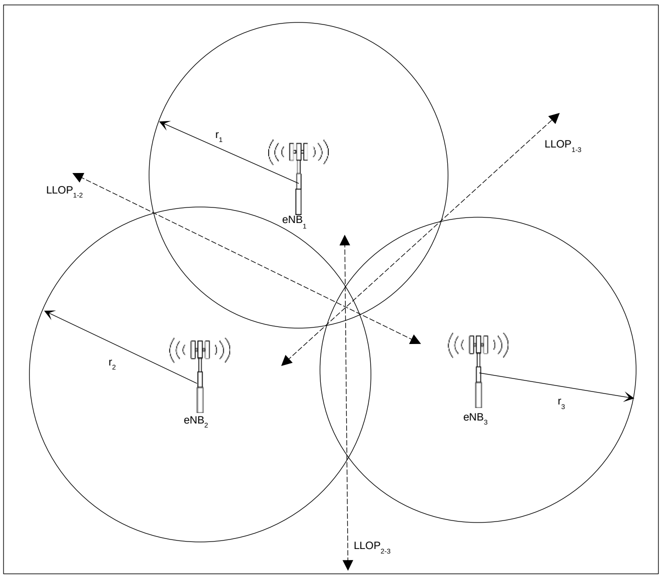

Figure 2: TOA-based Positioning using LLOP Technique

This method is suitable for SISO antenna configuration system since it handles single CLOP of every eNB. In this paper, we use this method to investigate the effect of NLOS condition scenarios at two different eNB antenna height.

B. *Multiple Linear Lines of Position Method*

The MLLOP technique is an expansion of LLOP by manipulating MIMO antenna configurations in enhancing the position estimation accuracy. The idea is to create multiple linear lines that connect the intersections of the corresponding CLOPs as described in Figure 3. Here, the multiple linear lines produce multiple new intersections which are considered as possible positions of the MT. The final estimated position of MT is calculated by averaging the intersections points.

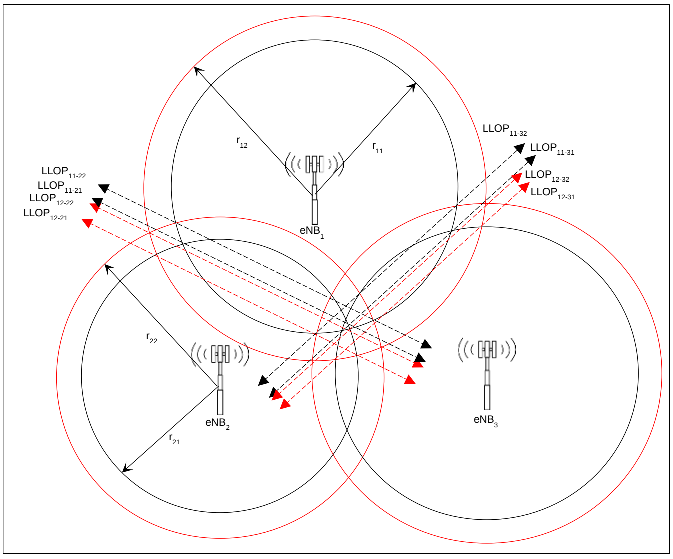

Figure 3: TOA-based Positioning using MLLOP Technique

By taking eNB$_j$ as the reference base station, Equation (4) can be rewritten as Equation (10) with n=1,2,3,…N_r x N_t where N_r is the number of antenna elements at the receiver and N_t is the number of antenna elements at the transmitter.

$$r_{j,n} = \sqrt{\left(x_j - x_e\right)^2 + \left(y_j - y_e\right)^2} \tag{10}$$

The linear lines are found by using Equation (11).

$$r_{j,n}{}^2 - r_{i,n}{}^2 - \left\|BS_j\right\|^2 + \left\|BS_i\right\|^2 = -2\left(x_e\left(x_j - x_i\right) + y_e\left(y_j - y_i\right)\right) \tag{11}$$

where:

$$\left\|BS_j\right\|^2 = x_j^2 + y_j^2, \qquad \left\|BS_i\right\|^2 = x_i^2 + y_i^2 \tag{12}$$

Then, the position of MT (x_e,y_e) is estimated by using Equation (13)-(15).

$$x_{e_n} = \frac{B_k\left(y_j - y_i\right) - A_k\left(y_j - y_{(i+1)}\right)}{C_k} \tag{13}$$

$$y_{e_n} = \frac{B_k\left(x_j - x_{(i+1)}\right) - A_k\left(x_j - x_i\right)}{C_k} \tag{14}$$

where:

$$\begin{aligned} A_k &= \frac{1}{2}\left[R_{i,n}{}^2 - R_{j,n}{}^2 + \left\|BS_j\right\|^2 - \left\|BS_i\right\|^2\right] \\ B_k &= \frac{1}{2}\left[R_{(i+1),n}{}^2 - R_{j,n}{}^2 + \left\|BS_j\right\|^2 - \left\|BS_{(i+1)}\right\|^2\right] \\ C_k &= \left(x_j - x_{(i+1)}\right)\left(y_j - y_i\right) \\ &\quad - \left(x_j - x_i\right)\left(y_j - y_{(i+1)}\right) \end{aligned} \tag{15}$$

for k=1,2,…N-1.

The equations are solved by matrix form representation ~~as~~ by following the similar method as in Equation (5) and (6).

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

A. *Simulation Set Up*

We consider the B1 hotspot propagation scenario which models a typical urban microcell as defined in [10]. The system layout is set up in an 800x600m^2 area with three eNBs located at fixed Cartesian coordinates of eNB$_1$(100,100), eNB$_2$(500,500) and eNB$_3$(800,100). The location of the MT is randomly assigned within the network area. The system parameters used are summarized in Table 1. The 3GPP consortium has specified a number of operating bands for LTE and their regional use [16]. In this paper, we use the downlink carrier frequency of 2.3GHz which falls within the frequency band number 40 in Table 5.5-1 of [16].

Table 1
System Parameters

Parameter	Value
Location of eNBs	[100 100; 500 500; 800 100]
Carrier Frequency	2.3GHz
eNB Antenna Height	7m/20m
MT Antenna Height	1.5m
Antenna Type	Uniform Linear Arrays (ULA)
Propagation model	WINNER II B1 (Urban Microcell)
Propagation condition	LOS/NLOS

B. *Effects of NLOS Error to the Estimation Accuracy*

In this part, we investigate the effects of NLOS propagation to the estimation accuracy by using SISO antenna configurations. For the purpose of comparison, we show a sample of output propagation delay measured in LOS and NLOS condition in Figure 4(a) and (b) respectively. We use the peak detection technique to determine the propagation delay of each wireless link. From the samples shown in Figure 4, the propagation delay is about 8.62ns which resolves to 3m in LOS condition. While in NLOS condition, the propagation delay is detected as 100ns which resolves to 30m.

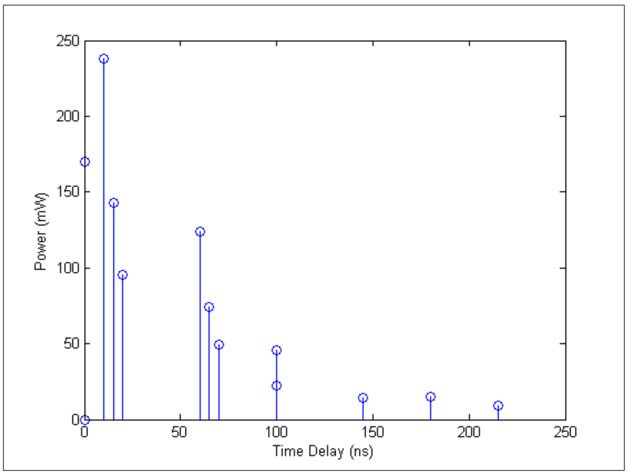

Figure 4(a): A sample of output time delay in LOS condition.

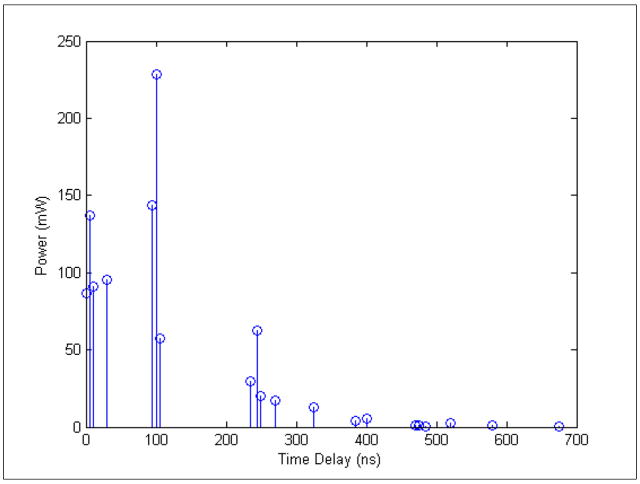

Figure 4(b): A sample of output time delay in NLOS condition.

To further investigate the effect of NLOS condition, the position of MT is estimated by using LLOP method. The estimation accuracy is measured in terms of the root mean square error (RMSE). The TOA measurement of multipath signals is made in both LOS and NLOS propagation conditions at two different eNB antenna heights. We choose the antenna height of 7m and 20m for the eNB and the MT antenna height is set to 1.5m, following the specification in [10]. The simulations are executed based on 100 error samples at 1000 different MT locations for four different cases: LOS condition with eNB antenna height of 7m, LOS condition with eNB antenna height of 20m, NLOS condition with eNB antenna height of 7m and NLOS condition eNB antenna height of 20m.

Figure 5 shows the cumulative probability (CDF) of RMSE for all four cases and Table 2 summarizes the mean and standard deviation values. From the graphs, we can see that both LOS condition cases result in higher accuracy compared to the cases of NLOS condition. This reflects the comparison of output propagation shown in Figure 4(a) and (b). Additionally, in LOS condition cases, the estimation accuracy is higher when the eNB antenna height is set to 20m. At a lower eNB antenna height of 7m, the estimation accuracy decreases by at least 20%. This shows that the antenna height contributes to the multipath propagation error of wireless channel in LOS condition where the signal paths might be distracted by the obstruction of the vehicles and pedestrians around the MT. Conversely, in NLOS condition, the transmitter height does not significantly affect the estimation accuracy. Both cases of NLOS condition give the estimation error of less than 70m and 85m for 67% and 90% of the time respectively.

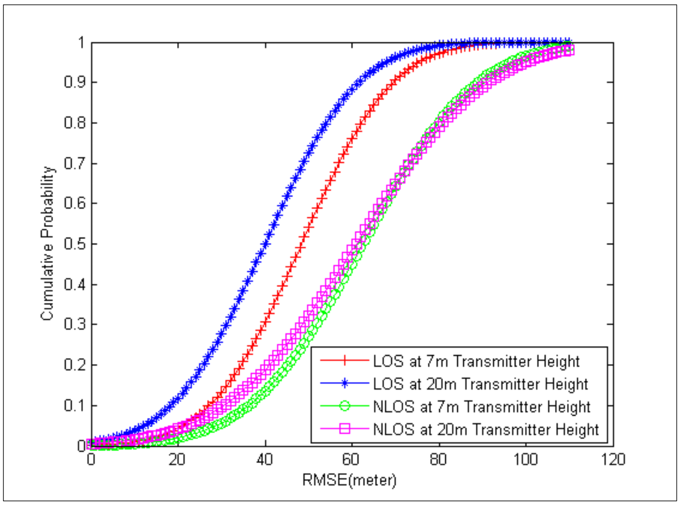

Figure 5: CDF of Location Errors in LOS and NLOS Environment by using SISO Configuration

Table 2
Estimation Error of SISO Configuration in LOS and NLOS Environment

Propagation Condition	Transmitter Height (m)	Mean, µ	Standard Deviation, σ
LOS	7	48.32	16.50
	20	39.94	16.85
NLOS	7	62.53	20.51
	20	60.92	23.70

C. The Performance of MLLOP in LTE system

In this part, we analyze the performance of MLLOP technique in NLOS condition. We utilize three MIMO antenna configurations which are MIMO 2x2, MIMO 4x2 and MIMO 4x4 for eNBs and the MT. The eNB antenna is set at the same height of 20m for all cases. The results obtained from this simulation are compared with the result of SISO antenna configuration case obtained in the previous section. Figure 6 depicts the CDF of RMSE for all four cases and the statistical values are summarized in Table 3.

From the graphs, it is obvious that all three cases that utilize MIMO antenna configuration outperform the case with SISO antenna configuration. For MIMO 2x2 case, the estimation error is less than 50m and 65m for 67% and 90% of the time respectively. The estimation accuracy increases tremendously when higher number of antenna elements of 4x2 and 4x4 are used. When MIMO 4x4 antenna configuration is used, the estimation error of less than 18m and 25m occurs for 67% and 90% of the time respectively. Overall, we can say that the number of antenna elements at the receiver and transmitter greatly influence the estimation accuracy of MT's position. This reflects the concept of MLLOP in which the higher the number of antenna elements, the higher the number of LLOPs created, thus narrowing the error area.

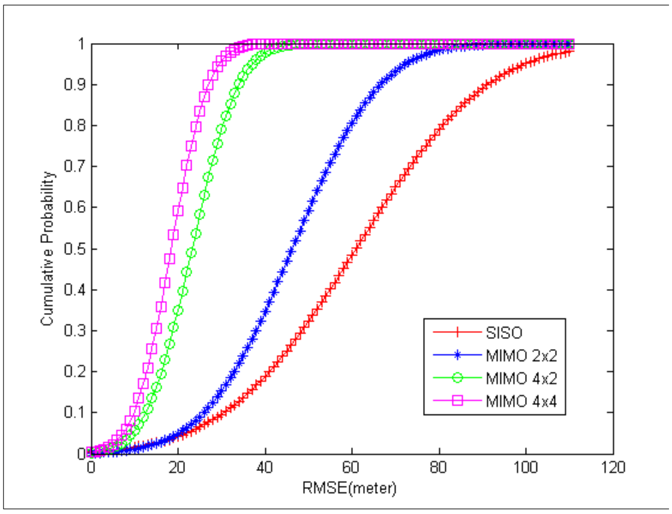

Figure 6: CDF of Location Errors in NLOS Environment by using MLLOP algorithm

Table 3
Estimation Error of MIMO Configurations

Antenna Configuration	Mean, μ	Standard Deviation, σ
SISO	60.92	23.70
MIMO 2x2	46.27	15.87
MIMO 4x2	23.22	8.37
MIMO 4x4	18.43	6.73

V. CONCLUSION

In this paper, we have investigated the potential of using MIMO feature in mitigating multipath and NLOS propagation errors in LTE systems. MIMO 4x4 antenna configuration shows the best performance with the estimation error of less than 18m and 25m for 67% and 90% of the time respectively. Based on the results, we can conclude that the number of antenna elements at the receiver and transmitter greatly influence the estimation accuracy of MT's position. This reflects the concept of MLLOP in which the higher the number of antenna elements, the higher the number of LLOPs created, thus narrowing the error area. In addition, the technique of averaging multiple possible estimated positions can further improve the estimation accuracy. We also compared the effect of eNB antenna height in LOS and NLOS conditions to the estimation accuracy. The results conclude that mounting the eNBs antennas at the suitable height is very important as it can affect the estimation accuracy. Even though the effect seems not severe in the NLOS condition, the factor should be considered in future works. Based on findings in this work, we plan to develop a new L&P technique by considering MIMO feature and observed time difference of arrival (OTDOA).

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