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Cooperative RF Pattern Matching Positioning for LTE Cellular Systems

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***Abstract*—In this paper, cooperative positioning for Long Term Evolution (LTE) cellular systems using Radio Frequency Pattern Matching (RFPM) is studied. Having the locations of users in a cellular system supports many applications such as location-based services and E911. Although Global Positioning System (GPS) can be found in every smartphone, its poor performance in indoor and dense environments encourages the development of cellular network-based solutions. Cellular localization has emerged in which the user locations can be determined by measurements obtained within the network without the aid of any external sources (e.g., GPS). Several positioning techniques have been considered in Release 9 of the 3rd Generation Partnership Project (3GPP) document such as Observed Time Difference Of Arrival (OTDOA) and Enhanced Cell ID (E-CID). In OTDOA, the User Equipment (UE) measures the time difference of signals from multiple eNodeBs and uses a trilateration algorithm to find its location. However, OTDOA performance can be highly degraded in rich multipath and non-line-of-sight environments particularly when there is strong interference. Hence, many companies and researchers are also evaluating other techniques such as RFPM in which the user location is estimated by comparing UE measurements with a series of reference data. RFPM is independent of line-of-sight conditions and has good performance in dense urban and indoor environments. In the current LTE networks, the UE can only communicate with eNodeBs. However, there are scenarios in which the UE is not able to communicate with a sufficient number of eNodeBs and cannot find its location without ambiguity. In this paper, a cooperative localization technique for LTE systems is proposed in which leveraging the Device-to-Device (D2D) communications protocol the UE communicates not only with eNodeBs but also with other UEs. It will be shown through computer simulations that the proposed positioning algorithm can significantly improve the positioning performance in LTE networks.**

***Index Terms*—Radio frequency pattern matching, fingerprinting, cooperative localization, long term evolution (LTE).**

I. INTRODUCTION

Having the location of users in a cellular network is associated with several applications such as location-based services, emergency services, and law enforcement. Cellular carriers also need to provide the locations of E911 callers as a mandatory requirement by the U.S. Federal Communications Commission (FCC). Nowadays, smartphones are equipped with Global Positioning System (GPS) which operates independently from the cellular network. However, GPS receivers can provide a unique location only if they are able to acquire at least four satellite signals. In dense environments without clear sky visibility (such as indoor or urban areas), GPS often fails to provide a reliable estimate [1]. Therefore, the 3rd Generation Partnership Project (3GPP) considers several cellular-based localization techniques for Long Term Evolution (LTE) networks as a back-up to GPS [2]. In cellular-based localization, the location of the User Equipment (UE) is determined via noisy measurements obtained within the network without using any external sources such as GPS. These measurements are either range-based, such as time-of-arrival (TOA) [3], [4], time-difference-of-arrival (TDOA) [5], [6], and received-signal-strength (RSS) [7], [8], or angle-based, such as angle-of-arrival (AOA) [9]. 3GPP currently supports four positioning techniques including Enhanced Cell ID (E-CID), Assisted-Global Navigation Satellite System (A-GNSS), and Observed Time Difference Of Arrival (OTDOA) defined in Release 9 and Uplink Time Difference Of Arrival (UTDOA) defined in Release 11 [10].

The cell ID (CID) method provides a fast and low-complexity network-based positioning technique [11]. More specifically, the UE location is simply estimated by using the location of the eNodeBs (the base station in LTE networks) with which it is associated. Unfortunately, this method can result in a very poor position estimate which is significantly worse than FCC E911 requirements, as the UE serving cell can span multiple kilometers. In E-CID, additional radio-related measurements such as AOA or round-trip time (RTT) are used to improve the accuracy of positioning [6]. The downlink TDOA positioning method which is called OTDOA measures the differences in arrival times of downlink signals from multiple eNodeBs at the UE. Then, a hyperbolic trilateration estimator is used to estimate the UE location. Using this technique requires either the eNodeBs to be synchronized or transmit times relative to the serving eNodeB to be known. The uplink TDOA positioning method in LTE, known as UTDOA, is conceptually similar to OTDOA with the difference that the timing measurements are made on signals originating from the UE and received at neighboring eNodeBs [12].

The performance of trilateration techniques are highly affected by multipath and non-line-of-sight (NLOS) propagation which occur frequently in indoor and urban environments. In such environments, the direct view between the UE and eNodeB is blocked by walls and objects. Therefore, the measured time delays can be significantly larger than their true values leading to considerable performance degradation in trilateration techniques. Another positioning technique which has been recently developed but not included in the LTE Positioning Protocol (LPP) is Frequency Pattern Matching

(RFPM) [13]. RFPM is shown to be independent of NLOS propagation making it suitable for dense environments. RFPM which is usually referred to as RF fingerprinting in the academic literature includes two phases [5], [14]. In the first phase, a series of reference data is created for the area of the interest. In the second phase, actual measurements between the UE and eNodeBs are collected and the location of the UE is estimated by comparing the actual measurements with the reference data.

In the academic literature, localization approaches can be divided into two categories: noncooperative and cooperative [4], [7], [15], [16]. In noncooperative localization, the mobile node only communicates with anchor nodes. Current cellular communication networks support only noncooperative positioning methods. As a result, a high density of eNodeBs and longer communication ranges are required to ensure that the UE is connected to a sufficient number of eNodeBs to enable positioning. A limited number of accessible anchor nodes and short communication ranges in many networks have led to the emergence of cooperative localization. In collaborative localization, the mobile nodes communicate not only with anchor nodes, but also with each other. Cooperation among mobile nodes provides additional measurements which alleviate the need for dense anchor deployments and longer communication ranges.

In this paper, a cooperative RFPM-based localization technique for cellular LTE systems is proposed. In the proposed technique, UEs communicate with eNodeBs and capture a series of RF measurements. UEs are also collaborating with each other and collect a series of timing measurements. It should be noted that Device-to-Device (D2D) communications which is being discussed for 3GPP Release 13 enables UEs to transmit signals to each other over a direct link rather than through an intermediate eNodeB. A localization algorithm is introduced in which the UE location is estimated by incorporating the measurements from eNodeBs as well as other UEs. The advantages of cooperative localization in terms of positioning accuracy will be shown through computer simulations where the 3GPP simulation parameters are considered.

II. SYSTEM MODEL

An LTE network with M eNodeBs and N UEs is considered. Let $\mathbf{x}_k = [x_k, y_k]^T \in \mathbb{R}^2$, $k \in \mathcal{B}$ be the unknown coordinates of the kth UE, where $\mathcal{B} = \{1, \ldots, N\}$ is the set of UE indices. Each eNodeB is equipped with a 3-sector antenna and each sector covers a hexagonal cell. Note that in 3GPP documents, an eNodeB is termed a *site* and a sector of that site is termed a *cell*. A site and a cell are represented in Fig. 1. Denote by $\mathcal{A} = \{N+1, \ldots, N+M\}$ the set of eNodeB indices and by $\mathbf{y}_i = [x_i, y_i]^T \in \mathbb{R}^2$, $i \in \mathcal{A}$ the known coordinates of the ith eNodeB. In cooperative localization, the UE has access to two sets of measurements: UE-eNodeB and UE-UE. Hence, the following sets can be defined

$$\begin{aligned} \mathcal{A}_k &= \{\ i \in \mathcal{A} \mid \text{eNodeB } i \text{ is connected to UE } k\ \} \\ \mathcal{B}_k &= \{\ i \in \mathcal{B} \mid \text{UE } i \text{ is connected to UE } k\ \} \end{aligned} \tag{1}$$

where the former and latter define UE-eNodeB and UE-UE links, respectively. In the following section, the types of measurements used for each link are discussed.

A. UE-eNodeB

UE-eNodeB measurements include the signal strength measurements corresponding to Reference Signal Received Power (RSRP) and the timing measurements corresponding to timing advance (TA) [17]. RSRP is a physical layer measurement at the UE which indicates the average received power of the downlink reference signal over the signal bandwidth. RSRP is an important measurement and enables the UE and eNodeB to optimize transmit power settings. It is also required to calculate reference signal receive quality (RSRQ) which determines UE connectivity at the cell edges. Unlike received signal strength indicator (RSSI) which is determined by the received power of the entire signal, RSRP is only the received power of the reference signals in the downlink radio frame. Reference signals existing in the physical layer do not carry any information. There are several reference signals considered in the LTE radio frame, two of which are widely used for positioning: Cell-specific Reference Signal (CRS) and Positioning Reference Signal (PRS). The CRS is designed to enable the UE to estimate the downlink channel and extract the data [11]. However, it is also used for the RSRP measurement. LTE Release 8 allows eNodeBs to have CRS patterns with a reuse factor of 3 for 2 antenna ports [18]. PRS, which is included in LTE Release 9, is specifically designed for positioning purposes. PRS provides more power and less inter-site interference by using a reuse factor of 6 [18]. Compared with CRS which has a reuse factor of 3, PRS results in less interference which increases the signal-to-interference-plus-noise ratio (SINR) at the UE and the hearability of the eNodeBs. The RSRP can be predicted by the log-distance path loss model

$$P_{ik} = \alpha - 10\beta \log_{10} d_{ik} + n_{ik}, \quad i \in \mathcal{A}_k \tag{2}$$

where d_{ik} is the distance between the kth UE and the ith site and n_{ik} represents the shadowing components. α and β are the reference power and path-loss exponent which are dependent on several parameters such as the propagation environment, carrier frequency, and tower height. Although 3GPP has some typical values for these parameters, they are very difficult to determine in real scenarios. In the model-based estimation, the measurement obtained by the UE is compared with the model and its location is estimated by applying an estimator [6], [19]. However, this method leads to poor estimates as the true model cannot be easily determined. As a result, RFPM techniques have been developed. These techniques include two phases. The first phase which is typically performed offline includes creating a data map from the area of interest. The area is covered by many calibration points with known locations and useful information from the UE at each calibration point is captured. The information can be obtained either by collecting measurements or by predicting from experiential models. For our specific application, a drive test is typically performed and RSRP measurements at different calibration points are stored in the data map. For the calibration points where a drive test cannot be performed, a predication is obtained by either interpolation or sophisticated channel estimation techniques. The second phase includes collecting actual UE measurements which is carried out during the location procedure. In this phase, the UE location is estimated by comparing the actual measurements with the data map. The vector of measurements (and its associated location) in the data map which is closest to what was actually measured by the UE is chosen as the most likely location.

Another UE physical layer measurement is TA which measures the RTT of the signal between the UE and eNodeB. TA is designed for adjusting uplink transmission timing for UE. However, it can be also utilized for positioning purposes. TA is ideally a function of the distance between the UE and eNodeB. However, extracting the direct distance between the UE and eNodeB from TA is very difficult, since it is highly affected by NLOS and multipath propagation. Therefore, a RFPM technique is also used for this type of measurement. The resolution of TA is $2T_s$, where T_s is the sampling time. Therefore, the accuracy of range measurement using TA in LTE ($T_s = 32.6$ ns) can be as good as 9.8 m [20].

B. UE-UE

D2D communications is currently being discussed for inclusion in 3GPP Release 13 [21]. D2D communications is proposed to allow UEs to communicate with each other directly, although an eNodeB needs to control and manage the resources for the transmission. Synchronization is one of the key functions that needs to be addressed in D2D design. Generally speaking, synchronization can be performed by transmitting known synchronization signals between UEs. Leveraging this concept, we assume that the UEs are able to measure RTT between each other through the D2D protocol (similar to TA in UE-eNodeB link). The RTT measurements are modeled as

$$R_{ik} = 2d_{ik}/c + w_{ik}, \quad i \in \mathcal{B}_k \tag{3}$$

where w_{ik} represents the measurement error modeled as a Gaussian random variable with variance σ_R^2. The variance of RTT measurements depends on several parameters including SINR and bandwidth [22], [23]. The measurement variances are typically estimated by simulating the LTE orthogonal frequency-division multiplexing (OFDM) radio frame and the wireless channel [24]. The standard deviation of TOA estimation varies from 0.02 to 0.12 µs depending on aforementioned factors as well as the multipath channel characteristics [24].

III. POSITIONING ALGORITHM

The proposed cooperative positioning algorithm is described in this section. Assume the area of interest is covered by L calibration points. Let $\mathbf{z}_j = [x_j, y_j]^T \in \mathbb{R}^2$, $j \in \mathcal{L}$ be the known coordinates of the jth calibration point, where $\mathcal{L} = \{1, \ldots, L\}$ is the set of calibration point indices. A measurement is performed and for each calibration point, the RSRP and TA are recorded in the data map. Let $\bar{P}_{ij}$ and $\bar{T}_{ij}$ be the RSRP and TA measurements captured between the ith cell and the jth calibration point, respectively.

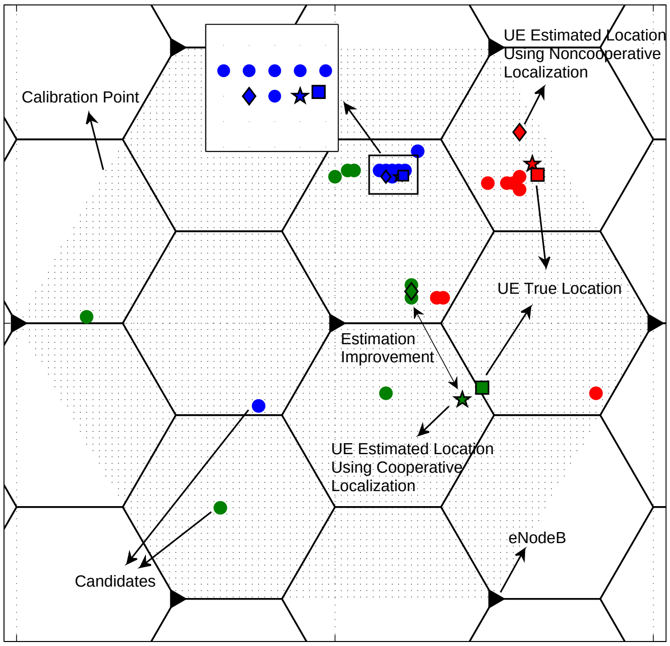

Fig. 1. Cooperative RFPM-based positioning technique. eNodeBs and UEs are depicted by triangles and squares, respectively. Each hexagon represents a cell covered by a sector. Small dots and circles represent the calibration points and the candidates, respectively. Diamonds and stars depict the estimated locations of UEs using noncooperative and cooperative localization, respectively.

In noncooperative localization, the UE location is obtained by comparing the UE measurements (RSRP and TA) with the calibration point data map. The calibration point which has the closest data to the UE measurements would be the estimate of UE location. A minimum mean square error (MMSE) estimator can be used in this case which is obtained by minimizing the mean square error as follows

$$\hat{\mathbf{x}}_k = \underset{\mathbf{z}_j, j \in \mathcal{L}}{\arg\min} \sum_{i \in \mathcal{A}_k} (P_{ik} - \bar{P}_{ij})^2/\sigma_P^2 + (T_{ik} - \bar{T}_{ij})^2/\sigma_T^2 \tag{4}$$

where σ_P^2 and σ_T^2 is the measurement error variances which can be either calculated from the drive test or estimated from simulations. Sometimes the area is very large and there are many calibration points to compare. There are some techniques that can limit the search area and decrease the computation time. For instance, one can limit the search only to the calibration points inside the serving cell.

For cooperative localization, the above technique cannot be used directly. Therefore, Algorithm I is proposed to use RFPM data for cooperative localization. There is a loop in Algorithm I (Line 01 to Line 06) in which for each UE, the error between the UE measurements and all calibration data is calculated, similar to the noncooperative case. In Line 05, for each UE, C calibration points with the smallest errors are selected as candidates and their indices are stored in $\mathcal{L}_k$. In Line 07, the sets, $\mathcal{C}_l$, including combinations of N elements from the $\mathcal{L}_k$

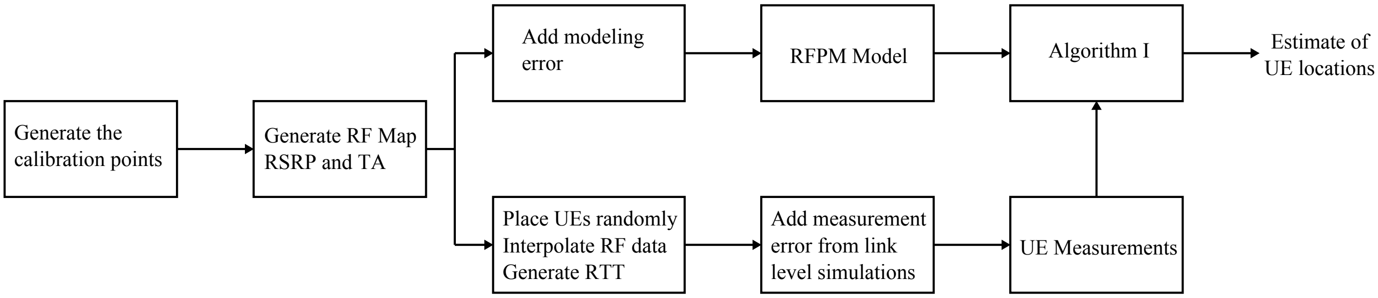

Fig. 2. The block diagram of the simulation methodology. The simulation of LTE positioning techniques are divided into link level and system level.

are created. Suppose there are 3 UEs and for each of them there are 2 candidates as follows

$$\mathcal{L}_1 = \{11, 38\}, \quad \mathcal{L}_2 = \{25, 31\}, \quad \mathcal{L}_3 = \{15, 47\}.$$

There are $2^3 = 8$ combination sets with 3 elements

$$\begin{aligned} \mathcal{C}_1 &= \{11, 25, 15\}, & \mathcal{C}_5 &= \{38, 25, 15\}, \\ \mathcal{C}_2 &= \{11, 25, 47\}, & \mathcal{C}_6 &= \{38, 25, 47\}, \\ \mathcal{C}_3 &= \{11, 31, 15\}, & \mathcal{C}_6 &= \{38, 31, 15\}, \\ \mathcal{C}_4 &= \{11, 31, 47\}, & \mathcal{C}_8 &= \{38, 31, 47\}. \end{aligned}$$

In Line 09, the UE-UE link error is calculated for each set

$$e_R^2 = \sum_{k=1}^{N} \sum_{i=1, i\neq k}^{N} (R_{ik} - 2d_{\mathcal{C}_l(i)\mathcal{C}_l(k)}/c)^2/\sigma_R^2 \tag{5}$$

where $\mathcal{C}_l(i)$ is the ith element of the lth set and d_{mn} is the true distance between the mth and nth calibration point. In Line 10, a new error is calculated including both UE-eNodeB and UE-UE measurements. Finally, the set of the calibration points which produces the smallest error would be the estimate of the UE locations.

Fig. 1 shows an example of a cellular LTE network. The locations of the eNodeBs (or sites) are depicted by solid triangles. Each site has three cells covered by a directed antenna (each sector or antenna coverage area is represented by a hexagon). The small black dots represent the calibration points. There are three cooperating UEs in the network represented by colored squares. According to Algorithm I, for each UE, C calibration points with the lowest error are selected as possible candidates. In this case, 10 candidates are selected for each UE represented by colored circles. In noncooperative localization, the candidate with the lowest noncooperative error would be the estimate of the UE location represented by colored diamonds. Fig. 1 shows that the estimates of the green and red UEs are far from their true locations. In the cooperative case, the UE-UE RTT measurements are also incorporated and the estimates of UE locations are improved. The estimates of UE locations using cooperative positioning are depicted by colored stars where significant improvement can be seen.

IV. SIMULATION METHODOLOGY

This section describes the steps need to be taken to simulate the performance of the proposed positioning technique in LTE networks. The simulation of LTE positioning techniques is generally divided into two levels: the link level and the system level. The block diagram of the simulation methodology is depicted in Fig. 2.

Algorithm I. Cooperative RFPM-based Positioning Algorithm

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01. for $k = 1$ to $N$
02.   for $j = 1$ to $L$
03.     $e_{jk}^2 \leftarrow \sum_{i\in\mathcal{A}_k}(P_{ik}-\bar{P}_{ij})^2/\sigma_P^2 + (T_{ik}-\bar{T}_{ij})^2/\sigma_T^2,\ j \in \mathcal{L}$
04.   end for
05.   $\mathcal{L}_k = \{j$ |the first $C$ calibration points with the smallest error, $e_{jk}^2\}$
06. end for
07. $\mathcal{C}_l \leftarrow$ combination of $N$ elements from $\mathcal{L}_k$ indices, $l = 1, \ldots, C^N$
08. for $l = 1$ to $C^N$
09.   $e_R^2 \leftarrow \sum_{k=1}^{N}\sum_{i=1,i\neq k}^{N}(R_{ik} - 2d_{\mathcal{C}_l(i)\mathcal{C}_l(k)}/c)^2/\sigma_R^2$
10.   $e_l^2 \leftarrow (\sum_{k=1}^{N}\sum_{j\in\mathcal{C}_l} e_{jk}^2) + e_R^2$
11. end for
12. $l^* \leftarrow \{l \mid \min_l\{e_l^2\}\}$
13. $\hat{\mathbf{x}}_k = \mathbf{z}_{\mathcal{C}_{l^*}(k)}, \quad k = 1, \ldots, N$
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In the link level simulation, the OFDM waveform considering LTE specifications is generated. The LTE downlink radio frame needs to be generated in which all required reference signals (CRS and PRS) are considered. Since we are only interested in reference signals, random data is placed in the PDSCH frame. Note that if a positioning subframe is used, there is no data present in the radio frame. Once the OFDM frame is generated, it is passed through a wireless channel. There are three types of channels widely used in the 3GPP contributions for the test and verification of UE and eNodeB radio transmission: Extended Pedestrian A model (EPA), Extended Vehicular A model (EVA), and Extended Typical Urban model (ETU). The multipath delay profiles of these channels are defined in 3GPP specifications [25]. Then, a Gaussian random variable representing measurement noise with a variance corresponding to the given SINR is added to the output of the channel. At the UE side, the received signal is processed and the desired information is extracted. For instance, for TA measurement, the signal is passed through a correlator and the delay of the first arriving path is detected. Finally, the estimation error is calculated by comparing the estimated and true delays. The procedure is repeated several times for different SINR levels and noise realizations, and the corresponding results are stored.

In the system level simulation, a uniform grid representing the locations of the calibration points is first created. Then,

TABLE I
SUMMARY OF SIMULATION PARAMETERS.

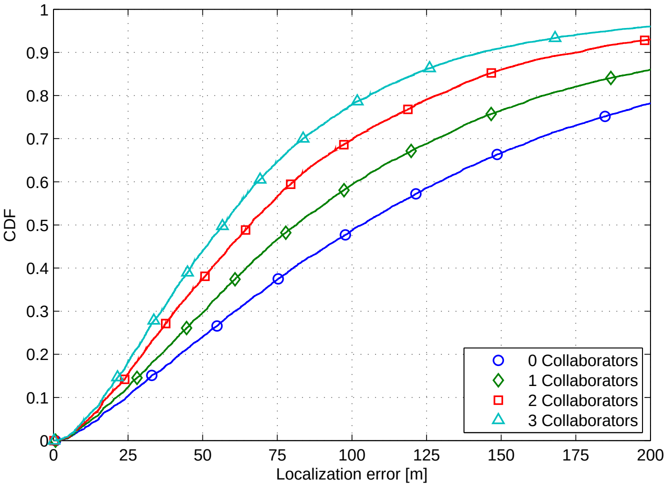
Parameter	Assumption
Cell	Hexagonal grid, 19 sites, 3 cells/site
Inter-Site distance	500 m
Pathloss model	$L = 128.1 + 37.6 \log_{10} R$
Penetration loss	20 dB (Case 1)
Shadowing SD	8 dB
Shadowing correlation	0.5 (Between sites), 1 (Between sectors)
Correlation distance	50 m
Antenna gain	15 dBi
Antenna pattern	$A(\theta) = -\min[12(\theta/65^o)^2, 20]$ dB
eNodeB power	43 dBm
UE power	21 dBm
UE noise figure	9 dB
RSRP modeling error	6 dB
TA modeling error	0.2 µs

a RF map is generated in which the true RSRP and TA at the calibration points are calculated by using the simulation parameters defined in Table I. The modeling error is added to the true values to generate the RFPM model which represents the data that can be obtained through a drive test. The modeling error, which is defined in Table I, represents the difference between the true values and the data obtained from the drive test. Once the RFPM model is created, UEs are randomly placed in the network. The true RF data of the UEs is obtained by interpolation of the calibration points in the RF map. The true RTT for UE-UE links are also created by calculating the pair-wise distances between UEs. Then, the UE measurements are generated by adding the measurement errors created in the link level simulation. Finally, Algorithm I is applied to estimate the UE locations.

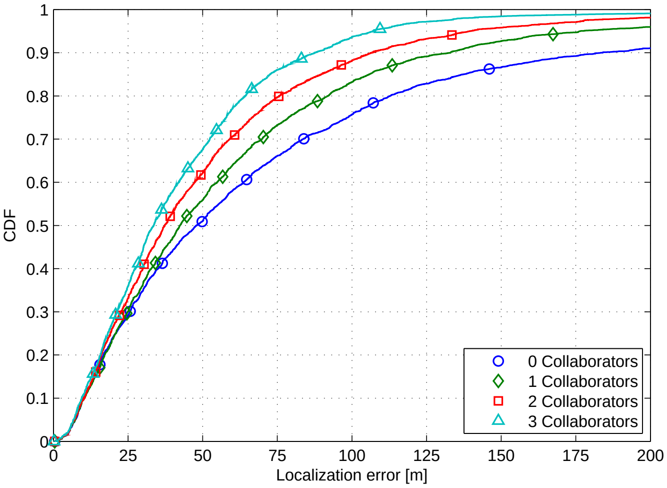
V. SIMULATION RESULTS

This section discusses a series of computer simulations used to evaluate the performance of the proposed cooperative localization technique in an LTE network. A typical LTE network in accordance with parameters in 3GPP specifications was created [24], [26]. Table I summarizes the parameters used in our simulations. Fig. 1 shows the network topology. There are 19 eNodeBs and the central large hexagon is covered by 6515 calibration points. The grid size of the calibration points is 10 m. UEs are randomly placed in the central hexagon.

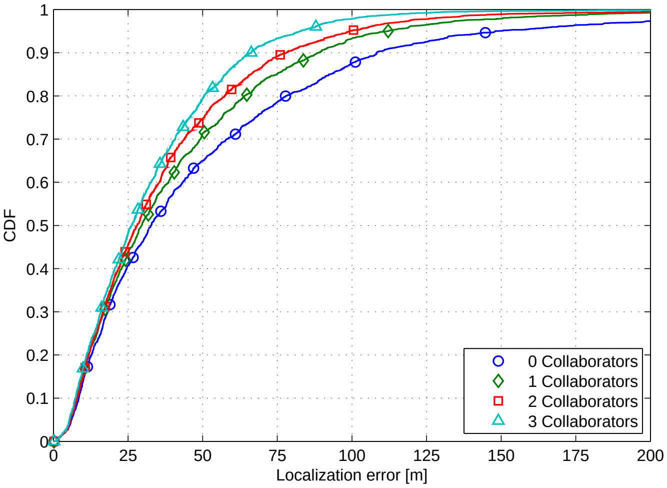
Fig. 3 shows the cumulative distribution function (CDF) of the localization error versus the number of collaborators. Zero collaborators represent the noncooperative case. The SINR threshold is set to -6 dB, meaning that if the SINR at the UE terminal from a cell is higher than -6 dB, the UE can detect the signal from the corresponding cell. Otherwise, the signal is too weak to be either detected or useful for positioning. ETU channel is used in link level simulations. The performance of RFPM-based localization is compared for three different LTE radio frame structures: CRS-Full Collision where data is present in the radio frame and the received signal from a cell is interfered by the signals from other cells; CRS-Reuse 3 and PRS-Reuse 6 where there is no data in the radio frame and a reuse factor of 3 and 6 is used, respectively. Fig. 3 shows



(a) CRS-Full Collision



(b) CRS-Reuse of 3



(c) PRS-Reuse of 6

Fig. 3. The CDF of localization error parameterized by the number of collaborators for different LTE radio frame structures. The SINR threshold is set to -6 dB and ETU channel is used in link level simulations. Zero collaborators represent the performance of noncooperative localization. The positioning performance improves as the number of collaborators increases.

that the performance of cooperative localization is superior to noncooperative localization in all three radio frames. In CRS-Full Collision, the UE has limited connections most the time, since interference among cells decreases the SINR significantly. In this case, cooperation between UEs improves the performance considerably by providing a powerful link. Note that for the UE-UE links no interference is assumed. The reason is that the cooperating UEs are typically close to each other (less than 500 m) and presumably there is no other signal in their transmission band. In CRS-Reuse 3, cooperative localization can still provide significant improvement over noncooperative localization. In PRS-Reuse 6, the rate of improvement diminishes slightly, since the UE already receives several high SINR signals from the eNodeBs and adding an extra UE-UE link does not provide significant improvement. However, cooperation is still useful in this case, especially at high reliability levels. For instance, at 90% CDF, the localization error for noncooperative localization is 110 m, while it is 65 m for cooperative localization with 3 collaborators. This would be more than 45 m improvement which is crucial for cellular localization.

There are two important factors that have a large impact on the performance of the proposed localization technique. The first factor is the grid size of calibration points. The smaller the grid size is, the better the performance will be. However, decreasing the grid size will increase the complexity of the algorithm. Therefore, a trade-off between the two should be maintained depending on the application. Note that this factor also affects the performance of the noncooperative localization. The second factor is the number of candidates in Algorithm I. The higher the number of candidates is, the higher the improvement would be. Again, increasing the number of candidates increases the complexity exponentially. Our simulation results show that having 10 candidates provides a balance between the complexity and the performance. For instance, with 20 candidates, the complexity of the cooperative localization with 3 collaborators is 16 times higher than with 10 candidates, while only 1-2% improvement can be achieved.

VI. CONCLUSIONS

In this paper, a RFPM-based positioning technique for LTE cellular systems was studied. Currently, LTE carriers only support noncooperative positioning methods. Leveraging D2D communications being considered for LTE networks, a cooperative RFPM-based localization algorithm was proposed. RFPM localization is independent of line-of-sight links and performs very well in rich multipath and NLOS environments. It was assumed that the UE uses RSRP and TA measurements for UE-eNodeB connections and RTT measurements for UE-UE connections. Complexity can be an issue in RFPM techniques, especially for cooperative networks where the complexity increases exponentially with the number of collaborators. The proposed localization algorithm was designed to maintain the complexity as low as possible without sacrificing the performance. Computer simulations were conducted to show the effectiveness of the proposed cooperative localization technique. Simulation results showed that the proposed cooperative algorithm can significantly improve the positioning accuracy in cellular LTE networks.

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