Low Complexity Cooperative Positioning in Multipath Environment

Boda Liu*, Xu Zhu*, Yufei Jiang†, and Yi Huang*
*Department of Electrical Engineering and Electronics, University of Liverpool, Brownlow Hill, Liverpool, U.K.
Email: {B.Liu10, xuzhu, huangyi}@liverpool.ac.uk
†School of Electronic and Information Engineering, Harbin Institute of Technology, Shenzhen, China
Email: Jiangyufei@hit.edu.cn

***Abstract*—In this paper, we propose a cooperative positioning technique based on time-of-arrival (TOA), angle-of-arrival (AOA), angle-of-departure (AOD), and received-signal-strength (RSS) collected from user equipment (UE) in single-bounce multipath environment, referred to as CPTAAR, to mitigate non-line-of-sight (NLOS) error due to single-bounce scattering. This technique can be further improved by a proposed weight function of variance of measurements. Then, a grouping strategy is integrated with the proposed work to reduce the running time of estimation progress, referred to as eCPTAAR. The system performance is verified by simulations and Cramer-Rao Lower Bound (CRLB). It is shown that the proposed techniques can outperform other approaches in terms of positioning accuracy and running time.**

***Index Terms*: cooperative positioning, single-bounce scattering, NLOS**

I. INTRODUCTION

Mobile positioning is an important yet challenging issue due to adverse propagation environment [1]. Widely used mobile positioning methods are based on parameters like time-of-arrival (TOA) [2], angle-of-arrival (AOA) [3], angle-of-departure (AOD) [4], and received-signal-strength (RSS) [5-6].

The main error of mobile positioning is the non-line-of-sight (NLOS) error caused by multipath and scattering environment, which significantly affects TOA, AOA, and AOD. The study on mitigating single-bounce NLOS error caused by scattering of different models can be found in [7-9]. But these methods are based on stationary environment, and their positioning accuracy is lower than that of the techniques in [10-12] which utilize successive measurements and study mobile tracking in scattering environment. Their results show that the accuracy can be improved by continuous iteration and utilizing more measurements. Therefore, it is crucial to improve the original work by other methods which can supply more measurements, such as cooperative positioning.

The single-bounce scattering model is considered to be suitable for mm-wave transmission environment [13-14]. Thus, it is worth studying positioning with single-bounce NLOS dominant scattering environment. The previous work on positioning with single-bounce scattering was based on non-cooperative positioning. In the design of weight for each path in the problem formulation, they utilized equal weight [7-9], or variance of estimated location [10-11], or only the variance of TOA ranging [12] as weight to reduce the variation of estimation, but did not consider the effect of AOA and AOD on weight.

Cooperative positioning is an approach to localize the target with measurements collected from both known and unknown nodes in collaboration. Distributed cooperative positioning based on Bayesian estimation methods were investigated for wireless sensor networks (WSN) [15-16] and wireless local area network (WLAN) [17]. Centralized cooperative positioning is more suitable for cellular networks thanks to the availability of Evolved Serving Mobile Location Center (E-SMLC) [18]. Most work on cooperative positioning [18-19] did not consider NLOS errors due to scattering and requires higher computational complexity than non-cooperative positioning [20] in contrast to mobile users' demands for timely estimation of their location. However, most previous work on reducing running time of distributed cooperative positioning techniques like [15-16] are limited by their own problem formulation and Bayesian estimation methods, and they cannot be employed by centralized cooperative positioning which is solved by nonlinear programming.

In this paper, a cooperative positioning technique is proposed, which employs not only RSS but also TOA, AOA, and AOD, to mitigate NLOS errors caused by single-bounce scattering. This work is different from the conventional work on cooperative positioning which usually ignore the NLOS error caused by scattering. To the best of our knowledge, this is the first work to consider cooperative positioning for mitigating the scattering effect on TOA, AOA, and AOD. Also, it achieves higher accuracy than conventional cooperative positioning [1] in presence of single-bounce scattering. Second, an UE grouping strategy is utilized to decompose the original centralized cooperative positioning to distributed positioning and save running time. The superiority of the UE grouping strategy over existing work is that this method does not make any change on estimation algorithm, so that it is compatible with others' estimation algorithms. To prove its superiority, we propose the integrating method of CPTAAR and UE grouping, referred to as cooperative TOA, AOA, AOD and RSS positioning enhanced by UE grouping for mitigating single-bounce scattering (eCPTAAR). Simulation results show that eCPTAAR can quickly estimate the location of unknown UE

This work was supported in part by Innovate UK under the "Liverpool 5G" project, and by the Science and Technology Innovation Commission of Shenzhen under Project No. JCYJ20170307151258279

with little cost of accuracy. The CRLB is also derived for analytical assessment. Finally, a weight function of TOA, AOA, and AOD is also proposed to further mitigate NLOS errors of BS-UE detection in scattering environment, which has not been studied by the previous work [7-12].

The rest of the paper is organized as follows. Section II illustrates the assumptions made and system model adopted by the work. CPTAAR and eCPTAAR technique with UE grouping strategy are proposed in Section III, along with the CRLB. The system performance is assessed in Section IV. A throughout discussion is contained by the same section. Finally, the conclusion is drawn in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We assume a cluster of M-UEs are distributed among the coverage of several vicinity B-cells, where each UE is surrounded by m-scatters, and each scattered path is measured once. The dominant paths, $s = 1, 2, \ldots, m$, between BS and UE are assumed LOS paths and single-bounce NLOS paths. Figure 1 displays an example of 1 BS detecting 2 UEs in single-bounce scattering environment. Denote the position of j-th UE as $\{\mathbf{x}_j = [x_j, y_j]^{\mathrm{T}},\ j = 1, 2, \ldots, M\}$. The coordinate of i-th BS $\{\mathbf{x}_{\mathrm{BS}i} = [x_i, y_i]^{\mathrm{T}}, i = 1, 2, \ldots, B\}$ is prior known. Thus, the real distance between UE j and BS i is

$$D_{ji} = \sqrt{(x_{\mathrm{BS}i} - x_j)^2 + (y_{\mathrm{BS}i} - y_j)^2} \qquad (1)$$

Based on the assumptions, the typical statistic model of TOA ranging is [1-2]

$$ct = r = \begin{cases} D + n_r, & \text{LOS} \\ D + b + n_r, & \text{NLOS} \end{cases} \qquad (2)$$

where t is the measured TOA, $c = 3\times10^8$ m/s is the speed of light, r is the TOA ranging measurement, b is the NLOS error, and n is the zero-mean Gaussian distributed error. And $b = (r - D)$ is NLOS error assumed to be influenced by only single-bounce scattering effect as shown by Figure 1.
And the models of measured AOA and AOD are [1, 3-4]

$$\tilde{\theta} = \begin{cases} \theta + \varepsilon_\theta, & \text{LOS} \\ \theta + \varepsilon_\theta + \xi_\theta, & \text{NLOS} \end{cases}, \quad \tilde{\vartheta} = \begin{cases} \vartheta + \varepsilon_\vartheta, & \text{LOS} \\ \vartheta + \varepsilon_\vartheta + \xi_\vartheta, & \text{NLOS} \end{cases} \qquad (3)$$

where θ is the real AOA and ϑ is the real AOD, ξ_θ and ξ_ϑ are the extra angle deflected by a scatter in a single-bounce NLOS path for AOA and AOD respectively, ε_θ and ε_ϑ are the measurement noise of AOA and AOD, following Gaussian distribution.

Denote the i-th TOA, local AOD and AOA measurements with respect to BS-UE real direction as r_i, α^T, and α^R in Figure 1. With the fixed length between BS and UE, the position of a scatter determines the trace of a NLOS path. Set l_s as the distance between the s-th scatter and target UE, the coordinate of the scatter is estimated as $(\mathbf{x}_{\mathrm{BS}} + (r_s - l)\angle\vartheta_s)$, which reflects the signal sent to UE $(\mathbf{x}_{\mathrm{BS}} + (r_s - l_s)\angle\vartheta_s - l_s\angle\theta_s)$.

The probability density function (PDF) of a uniform disk scattering model can be expressed as [21]

$$p(r, \alpha^R) = \begin{cases} \dfrac{r}{\pi R^2}, & 0 \le r \le R \text{ and } -\pi \le \alpha^R < \pi \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

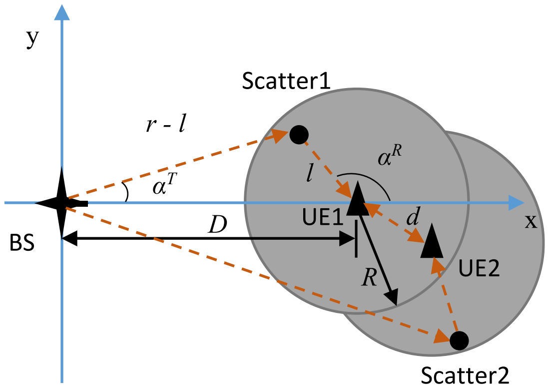


Figure 1. Uniform Disk Model for Single-bounce Scattering Scenario and Cooperative Positioning with the Serving BS

where R is the radius of scattering environment. The total deflected path length is expressed by

$$r = l + \sqrt{l^2 + D^2 + 2lD\cos(\alpha^R)} \qquad (5)$$

The UE in proximity locates the neighboring UE by RSS. RSS is a measurement indicating the power of received signal in 'dBm'. It can be transformed to distance estimation through path loss model [1]

$$\text{RSS}\,[\text{dBm}] = P'[\text{dBm}] - (A + 10n\log(d)) + X_S \qquad (6)$$

where P' is the transmit power, A is the constant term related to environment parameters, e.g. frequency, height of antenna, etc., n is the path loss exponent, X_S is the shadowing term following Gaussian distribution $N(0, \sigma_S^2)$, σ_S^2 is variance of shadowing in unit of 'dB', and d is the real distance between collaborated UE. For example, distance between the k-th UE and the j-th UE can be expressed by

$$d_{j,k} = \sqrt{(x_k - x_j)^2 + (y_k - y_j)^2} \qquad (7)$$

In order to obtain coordinates of UE, the number of NLOS path of each UE should be greater than or equal to two to guarantee acceptable estimation accuracy [7-9].

III. COOPERATIVE POSITIONING FOR MITIGATING NLOS ERROR DUE TO SINGLE-BOUNCE SCATTERING EFFECT AND THE USER EQUIPMENT GROUPING METHOD

First, we present CPTAAR technique to search the optimal location of collaborated UEs which achieve the minimum summation of residual error of BS-UE ranging and UE-UE ranging. Second, UE grouping strategy is proposed to reduce the complexity of cooperative approaches. Third, eCPTAAR is obtained from separating the unknown UEs in CPTAAR according to UE grouping method.

A. *Cooperative Positioning for Mitigating NLOS Error due to Single-Bounce Scattering*

Cooperative positioning is an approach to determine geographical location of the target with measurements collected from a number of nodes. The cooperative positioning is formularized as an optimization problem with respect to multivariable objective function. The CPTAAR is formed by the BS-UE ranging and angle objective function $\mathrm{f}_{\mathrm{BS-UE}}$, and UE-UE ranging objective function $\mathrm{f}_{\mathrm{UE-UE}}$. The weight function w_{jis} denotes the weight of residual error for the s-th path between j-th UE and i-th BS, and it is derived as the variation of each term introduced by $\mathrm{f}_{\text{BS}-\text{UE}}$

$$w_{jis} = \mathrm{var}(b_{jis}) + \mathrm{var}(\mathtt{A}_{jis})\left[(x_j - x_{\text{BS}i})^2 \quad (y_j - y_{\text{BS}i})^2\right]^{\mathrm{T}}$$

$$\mathrm{var}(b_{jis}) = (\sigma_r^2 + D_{ji}^2)(0.5 - 0.5\cos(2\theta_{jis} - 2\vartheta_{jis})\cdot$$
$$e^{-2(\sigma_\theta^2+\sigma_\vartheta^2)}) - D_{ji}^2(\sin(\theta_{jis} - \vartheta_{jis})e^{-0.5(\sigma_\theta^2+\sigma_\vartheta^2)})^2$$

$$\mathrm{var}(\mathtt{A}_{jis}) = \left[A1 \quad A2\right]$$

$$A1 = 1 - 0.5\cos(2\theta_{jis})e^{-2\sigma_\theta^2} - (\sin(\theta_{jis})e^{-0.5\sigma_\theta^2})^2 -$$
$$0.5\cos(2\vartheta_{jis})e^{-2\sigma_\vartheta^2} - (\sin(\vartheta_{jis})e^{-0.5\sigma_\vartheta^2})^2$$

$$A2 = 1 + 0.5\cos(2\theta_{jis})e^{-2\sigma_\theta^2} - (\cos(\theta_{jis})e^{-0.5\sigma_\theta^2})^2 +$$
$$0.5\cos(2\vartheta_{jis})e^{-2\sigma_\vartheta^2} - (\cos(\vartheta_{jis})e^{-0.5\sigma_\vartheta^2})^2$$

The problem of CPTAAR is formularized as optimization problem of nonlinear programming

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}\in R^{2M}}\{\mathrm{f}(\mathbf{x})\} = \arg\min_{\mathbf{x}\in R^{2M}}\{\mathrm{f}_{\text{BS}-\text{UE}}(\mathbf{x}) + \mathrm{f}_{\text{UE}-\text{UE}}(\mathbf{x})\} \tag{8}$$

where the BS-UE objective function is defined as sum of squared Euclidean distance error [7-8]

$$\mathrm{f}_{\text{BS}-\text{UE}}(\mathbf{x}) = \sum_{j=1}^{M}\sum_{i=1}^{B}\sum_{s=1}^{m}\left(B_{jis} - \mathtt{A}_{jis}\mathtt{X}\right)^2$$

If the coordinates difference is $\mathtt{X} = \mathbf{x}_j - \mathbf{x}_{\text{BS}i}$, then the original objective function is updated to

$$\mathrm{f}_{\text{BS}-\text{UE}} = \sum_{j=1}^{M}\sum_{i=1}^{B}\sum_{s=1}^{m}\frac{\left(B_{jis} + \mathtt{A}_{jis}\mathbf{x}_{\text{BS}i} - \mathtt{A}_{jis}\mathbf{x}_j\right)^2}{w_{jis}} \tag{9}$$

$$\mathtt{A}_{jis} = \left\lfloor \sin\tilde{\theta}_{jis} + \sin\tilde{\vartheta}_{jis} \quad -(\cos\tilde{\theta}_{jis} + \cos\tilde{\vartheta}_{jis})\right\rfloor$$

$$B_{jis} = r_{jis}\sin(\tilde{\theta}_{jis} - \tilde{\vartheta}_{jis})$$

and the squared residual error of UE-UE ranging is

$$\mathrm{f}_{\text{UE}-\text{UE}}(\mathbf{x}) = \sum_{j=1}^{M}\sum_{\substack{k=1\\k\neq j}}^{M}\frac{\left(\tilde{d}_{j,k} - d_{j,k}\right)^2}{\sigma_{j,k}^2} \tag{10}$$

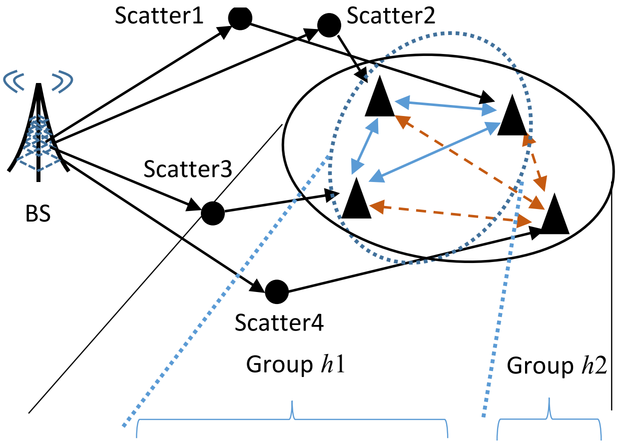
where the employed weight, $\sigma_{j,k}^2$ is the standard deviation of estimate distance between k-th UE and j-th UE, and the true data can be replaced by mean of measurements alternatively. For simplicity, the derivation of (8)-(10) are omitted here.

The minimization of (9) and (10) is the nonlinear programming problem. The above multivariable optimization problem can be solved by iterative numerical algorithm, such as Quasi-Newton, and Nelder-Mead method.

B. User Equipment Grouping Method

UE grouping reallocates the clustered UE with different sequences of localization in terms of the standard deviation of measurements and reduce running time of estimation algorithm wherein all collaborated UEs are reallocated with new labels. This separation strategy reduce the running time by simply transforming the original whole optimization problem to several fractional optimization of smaller sets of unknown variables. In order to keep a certain degree of accuracy, the UE of the low measurement error are assigned to one group, and the UE of the high error are assigned to the other group, so that the UE of high measurement error can be isolated from those of low error. The degree of measurement error is indicated by the standard deviation of relative measurements from each UE. Then, position of the UE of low error are estimated first, based on which those of high error are estimate latter. For example of a terminal group with two-grouping separation in Figure 2, the index of UE in group $h1$ is j=1, 2… a, and the index of UE in group $h2$ is j=a+1, 2... M. Then, the problem is transformed to

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}\in R^{2M}}\{\mathrm{f}(\mathbf{x})\} = \arg\min_{(\mathbf{x}^{h1}\in R^{2h1},\mathbf{x}^{h1}\in R^{2h2})}\{\mathrm{f}(\mathbf{x}^{h1}) + \mathrm{f}(\mathbf{x}^{h2})\} \tag{11}$$



	UE1	UE2	UE3	UE4
UE1	NaN	$\tilde{d}_{1,2}$	$\tilde{d}_{1,3}$	$\tilde{d}_{1,4}$
UE2	$\tilde{d}_{2,1}$	NaN	$\tilde{d}_{2,3}$	$\tilde{d}_{2,4}$
UE3	$\tilde{d}_{3,1}$	$\tilde{d}_{3,2}$	NaN	$\tilde{d}_{3,4}$
UE4	$\tilde{d}_{4,1}$	$\tilde{d}_{4,2}$	$\tilde{d}_{4,3}$	NaN

Figure 2. Cooperative Positioning Enhanced by Two-Grouping Separated 4-UE Terminal Group and Reallocated UE-UE Detection

where positioning of MS in different groups are calculated by two steps respectively as specified by

$$\begin{cases} \mathrm{f}(\mathbf{x}^{h1}) = \sum_{h1}\sum_{BS}\mathrm{f}^2_{\text{BS-UE}}(\mathbf{x}^{h1}) + \sum_{h1}\sum_{h1}\mathrm{f}^2_{\text{UE}-\text{UE}}(\mathbf{x}^{h1}) \\ \mathrm{f}(\mathbf{x}^{h2}) = \sum_{h2}\sum_{BS}\mathrm{f}^2_{\text{BS-UE}}(\mathbf{x}^{h2}) + \sum_{h2}\sum_{h1}\mathrm{f}^2_{\text{UE}-\text{UE}}(\mathbf{x}^{h2}) \\ \qquad + \sum_{h2}\sum_{h2}\mathrm{f}^2_{\text{UE}-\text{UE}}(\mathbf{x}^{h2}) \end{cases} \tag{12}$$

The time reduction brought by UE grouping strategy is attributed to the less computation and unknown variables in optimization progress, even if the total number of unknown variables is not changed. Here is an example of complexity analysis for positioning two-grouping separated UEs solved by Quasi-Newton method of ε - optimality.

Tables I and II display the complexity of the positioning problem solved by quasi-newton method in terms of number of multiplications and square root before and after UE grouping. UE grouping method is expected to be effective with large terminal group which consists of many anchors and measurements.

C. Cooperative Positioning Enhanced by User Equipment Grouping for Mitigating NLOS Errors due to Single-Bounce Scattering

Based on the above two parts, the eCPTAAR technique leverages the same objective function as CPTAAR technique, but reallocate the estimation sequence with UE grouping. The estimation of eCPTAAR technique can be summarized as:

TABLE I
COMPUTATIONAL COMPLEXITY OF ESTIMATION SOLVED BY QUASI-NEWTON METHOD OF E-OPTIMALITY FOR THE WORST CASE (Q: NUMBER OF GROUPS, C_Q: NUMBER OF UE ASSIGNED TO ONE GROUP, B: NUMBER OF BS, M: NUMBER OF PATHS)

item	analytical complexity	
	before UE grouping, i.e. (8)	after UE grouping, i.e. (11)
solved by Quasi-Newton	$O((M^2+6M^2Bm+4M^3)\varepsilon^{-2})$	$O(\sum_{q=1}^{Q}(C_q^2+6BmC_q^2+4C_q^3)\varepsilon^{-2}$

TABLE II
NORMALIZED COMPUTATIONAL COMPLEXITY OF ESTIMATION SOLVED BY QUASI-NEWTON METHOD OF E-OPTIMALITY FOR THE WORST CASE (E=0.1, Q=2, M=6, C_1=3, C_2=3, B=1, M=4)

item	normalized complexity	
	before UE grouping	after UE grouping
Quasi-Newton method	2.65	1

Step 1: Reallocate the terminal group based on the obtained standard deviation of UE-UE relative measurement as (11)-(12).

Step 2: Estimate the coordinates of UE in group $h1$ through (8)-(10).

Step 3: Based on the fine results of $h1$ group, estimate the coordinates of the left UE in group $h2$ through (8)-(10).

For the real practice, the number of collaborated UE is expected to be not greater than six. Thus, a two-grouping separation is sufficient to apply for eCPTAAR in a cell.

D. Cramer-Rao Lower Bound on the Proposed Cooperative Positioning

Cramer Rao Lower Bound (CRLB) expresses the minimum variance of an estimator. Now, we present the CRLB of the proposed CPTAAR and eCPTAAR location problem.

Denote the measurement error of TOA, AOA, AOD, and RSS brought by receiver noise as n_r, n_θ, n_ϑ, and n_d, and the covariance matrix are Q_r, Q_θ, Q_ϑ, and Q_d. Conditional pdf of θ, ϑ, and d are omitted here since they have the same format as that of r

$$p(\tilde{\mathrm{r}} \mid \mathrm{x}_j) = \frac{1}{(2\pi)^{m/2}\sqrt{|\mathrm{Q}_r|}} e^{-\frac{(\tilde{\mathrm{r}}-\mathrm{r})^T(\tilde{\mathrm{r}}-\mathrm{r})}{2\mathrm{Q}_r}} \quad (13)$$

The Fisher Informatioin Matrix of CPTAAR (14) follows the same format as that of cooperative positioning in [22]

$$\mathrm{F} = \mathrm{F}_{\text{BS-UE}} + \mathrm{F}_{\text{UE-UE}} \quad (14)$$

where $\mathrm{F}_{\text{BS-UE}}$ and $\mathrm{F}_{\text{UE-UE}}$ represent the FIM of BS-UE objective function and UE-UE objective function respectively. But the *j*-th block of $\mathrm{F}_{\text{BS-UE}}$, corresponding to BS-UE FIM allocated to the *j*-th UE, is expressed as

$$\mathrm{F}_j^{\text{BS}} = -\mathrm{E}\left[\frac{\partial^2}{\partial \mathbf{x}^2}\Lambda_{\text{BS-UE}}(\mathrm{x}_j)\right] \quad (15)$$

where the likelihood function of the joint distribution of TOA, AOA, and AOD is

$$\Lambda_{\text{BS-UE}}(\mathrm{x}_j) = \ln(\,p(\tilde{\mathrm{r}} \mid \mathrm{x}_j)p(\tilde{\theta} \mid \mathrm{x}_j)p(\tilde{\vartheta} \mid \mathrm{x}_j))$$

Fisher Information Matrix of eCPTAAR is similar as that of CPTAAR technique, but the FIM is separated into two groups. Therefore, the derivation of FIM and CRLB of eCPTAAR are separated in terms of different groups. Based on the aforementioned example of two-group UE, FIM of the group $h1$ has the same format as CPTAAR, but only call for the UEs in group $h1$

$$\mathrm{F}^{h1} = \mathrm{F}_{\text{BS-UE}}^{h1} + \mathrm{F}_{\text{UE-UE}}^{h1} \quad (16)$$

Whereas FIM of the group $h2$ is different, since the UEs in group $h1$ have been obtained and work as anchors as BS for the UEs in group $h2$

$$\mathrm{F}^{h2} = \mathrm{F}_{\text{BS-UE}}^{h2} + \mathrm{F}_{\text{UE-UE}}^{h2} \quad (17)$$

where

$$\mathrm{F}_{\text{BS-}UE}^{\text{h2}} = \begin{bmatrix} \mathrm{F}_{m+1}^{\text{BS-UE}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathrm{F}_{M}^{\text{BS-UE}} \end{bmatrix} + \begin{bmatrix} \mathrm{F}_{m+1}^{\text{UE[h1] - UE[h2]}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathrm{F}_{M}^{\text{UE[h1] - UE[h2]}} \end{bmatrix}$$

$$\mathrm{F}_{\text{UE-UE}}^{h2} = \begin{bmatrix} \mathrm{F}_{a+1}^{\text{UE}} & \mathrm{K}_{a+1,a+2} & \cdots & \mathrm{K}_{a+1,M} \\ \mathrm{K}_{a+2,a+1} & \mathrm{F}_{a+2}^{\text{UE}} & \cdots & \mathrm{K}_{a+2,M} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{K}_{M,a+1} & \mathrm{K}_{M,a+2} & \cdots & \mathrm{F}_{M}^{\text{UE}} \end{bmatrix}$$

$\mathrm{K}_{j,k}$ is correlation matrix equal to negative *k*-th element of matrix $\mathrm{F}_j^{\text{UE-UE}}$.

Finally, the CRLB for *j*-th UE in both CPTAAR and eCPTAAR can be obtained through $\sqrt{\mathrm{J}_j(1,1)+\mathrm{J}_j(2,2)}$, where J is the inverse of FIM.

IV. SIMULATION RESULTS

In this section, the effect of the proposed CPTAAR and weight function, and eCPTAAR technique have been assessed by simulation. 1000 trials of 6-UE terminal group in radius of 50 m randomly are generated among classical 7 hexagon cells in radius of 1000 m, where only one BS is available. Signal frequency is 6 GHz. BS is 10 m high, and UE was 1.5 m high. 4 scatters are uniformly distributed near each UE in the circular area in radius of 200 m. And each NLOS path is measured once. Standard deviation of positioning measurements, i.e. TOA ranging, AOA, and AOD, are 60 m, 5°, and 5° respectively. UE-UE links are always LOS, and the standard deviation of shadowing of UE belonging to group $h1$ is random value between 4 dB, and that of UE in group $h2$ is 12 dB. The D2D path loss model in [23] is leveraged to generate relative measurements. The setup data is same in all simulation unless specified otherwise. Least square estimation based on TOA, AOA, and AOD measured on single-bounce NLOS scattered path in [8] and conventional cooperative positioning based on BS-UE detected TOA and UE-UE detected RSS in [1], labelled as 'LS method' and 'ranging based cooperative positioning', are simulated to make comparisons with proposed work. The optimization problems in the three cooperative approaches are solved by the MATLAB routine `fminsearch` using the Nelder-Mead method.

Figure 3 describes the higher positioning accuracy achieved by the proposed CPTAAR (no weight), weighted CPTAAR (wCPTAAR), and eCPTAAR techniques over the other two methods. The RMSE of the LS [8], ranging based cooperative positioning [1], CPTAAR, eCPTAAR, and wCPTAAR were about 86 m, 224 m, 51 m, 54 m, and 39 m. And STD of them were about 86 m, 103 m, 32 m, 33 m, and 29 m. Whereas the ranging based cooperative positioning method [1] performed even worse than least square method [8], because it was not designed for positioning with one BS and scattering environment. But the proposed CPTAAR succeeds to integrate the ranging based cooperative positioning [1] with LS [8] and outperforms these two methods. Another proposed eCPTAAR technique is designed to reduce complexity of estimation, and its cumulative percentage error curve almost overlaps that of CPTAAR, which reflects the same degree of accuracy as CPTAAR. Due to weight function, estimation variation is reduced and an improvement of 12-meter average error have been saved by wCPTAAR than CPTAAR.

Figure 4 displays the RMSE of LS [8], CPTAAR, eCPTAAR, and wCPTAAR methods various number of scatters. It is obvious that the accuracy of them increases with the number of measured NLOS paths, which performs the higher stability and superiority of the CPTAAR over the other two methods.

Moreover, running time consumed by estimation progress is succeeded reduced by eCPTAAR technique with cost of a few meters accuracy. The average time spent on locating each UE was about 0.131078 s by CPTAAR technique, while it were 0.034214 s and 0.997767 s by eCPTAAR and wCPTAAR. Almost 74% reduction has been achieved by UE grouping of eCPTAAR over CPTAAR. Whereas the weight function of wCPTAAR increases about 6-fold running time, since it is a function of UE coordinates and brings extra iteration.

In summary, CPTAAR succeeds to improve accuracy further over the original work [7-8], based on which the eCPTAAR technique is effective on reducing the complexity of cooperative approaches, and wCPTAAR technique is able to achieve even higher accuracy with assistance of the proper weight function.

V. CONCLUSIONS

In this paper, we have proposed CPTAAR, wCPTAAR and eCPTAAR approahces to locate collaborated UE in single-bounce scattering environment, and the CRLBs for CPTAAR and eCPTAAR have been derived. The proposed eCPTAAR technique achieves nearly the same accuracy as CPTAAR with reduced computational complexity by applying UE grouping for the nonlinear nonconvex positioning problem. And the weight function based on variance of on TOA, AOA, and AOD measurements has been proved effective with cooperative positioning in scattering environment, as wCPTAAR further improves the accuracy of CPTAAR. In summary, CPTAAR and eCPTAAR both achieve enhanced positioning accuracy, and eCPTAAR supplies an extra reduction on running time consumed by optimization progress in sacrifice of just a few meters accuracy. According to simulation results, about 74% running time consumed by the estimation progress has been saved by eCPTAAR.

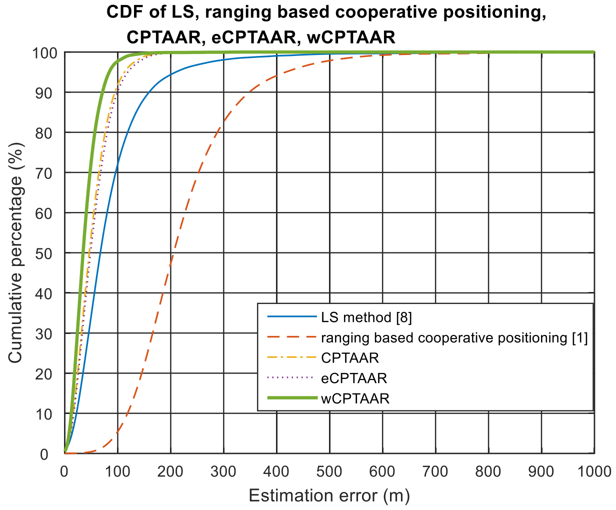


Figure 3. Accumulative Percentage of Estimation Error of the four Methods,

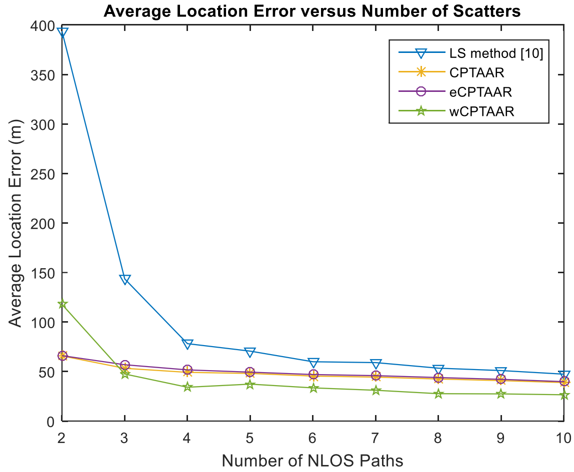


Figure 4. Average Location Error Influenced by Number of Scatters

REFERENCES

[1] J. Figueiras, S. Frattasi, and J. Figueiras, Mobile positioning and tracking: from conventional to cooperative techniques, 2nd Edition, Wiley. 2017

[2] Z. Abu-Shaban, X. Zhou, and T. D. Abhayapala, “A novel TOA-based mobile localization technique under mixed LOS/NLOS conditions for cellular networks,” *IEEE Transactions on Vehicular Technology*, vol. 65, no. 11, pp. 8841 – 8853. Nov. 2016

[3] L. Xiong, “A selective model to suppress NLOS signals in angle-of-arrival (AOA) location estimation,” in *Proc. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Boston, MA, USA, Sep. 1998, vol. 1, pp. 461 – 465.

[4] W. Zhang, Q. Yin, H. Chen, F. Gao, and N. Ansari, “Distributed angle estimation for localization in wireless sensor networks,” *IEEE Transactions on Wireless Communications*, vol. 12, no. 2, pp. 527 – 537. Feb. 2013

[5] J. Li, J. Conan, and S. Pierre, “Mobile terminal location for MIMO communication systems,” *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 8, pp. 2417 – 2420. Aug. 2007

[6] C. Chen, and K. Feng. “Statistical distance estimation algorithms with RSS measurements for indoor LTE-A networks,” *IEEE Transactions on Vehicular Technology*, vol. 66, no. 2, pp. 1709 – 1722. Feb. 2017

[7] Y. Xie, Y. Wang, and X. You, “Closed-form location estimator from TOA/AOA/AOD measurements in MIMO communication systems,” in *Proc. IEEE Sarnoff Symposium*, Princeton, NJ, USA. Apr. 2009

[8] X. Wei, N. Palleit, and T Weber, "AOD/AOA/TOA-based 3D positioning in NLOS multipath environments," in *Proc. IEEE 22nd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, Toronto, ON, Canada. Sep. 2011

[9] B. Y. Shikur and T. Weber, "TDOA/AOD/AOA localization in NLOS environments," in *Proc. IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Florence, Italy, May 2014

[10] S. W. Chen, C. K. Seow, and S. Y. Tan, "Elliptical lagrange-based NLOS tracking localization scheme," *IEEE Transactions on Wireless Communications*, vol. 15, no. 5, May 2016

[11] S. A. Banani, M. Najibi, and R. G. Vaughan, "Range-based localisation and tracking in non-line-of-sight wireless channels with gaussian scatterer distribution model," *IET Communications*, vol. 7, no. 18, pp. 2034 – 2043. Jul. 2013

[12] D. Liu, K. Liu, Y. Ma, and J. Yu, "Joint TOA and DOA localization in indoor environment using virtual stations," *IEEE Communications Letters*, vol. 18, no. 8. Aug. 2014

[13] M. Kyro, V. Kolmonen, and P. Vainikainen, "Experimental propagation channel characterization of mm-wave radio links in urban scenarios," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 865 – 868. Jul. 2012

[14] A. Shahmansoori, G. E. Garcia, G. Destino, G. Seco-Granados, and H. Wymeersch, "5G position and orientation estimation through millimeter wave MIMO," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, San Diego, CA, USA. Dec. 2015

[15] K. Das, and H. Wymeersch, "Censoring for bayesian cooperative positioning in dense wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 30, iss. 9, pp. 1835 – 1842. Oct. 2012

[16] J. Cui, Z. Wang, C. Zhang, Y. Zhang, and Z. Zhu, "Message passing localisation algorithm combining BP with VMP for mobile wireless sensor networks," *IET Communications*, vol. 11, no. 7, pp. 1106 – 1113. May 2017

[17] F. D. Rosa, T. Paakki, H. Leppäkoski, and J. Nurmi, "A cooperative framework for path loss calibration and indoor mobile positioning," in *Proc. IEEE 7th Workshop on Positioning Navigation and Communication (WPNC)*, Dresden, Germany, Mar. 2010, pp. 86 – 92.

[18] K. McDermott, R. M. Vaghefi, and R. M. Buehrer, "Cooperative UTDOA positioning in LTE cellular systems," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, San Diego, CA, USA. Dec 2015

[19] A. Dammann, R. Raulefs, and S. Zhang, "On prospects of positioning in 5G," in *Proc. IEEE International Conference on Communication Workshop (ICCW)*, London, UK. Sep. 2015

[20] C. Gentile, N. Alsindi, R. Raulefs, and C. Teolis, Geolocation Techniques Principles and Applications, Springer, 2013

[21] A. Borhani, and M. Patzold, "A unified disk scattering model and its angle-of-departure and time-of-arrival statistics," *IEEE Transactions on Vehicular Technology*, vol. 62, iss. 2, pp. 473 – 485. Feb. 2013

[22] F. Penna, M. A. Caceres, and H. Wymeersch, "Cramér-Rao bound for hybrid GNSS-terrestrial cooperative positioning," *IEEE Communications Letters*, vol. 14, no. 11, pp. 1005 – 1007, Nov. 2010

[23] ITU-R report M.2135, Guidelines for evaluation of radio interface Technologies for IMT-Advanced. 2008