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# Location Awareness in 5G Networks Using RSS Measurements for Public Safety Applications

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**ABSTRACT** One of the notable aspects of public safety applications in 5G networks is location awareness, which is a feature of contemporary technology that imparts details about a user‘s geographical location to another user or application. Mobile users take their cell phones and other gadgets with them almost everywhere. Thus, integrating location awareness in mobile applications gives users a much more real experience. Therefore, this paper presents an algorithm to predict user location in 5G networks by using received signal strength measurements. Initially, the relative coordinates of users are computed using Isomap. Then the relative coordinates of users are transformed by Procrustes analysis. In order to evaluate the performance of the proposed algorithm, the Cramer–Rao lower bound is derived, which is the lower bound on error variance. It can be concluded from our results that the proposed approach outperforms those found in the existing literature.

**INDEX TERMS** 5G, access points, received signal strength, isomap, Cramer-Rao lower bound.

## I. INTRODUCTION

Similar to 3G and 4G, 5G is a wireless communication system being developed with particular emphasis on keeping pace with the rapid multiplication of devices that demand a wireless connection to the internet. It is well-known that phones and computers need connectivity, but home appliances, cameras for security, door locks, vehicles, dog-collars, and a multitude of other devices are starting to connect to the internet as well [1]. Gartner has predicted that 20.8 billion devices will be anchored to the internet no later than 2020 [2]. Currently, there are an estimated 6.4 billion gadgets connected to the internet across the world. That is, many more devices will be requiring a fast connection soon. 5G will be erected on the foundations laid by 3G and 4G LTE [3]. 5G will still enable users to send text messages, make audio and video calls, and surf the internet, but it will also create a large increase in the speed of data transfer throughout the network [4]. 5G will make it easy for users to download as well as upload ultra high definition (UHD) and 3D videos. Additionally, 5G will make it possible to connect thousands of devices that are entering our everyday world in addition to those that already exist [5].

Converging 5G with public safety applications is a challenging task because of the strict requirements of this type of application. In public safety applications, more reliable information is needed with shorter delays. One of the notable aspects of public safety applications is location awareness [6], which is a feature of contemporary technology that imparts details about a user's geographical location to another user or application. Mobile users take their cell phones and other gadgets with them almost everywhere. Therefore, integrating location awareness in mobile applications gives users a much more real experience. In the age of information and social connectivity, users are not just creating content for the World Wide Web, but are also geographically localizing it [7].

Location awareness is of great importance because very effective and systematic congestion management can be accomplished when the radio cell in which the user is located, is known and is integrated with rich intelligence and packet logic. Additionally, different types of traffic handling and root cause analysis can be carried out [8]. Location awareness is also essential regarding marketing endeavors, such as knowing the sequence of movements of people and where they are proceeding to and from. For example, in what manner are they proceeding? Are people in a car? Are they pedestrians? Are they moving quickly? What kind of applications are usually used by people while driving or while walking? All these activities include location information [9]. Location awareness in future 5G networks will play an important role. Location awareness in 5G will not only enable different location based services such as autonomous vehicles and intelligent traffic management system (ITS), but it will also provide valuable location aware communication applications such as radio resource management (RRM). Therefore, the concept of location awareness in 5G is to develop different techniques, that how the localization can provides different concepts for mobility management and enhanced communication in 5G networks.

Merging social impact on localization in 5G makes user capable of establishing social relationship with each other in an autonomous way. By social relationship establishment, users form a friendship network to provide trustworthy and useful information services to the other users. It increases common social and public services such as an early warning system for users using social status of users, location of users and status of friends. Combining social aspect with localization in 5G networks solves many problems faced by the internet of things i.e. 5G technology will come over the problem of limited connectivity among users, effective content distribution, privacy etc. [10].

Operators providing quality of experience (QoE) in mobile networks are entirely relying on the user's location. Telecommunication service providers currently face the problem of delivering real-time location and quality of service (QoS) information in a cost-effective way to be able to successfully provide better quality mobile broadband services [11]. Obtaining the location information of users allows for the design of new value-added business-to-consumer (B2C) and business-to-business (B2B) applications and services. A user's location information can be shared with other users for a number of purposes e.g., location-aware routing, spatial spectrum sensing [12], and radio resource management (RRM) [13].

Locating mobile users has gained increasing attention and has the potential for applications and services to upgrade both location based services (LBS) and cellular network performance. Although some work has been done to develop methods and algorithms for locating users in 3G and 4G networks, there have been no satisfactory efforts in the case of 5G network [14]. Locating mobile devices has always been a problem of utmost importance in 3G and 4G and will become even more essential, as the number of location-aware applications will obviously flourish with the commencement of 5G technology. The utilization of 5G technologies to acquire position was formerly studied in [15] and [16] for millimeter waves and in [17]–[19] for massive multiple input multiple output (MIMO). Beam training protocols through direction of arrival (DOA) were examined in [20]. Localization based on received signal strength (RSS) was explored in [16]. This technique gives accuracy in localization upto a meter level. An approach to approximate the position of the users using an extended Kalman filter integrated with time of arrival (TOA) of the signal from the transmitter to the receiver and direction of arrival (DOA) calculations in the uplink was suggested in [21]. A technique formed on DOA and RSS estimation for non-cooperative transmitter localization was explored in [22]. This technique utilizes a form of antenna that can particularly receive energy from different sectors (sectorized antennas) to achieve sector-powers as adequate measurements for DOA and RSS estimation. Therefore, by closely monitoring the commencement of 5G technology in the near future, we are interested in devising an algorithm to predict user location in 5G networks. Following are the major contributions of this paper:

1) 5G networks consists of different technologies such as device to device communication, millimeter waves communications, machine to machine communications etc. Therefore devising an algorithm which can find the location of users based on these different communication technologies is a challenging task. In this paper a RSS based localization algorithm is proposed for such kind of different multiple networks.
2) Isomap-based localization technique is proposed to locate all users in a 5G network. Isomap is a nonlinear technique applied for dimensionality reduction [23]. There are a number of broadly utilized low-dimensional embedding techniques, with Isomap being one of them. The Isomap technique is implemented for the computation of high dimensional data points into low-dimensional space. It renders an uncomplicated method for determining the fundamental geometry of multitudinous data based on a rough approximation of the multifarious neighbors of each data point.
3) Furthermore theoretical analysis is carried out to analyze the performance of the proposed algorithm by deriving its Cramer Rao Lower Bound.

## II. RELATED WORK

For the past few years the requirement for applications and systems that rely on precise localization of users has increased. The growing demand has brought about a noticeable development of many localization techniques. In this chapter, a general review of major localization techniques i.e. time of arrival (ToA), time difference of arrival (TDoA), direction of arrival (DoA) and received signal strength indicator (RSSI) is provided. Localization systems that are either being used or are under development for different applications are also discussed. Localization process is for determining the position of a user within a certain coordinate system or relative to a known position [24]. In the past few years a number of localization methods have been developed. Some of the major applications of localization systems include navigation [25], [26], monitoring [27], tracking [28], situation awareness and mobile ad-hoc networks.

### A. FUNDAMENTAL METHODS USED FOR LOCALIZATION

In this section the principal techniques for a localization system are explained. Various localization systems are formed by the combination of these techniques.

### B. TIME OF ARRIVAL (ToA) ESTIMATION

Determining the distance is the main thing for various localization systems such as sonar [29], radar [30] and wireless local positioning systems (WLPSs) [28]. Also, localization is needed in mobile ad-hoc networks (MANETs) for resource allocation as well as routing [31]. ToA based localization systems compute the signal propagation delay to find the distance between a transmitter and a receiver, that is greatly influenced by multipath and their associated delay profiles [32]. Most importantly, in ToA based methods the line of sight (LOS) signal is presumed to be available for the computation of signal propagation delay. Figure 1 shows the basic structure for localization system based on ToA [33].

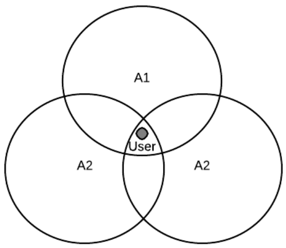


**FIGURE 1.** ToA based localization system.

In this setup, the user computes the ToA for the signal from three or more access points (nodes with already known locations). The speed of light being known, the distance between user and access point is computed. The disposition of points at the approximated range of user from each access point is a ring and the intersection of these rings gives the location of the user. Due to multipath error these rings do not intersect at a specific point. Therefore, it is of great importance to figure out the position of the user that is most suitable for the range calculations [33]. The basis for ToA based technique is the capability of receiver to exactly calculate the time of arrival for LOS signal. In literature, a number of time-delay estimation algorithms have been proposed to determine the delay of the earliest arriving signal. In time domain, Time delay estimation is done by estimating ToA based on channel impulse response [34],while in frequency domain, it is performed by finding the channel frequency response (CFR) [35].

### C. RECEIVED SIGNAL STRENGTH (RSS) ESTIMATION

Measurement that is ubiquitous in wireless systems is RSS. RSS based localization systems are less accurate than ToA based localization systems, but it can be implemented with little to no modification to existing systems. Specifically, received signal strength readings are obtainable in almost every wireless system without any extra hardware. Similar to ToA, in RSS, the user locates itself by receiving the signal from multiple access points. However, instead of measuring the ToA user computes the strength of the received signal [36].

In RSS measurements the received signal strength represents the distance between the user and access point. Path loss model for the RSS measurements can be expressed as

$$P_r(l) = P_r(l_0) - 10\psi \log \frac{l}{l_0}. \tag{1}$$

Where $P_r(l_0)$ is the received power at reference distance $l_0$ and $\psi$ is the path loss exponent according to the scenario shown in Table 1. As the received power $P_r(l)$ deteriorates exponentially the distance $l$ is easily obtained from (1). Assuming that the signal strength and channel characteristics are known, three access points are required to locate a user in 2-dimensional space.

**TABLE 1.** Path loss exponents corresponding to various environments.

| | |
|---|---|
| Free Space | 2 |
| Urban area cellular | 2.7 to 3.5 |
| Shadowed Urban | 3 to 5 |
| In Building LOS | 1.6 to 1.8 |
| In Building NLOS | 4 to 6 |

### D. DIRECTION OF ARRIVAL (DoA) TECHNIQUE

DoA based technique has applications in localization, beam-forming and detection. DoA calculation techniques can be further classified into two types:

- Online. These can be applied for online applications and having lower complexity.
- Offline. These are very complex and can barely be applied for online applications.

Detection and beam-forming require online DoA, where high precision is not required. Localization process needs high performance DoA estimation, however it may not be online.

Comparing to other ranging methods, DoA calculation requires the implementation of array antennas. Further, a radio frequency (RF) component is required for each antenna element, which is an expensive part of a radio system. Moreover, as compared to ToA and RSSI, DoA technique requires higher complexity and power consumption due to the relatively higher power consumption of RF components, thus it is expected that . Comparable to ToA and RSS calculation, the position of access points should be known in DoA. But, contrary to ToA and RSS in DoA just two access points having two DoA values are needed for a user to locate itself [37].

### E. TIME DIFFERENCE OF ARRIVAL (TDoA) ESTIMATION

In TDoA estimation the difference in time between the signals arriving from two different access points is measured. The time difference at the user can be represented by a hyperbola, whereas, the distance from two static points (foci) is fixed [38]. The intersection of hyperbolas from multiple TDoAs yields the user position. Comparing to the TOA measurements, in TDoA the user and access points do not need to be synchronized, since the TDoA measurement is the dissimilarity in the time of arrival of the signals from different anchor nodes. This makes the structure of transmitted signals simpler and eliminates potential errors. This advantage of TDoA estimation leads to its use in many applications such as sound and source localization by an artificially intelligent robot [39] and emergency call localization on highways [40], [41].

### F. RANGE FREE LOCALIZATION

In contrast to the range based estimation techniques range free localization does not require to measure the distance or angle between user and access point. Range free techniques estimate the length between user and access point by connectivity information or energy consuming information. Range free localization includes centriod localization algorithms [42]–[44], energy attenuation algorithms [45], [46], connectivity localization algorithms [47], [48] and region overlap algorithm [49]. Centriod localization uses the statistics of connectivity among the access points to calculate the location of a user with unknown location. In centriod localization the access points periodically broadcast their locations to the neighboring users with unknown location. When the user with unknown location receive this information the user and access point are said to be connected. Once the user is connected to several access points, the location of user with unknown location is calculated as the center of the polygon formed by the access points [42], [43].

In energy attenuation localization the user with unknown location is covered by the access points, the strength of the signal coming from access points degrades with increase in the space between the user and the access point. In energy attenuation algorithms, the user with unknown location estimates the distance to the access point depending on the degradation of the received signal strength.

Connectivity based localization follows the concept of graph theory with the network localization. In a unidirected graph $G$, if vertex $V_i$ has a path to vertex $V_j$, then $V_i$ and $V_j$ are said to be connected. If any two points of graph $G$ are connected then it is called a connected graph [50]. Connectivity based localization mostly depends on the topology of the network. Some of the connectivity based localization algorithms are distance vector hoping (DV-Hop) [51], localizable collaborative body (LCB) [36] and Multidimensional (MDS) based localization [52], [53]. In region overlap based localization the position of the user with unknown position is considered to be the centriod of the overlapping region. These algorithms also don't need to compute the distance between the access point and user with unknown location, thus, reduce the network communication overhead and save the users energy consumption [49].

WLAN based localization systems are also available in literature [54]–[56]. RADAR is another RF positioning system proposed by Microsoft research group [54]. RADAR system combines RSS and triangulation to compute the location of the target. COMPASS localization system uses the infrastructure of WLANs with digital compasses to provide the localization services with higher accuracy at relatively low cost [56].

### G. ISOMAP

Isomap is widely applicable to a broad range of data and is tremendously efficient [57]. It is one of the techniques that represent isometric mapping methods, and it enhances metric multidimensional scaling [58], [59] by including geodesic distances. Other scaling techniques perform low-dimensional embedding that is achieved from the pair-wise distance between data points by using the straight-line Euclidean distance, whereas Isomap is distinct in that it employs the geodesic distance generated by a neighborhood graph. By doing this, the multifarious structure gets encompassed in the produced embedding. Isomap represents the geodesic distance as the sum of edge weights along the shortest path between two nodes. The top $n$ eigenvectors [60] of the geodesic distance matrix represent the coordinates in the new n-dimensional Euclidean space. As examined in many published works the pair-wise distance $d_{ij}$ is vulnerable to error, mainly for distant users. The Isomap algorithm aims to keep the actual geometry of user location intact, as occupied in the geodesic multiple distances between each of the users. In the case of adjacent users, the Euclidean distance provides a suitable estimation of the geodesic distance. However, in the case of distant users, the geodesic distance is estimated by connecting a progression of "short links" between adjacent users. The shortest paths are obtained with edges connecting adjacent users in the neighboring graph to systematically calculate these estimations [61]. Isomap technique has previously been used for localization of nodes in wireless sensor networks but with the assumption of a fully connected network [61], [62], while considering full connectivity between all the nodes in a network is not practical. However, localization in the proposed technique is different where all the users are not directly connected to each other, which is a practical solution. The entire algorithm of Isomap for localization in 5G is illustrated in the next section.

## III. PROBLEM FORMULATION AND PROPOSED ALGORITHM

Let us consider a 5G network of $N$ users $1, \ldots, N$ with coordinates positioned in a two-dimensional geographic area. Let $X_i \in \mathcal{R}^2$ represent the location of user $i$, where $X_i = \{x_i, y_i\}$. Without loss of generality, the first $S$ users are access points, the locations of which are previously known, i.e., the position of access point $j$ is $X_j$ for all $j = 1, \ldots., S$, where $S << N$ and $X_j = \{x_j, y_j\}$. For all pairs of users $i$ and $j$, $d(x_i, x_j)$ denotes their Euclidean distance,

$$d(x_i, x_j) = \sqrt{\left(\sum_{k=1}^{m}(x_{ik} - x_{jk})^2\right)}, \quad (2)$$

where $m = 2$ for a 2D domain. The distances between neighboring users are computed using RSS measurements [63]. Localization using RSS measurements usually consists of two major types, i.e., tri-lateration and fingerprinting [64]. The relationship between the actual Euclidean distance

$d(x_i, x_j)$ and the RSS can be computed using the free space path loss model. However, uncertainty in the RSS measurements is introduced by shadowing. Therefore, to cope with this problem, we assume that each user receives the signals from the access points and calculate the RSS measurements with respect to $S$ access points. The $i$-th user computes the RSS values $\rho_{i,j}$ from $j$-th access point, where $\rho_{i,j} = d(x_i, x_j) + \eta$ with $\eta$ being the range error. Here, we assume that each user is able to compute multiple RSS values from different access points. Each user creates a $K \times L$ matrix, where $L$ is the number of samples at the $k$-th access point. The average RSS is then $\rho_{i,j}$, and $\sigma_{\rho_{i,j}}$ is the standard deviation of $N$ observations as:

$$\rho_{i,j} = \frac{1}{L} \sum_{k=1}^{L} \rho_{i,j}^{k}, \tag{3}$$

and

$$\sigma_{\rho_{i,j}} = \sqrt{\frac{1}{L} \sum_{k=1}^{L} \left(\rho_{i,j}^{k} - \rho_{i,j}\right)^2}. \tag{4}$$

The goal of localization is to retrieve the locations of $S+1, \ldots, N$ users based on $d(x_i, x_j)_{i,j=1}^{N}$ and $X_j$. If the access points are not available, i.e., $S = 0$, the relative coordinates of all users can be computed. However, the actual or global coordinates of the users cannot be retrieved. Note that when user $X_i$ is not in the communication range of user $X_j$, $\rho_{ij}$ cannot be attained directly. Here, we consider $\rho_{ij} = \infty$. Figure 2 represents flow diagram for the proposed 5G localization technique.

### A. PROPOSED ALGORITHM

The steps involved in proposed algorithm are shown in Fig. 2. Following are the details of each step in the proposed algorithm:

1) Assemble matrix $E$ of the RSS based estimated distances, where $E = [\rho_{ij}]_{N \times N}$. The RSS based estimated distances are larger than the actual Euclidean distance because of the additive white Gaussian noise. Euclidean metric is the ordinary straight-line distance between two points in Euclidean space [65].
2) Construct and define the neighborhood graph [66] $Z$ for all users by linking user $i$ and user $j$ if the distance $\rho_{ij}$ between $i$ and $j$ is less than $\gamma$, where $\gamma$ is the communication range of each user. Neighborhood graph is an undirected graph defined on a set of points in the Euclidean plane by connecting two points by an edge whenever there does not exist a third point that is closer to both p and q than they are to each other [67].
3) Determine matrix $E_Z$ of the geodesic distance over the neighborhood graph $Z$. Initialize $\rho_Z(x_i, x_j) = \rho(x_i, x_j)$ if users $i$ and $j$ are connected by an edge; also, $\rho(x_i, x_j)$ = some value or infinite if there is no direct connection. For all values of $l = 1, N$ in turn, substitute each $\rho_Z(x_i, x_j)$ value by $min\{\rho_Z(x_i, x_j), \rho_Z(x_i, x_l) + \rho_Z(x_l, x_j)\}$. The final matrix $E_Z = [\rho_{Z_{ij}}]_{N \times N}$ containing the distances of the shortest paths between all pairs of users in the neighborhood graph $Z$ is the geodesic distance matrix.

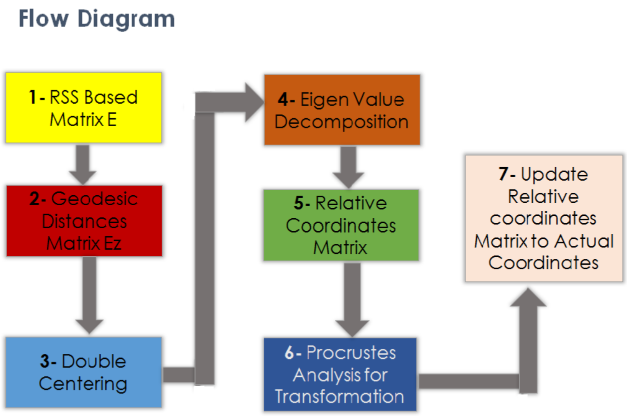


**FIGURE 2. Flow Diagram.**

4) Implement the double centering operation on matrix $E_Z$. Let $H = I - \frac{(qq^T)}{N}$, where $q$ is an $N$- dimensional column vector consisting of all ones and $I$ is the $N \times N$ identity matrix. Then, $J = -1/2HMH$, where $M_{ij} = E_{Z_{ij}}^2$. $J$ is also called the double-centered matrix.
5) Assess the eigen-decomposition of $J = UVU^T$, where $U$ are the eigen values and $V$ are the eigen vectors. Represent the matrix having the largest $m$ eigen values with $V_m$ and the first $m$ columns of $U$ with $U_m$. The $m$-dimensional matrix $\hat{\boldsymbol{Y}}$ contains the relative coordinates of each user and is equal to $U_m\sqrt{V_m}$.

$$\hat{\boldsymbol{Y}} = \boldsymbol{U}_m\sqrt{\boldsymbol{V}_m}, \tag{5}$$

which can be re-written as

$$\hat{\boldsymbol{Y}} = \{\hat{\boldsymbol{c}}_i\}_{i=1}^{N}, \tag{6}$$

where $\hat{\boldsymbol{c}}_i = \{\hat{x}_i, \hat{y}_i\}$ represents the 2D coordinates of $i$ in relative coordinate system.

6) After achieving the initial estimated coordinates by employing the Isomap technique, the relative coordinates are transformed into actual coordinates using the Procrustes analysis. Suppose there are $S$ access points, the locations of which are known in the 2D area, having absolute coordinates $\boldsymbol{c}_q = \{x_q, y_q\}$, and $1 \leq h \leq S$. Since the relative coordinates $\hat{\boldsymbol{c}}_q = \{\hat{x}_q, \hat{y}_q\}$ need to be congruent to the absolute coordinates $c_q$ for $S$ access points, the incongruity in the relative and absolute coordinates is calculated by

$$\nu = \sum_{h=1}^{S} (\hat{\boldsymbol{c}}_q - \boldsymbol{c}_q)^T (\hat{\boldsymbol{c}}_q - \boldsymbol{c}_q). \tag{7}$$

The actual function for transformation is defined as $t(s_c, t_r, r_o)$, where $s_c$, $t_r$ and $r_o$ are the scaling, translation and rotation factors [68], respectively. This is represented as

$$t(s_c, t_r, r_o)=\sum_{h=1}^{S}(\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r)^T (\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r). \tag{8}$$

The objective function in (8) can be simplified by determining the most appropriate values of $s_c$, $t_r$ and $r_o$ as

$$\{\hat{s}_c, \hat{t}_r, \hat{r}_o\} = arg_{s_c,t_r,r_o}\ min\ t(s_c, t_r, r_o). \tag{9}$$

Let $a_o$ and $b_o$ be the centroids of the absolute coordinates of the access points with actual coordinates and estimated relative coordinates, respectively, which are given as

$$a_o = \frac{1}{S}\sum_{h=1}^{S}\boldsymbol{c}_q, \tag{10}$$

and

$$b_o = \frac{1}{S}\sum_{h=1}^{S}\hat{\boldsymbol{c}}_q. \tag{11}$$

The optimal translation is then computed as

$$\begin{aligned} t(s_c, t_r, r_o) = \sum_{h=1}^{S} & ((\hat{\boldsymbol{c}}_q - b_o) - s_c {r_o}^T(\boldsymbol{c}_q - a_o) \\ & + \hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r)^T \\ & \times((\hat{\boldsymbol{c}}_q - b_o) - s_c {r_o}^T(\boldsymbol{c}_q - a_o) \\ & + \hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r), \end{aligned} \tag{12}$$

which is expanded as

$$\begin{aligned} t(s_c, t_r, r_o) = \sum_{h=1}^{S} & ((\hat{\boldsymbol{c}}_q - b_o) - s_c {r_o}^T(\boldsymbol{c}_q - a_o))^T \\ & \times((\hat{\boldsymbol{c}}_q - b_o) - s_c {r_o}^T(\boldsymbol{c}_q - a_o)) \\ & + S(\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r)^T \\ & \times(\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q - t_r). \end{aligned} \tag{13}$$

From (10), the perfect translation element $t_r$ that minimizes the objective function is computed as

$$t_r = b_o - s_c^T a_o. \tag{14}$$

Now assuming that $a_o = b_o = 0$ then

$$t(s_c, t_r, r_o)=\sum_{h=1}^{S}(\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q)^T (\hat{\boldsymbol{c}}_q - s_c {r_o}^T \boldsymbol{c}_q). \tag{15}$$

Now differentiating (12) with respect to $s_c$, the optimal value of $s_c$ which minimizes $t(s_c, t_r, r_o)$ as

$$s_c = \frac{Tr(\boldsymbol{c}_q r_o \hat{\boldsymbol{c}}_q^T)}{Tr(\boldsymbol{c}_q \boldsymbol{c}_q^T)}, \tag{16}$$

Finally to find the optimum rotation $r_o$, i.e.,

$$r_o = \boldsymbol{vu}, \tag{17}$$

where $v$ are the eigen vectors and $u$ are the eigen values of $\boldsymbol{c}_q\hat{\boldsymbol{c}}_q$, respectively, $r_o$ can also be written as

$$r_o = \frac{\sqrt{({\boldsymbol{c}_q}^T \hat{\boldsymbol{c}}_q \hat{\boldsymbol{c}}_q^T \boldsymbol{c}_q)}}{(\hat{\boldsymbol{c}}_q^T \boldsymbol{c}_q)}. \tag{18}$$

Assuming that at least three access points are available, the optimum values of $s_c$, $t_r$ and $r_o$ are computed. Then, these optimum values of $s_c$, $t_r$ and $r_o$ are used to find the actual locations of all other users, i.e.,

$$X = s_c r_o^T(\hat{X}) + t_r. \tag{19}$$

## IV. PERFORMANCE ANALYSIS

5G network localization problem is similar to the parameter estimation. Therefore, to evaluate any parameter estimation problem, the minimum unbiased variance estimation is taken as the evaluation criteria of any localization algorithm. Thus, the Cramer-Rao lower bound (CRLB) [69] is commonly used as a unbiased parameter estimator to evaluate the performance of parameter estimation. In this section, we derive the CRLB for the proposed 5G network localization algorithm. Since the range measurements $\rho_{ij}$ between users are affected by Gaussian noise, the probability density function (PDF) for the range measurements $\rho_{ij}$ is given by

$$f(\rho_{ij}|\boldsymbol{X}_i, \boldsymbol{X}_j) = \frac{1}{\eta_r\sqrt{2\pi}} \exp^{\left(-\frac{(\rho_{ij}-d_{ij})^2}{2\eta_r^2}\right)}. \tag{20}$$

To construct the corresponding fisher information matrix (FIM), log-likelihood ratio for the given PDF in (20) can be written as

$$\begin{aligned} l_{ij}[\text{dB}] = & -\log\sqrt{2\pi\mu} - \frac{\beta_{ij}}{4}\log(\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2) \\ & - \frac{1}{2\mu}\frac{\left(\rho_{ij} - \|\boldsymbol{X}_i - \boldsymbol{X}_j\|\right)^2}{(\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2)^{\beta_{ij}/2}}, \end{aligned} \tag{21}$$

where $\mu$ is scalar constant and $\beta_{ij}$ is the path loss exponent, then the joint log-likelihood ratio for all the users in the network is

$$\boldsymbol{\Pi}_{ij} = \sum_{i=1}^{S}\sum_{j=i+1}^{N}\log\left(f(\rho_{ij}|\boldsymbol{X}_i, \boldsymbol{X}_j)\right). \tag{22}$$

From (22), a sub-matrix $\mathbf{F}_i$ of FIM is defined as

$$\mathbf{F}_i = \begin{bmatrix} \mathbf{F}_{2i-1,2i-1} & \mathbf{F}_{2i-1,2i} \\ \mathbf{F}_{2i,2i-1} & \mathbf{F}_{2i,2i} \end{bmatrix}, \quad i = 1, 2, 3......K, \tag{23}$$

where each element in (23) is defined as

$$\mathbf{F}_{2i-1,2j-1} = \mathbf{F}_{2j-1,2i-1} = \begin{cases} \sum_{j\in H(i)} \frac{1}{\eta_r^2}\frac{(x_i - x_j)^2}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & i = j, \\ \frac{-1}{\eta_r^2}\frac{w_{ij}(x_i - x_j)^2}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & j \in H(i) \text{ and }, \\ & j \neq i \\ 0 & j \notin H(i) \end{cases} \tag{24}$$

$$\mathbf{F}_{2i-1,2j} = \mathbf{F}_{2j,2i} = \begin{cases} \sum_{j \in H(i)} \frac{1}{\eta_r^2} \frac{(y_i - y_j)^2}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & i = j, \\ \frac{-1}{\eta_r^2} \frac{w_{ij}(y_i - y_j)^2}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & j \in H(i) \text{ and } j \neq i \\ 0 & j \notin H(i) \end{cases}, \tag{25}$$

$$\mathbf{F}_{2i-1,2j} = \mathbf{F}_{2j,2i-1} = \mathbf{F}_{2i,2j-1} = \mathbf{F}_{2j-1,2i} = \begin{cases} \sum_{j \in H(i)} \frac{1}{\eta_r^2} \frac{(x_i - x_j)(y_i - y_j)}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & i = j, \\ \frac{-1}{\eta_r^2} \frac{(x_i - x_j)(y_i - y_j)}{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2} & j \in H(i) \text{ and } j \neq i \\ 0 & j \notin H(i) \end{cases}. \tag{26}$$

where $\omega_{ij}$ is the distance dependent scaling factor. Then, the Fisher Information Matrix (FIM) can be written based on the sub-matrices as

$$\mathbf{FIM} = \begin{pmatrix} \mathbf{F}_1 & & & \\ & \mathbf{F}_2 & & \\ & & \ddots & \\ & & & \mathbf{F}_K \end{pmatrix}. \tag{27}$$

By elementary matrix theory, the inverse of the FIM is given by

$$(\mathbf{FIM})^{-1} = \begin{pmatrix} \mathbf{F}_1^{-1} & & & \\ & \mathbf{F}_2^{-1} & & \\ & & \ddots & \\ & & & \mathbf{F}_K^{-1} \end{pmatrix}. \tag{28}$$

According to the CRLB, we obtain

$$\mathrm{E}\left((\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2\right) \geq (\mathbf{F}_i^{-1})_{1,1} + (\mathbf{F}_i^{-1})_{2,2}, \tag{29}$$

where $(\mathbf{F}_i^{-1})_{1,1}$ and $(\mathbf{F}_i^{-1})_{2,2}$ are the diagonal elements of $(\mathrm{FIM})^{-1}$, then by Cauchy-Schwarz inequality

$$(\mathbf{F}_i^{-1})_{1,1} \geq \frac{1}{(\mathbf{F}_i)_{1,1}} \geq \sum_{j \in H(i)} \eta_r^2 \left( \frac{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2}{(x_i - x_j)^2} \right), \tag{30}$$

and

$$(\mathbf{F}_i^{-1})_{2,2} \geq \frac{1}{(\mathbf{F}_i)_{2,2}} \geq \sum_{j \in H(i)} \eta_r^2 \left( \frac{\|\boldsymbol{X}_i - \boldsymbol{X}_j\|^2}{(x_i - x_j)^2} \right). \tag{31}$$

Thus, we have developed a generalized CRLB for the location estimation problem in the multi-hop scenario for 5G network. In the simulation section, the performance of the proposed 5G network localization method is compared to the CRLB.

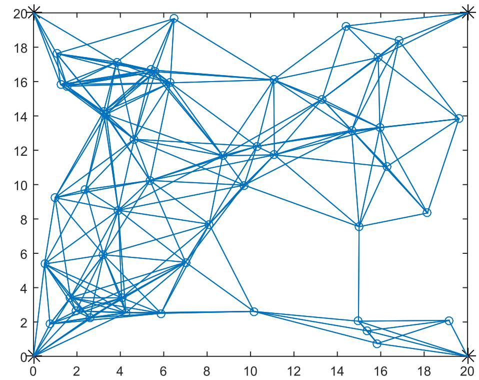


**FIGURE 3. Network setup with 50 users and range = 6 meters.**

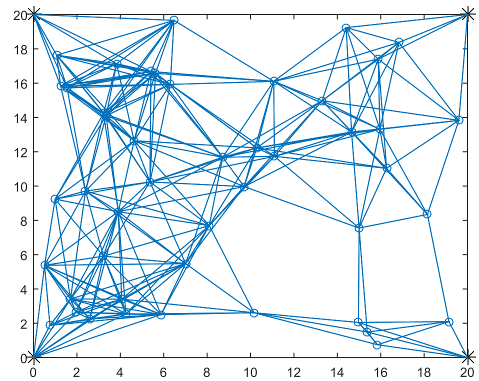


**FIGURE 4. Network setup with 50 users and range = 8 meters.**

## V. SIMULATION RESULTS

Numerous simulations have been performed in Matlab to analyze the performance of the proposed 5G localization algorithm based on RSS measurements by comparing with the literature [12], [70] and CRLB in terms of the MSLE $\Pi$, which is given by

$$\Pi = \mathbb{E}[(\hat{\boldsymbol{X}}_i - \boldsymbol{X}_i)^T (\hat{\boldsymbol{X}}_i - \boldsymbol{X}_i)] \tag{32}$$

where $\mathbb{E}$ is the mean or expected value, and $\hat{\boldsymbol{X}}_i$ and $\boldsymbol{X}_i$ are the estimated and actual positions the of users, respectively.

For simulation purposes, the following parameters are taken into consideration: a $20 \times 20$ $m^2$ area is considered with 50 users including 4 access points with users having ranges of 6m, 8m and 10m, as shown in Figures 3, 4 and 5, respectively. In our case, we initially placed 4 access points at each corner of the $20 \times 20$ $m^2$ area in a two-dimensional space. The range error is a zero-mean white Gaussian process. All results are performed for 4000 independent runs or otherwise stated. Initially, 50 users were considered in the specific area.

Figures 3, 4 and 5, having four stars on the corners as access points and blue lines as connecting distances between users, show that with an increase in the communication range of the users, the number of connecting paths increases substantially. Figure 6 shows the decrease in error of the estimated positions with an increase in the number of users while keeping the communication range of users constant. The green line shows CRLB, while the blue, pink and red

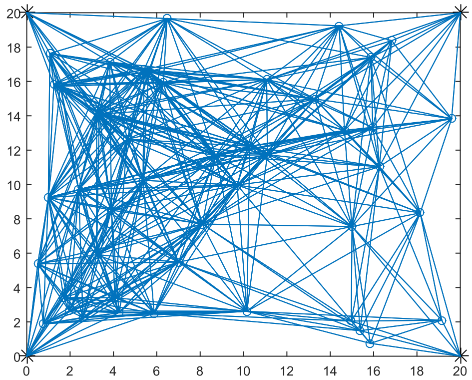

**FIGURE 5.** Network setup with 50 users and range = 10 meters.

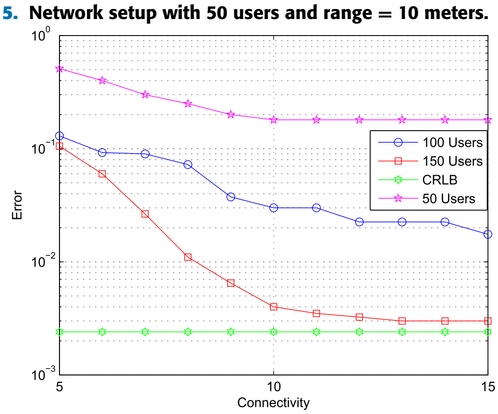


**FIGURE 6.** Localization error Vs. Connectivity in case of 50, 100 and 150 users.

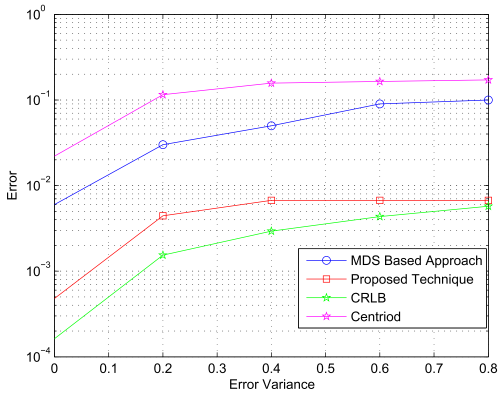


**FIGURE 7.** Localization error Vs. Range Error Variance.

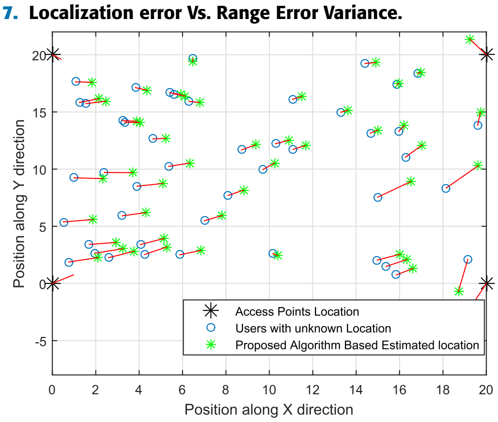


**FIGURE 8.** Proposed Solution for 50 users with range of 6 meters.

lines indicate 100, 50 and 150 users, respectively. It can be seen in the figure that in the case of the highest number of users, i.e, 150, error is minimized because there is large number of direct connecting paths between users. Figure 7 shows a comparison of the error between our proposed technique and the literature. It can be seen that our proposed technique performs better.

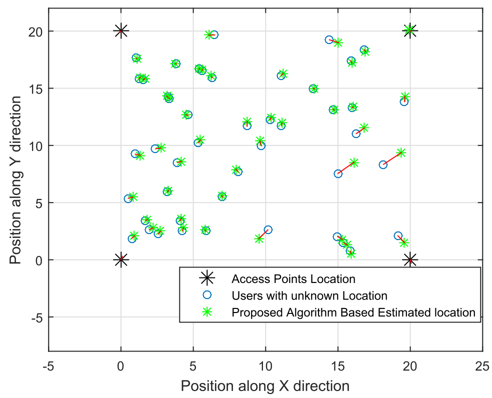


**FIGURE 9.** Proposed Solution for 50 users with range of 8 meters.

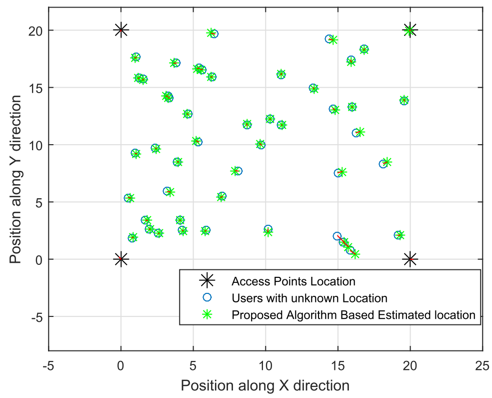


**FIGURE 10.** Proposed Solution for 50 users with range of 10 meters.

Figures 8, 9 and 10 show the relationship between the error in our estimated positions and the communication range of users. Blue circles in the graphs denote users with unknown locations, green stars show the actual positions and black stars are the access points. The red lines indicate the difference between the actual positions and the locations estimated by using our proposed technique, i.e, the localization error. Figure 8 reveals that the difference between the actual and estimated positions is noticeable because the range of users is kept at a minimum. This difference, i.e, error, decreases in Figure 9 as the range is increased. In the end, Figure 10 shows the least error, which is negligible because the range is large compared to the two previous cases. Therefore, comparing Figures 8, 9 and 10 reveals that the error in localization decreases as the communication range of users increases.

## VI. CONCLUSIONS AND FUTURE ENHANCEMENTS

In this paper, a 5G network localization technique is proposed based on RSS measurements for public safety applications. Initially, the relative coordinates of users are computed using Isomap and then they are transformed to the actual global coordinate system. The Cramer-Rao lower bound, which is the benchmark for analyzing any localization technique, is derived for the proposed technique. Numerous simulations were conducted to evaluate the performance of the proposed 5G network localization technique. It is observed that the proposed technique is much less prone to error and more accurate than the other techniques provided in the literature. In future, it is intended to enhance the proposed work as follows: This technique will be applied on users in 3-D environment. Other localization techniques will be implemented for location awareness in 5G networks. Lower bounds other than CRLB will also be derived for the proposed method as well as for other localization techniques.

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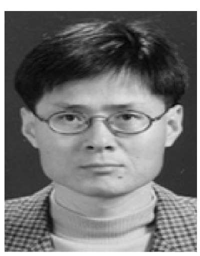

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