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An Approach of Extended Kalman Filter in Cooperative Localization

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Abstract: In this paper we explored the problem of localizing a mobile user within the range of a base station in 5G communication. For solving this problem we utilized Cooperative localization method over conventional localization technique to estimate the position of a mobile user. In cooperative localization we estimate position of the target user using Angle of Arrival(AOA), Time Difference of Arrival(TDOA) and Received Signal Strength(RSS) observations from nodes which are neighbour to target node and the base station. This estimation is done with the help of Extended Kalman Filter method.
Keywords: Extended Kalman Filter, TDOA, RSS, AOA.

I. INTRODUCTION

Localization or tracking is the field which helps in surveillance, tracking people who are in an emergency and in getting information about the traffic in a particular area. It also helps in network planning and optimization. For instance, like tracking the information about running criminal, identifying traffic hotspots, improving network in weak coverage areas are some of the applications of localization. In emerging technologies like 5G communication network, to make the task easier device to device or in other words, a user to user communication can be used to localize the mobile user. This device to device communication helps in improving the error performance of the estimation used for the localization.

In this paper, we have tried to apply the above technique using the Extended Kalman Filter method to estimate the position of the target user. We have taken two cases, first case in which we have 1 base station and 3 mobile user, in which all the 3 mobile users positions are unknown. Second case, in which out of 3 mobile user 2 user positions are known and other node position are unknown. In both the cases all the users are communicating with each other and also with base station. In cooperative localization to estimate the position of the target user we take the help of the neighbouring nodes of the target user. We have define a range of the base station, in within range of the base station we are estimating the position of the target user with help of its neighbouring nodes of certain range from the target user.

II. EXTENDED KALMAN FILTER

For the estimation of the position coordinates of the target node, we have used the Extended Kalman Filter. Kalman Filter takes the observation data and estimates the position based on the observation data. Since our system model is nonlinear, we have taken the EKF approach for the localization. EKF uses Taylor's Series approximation to linearize the nonlinear system model. Kalman filter has two steps: Prediction and Correction. In the first step, a prediction is made based on previous states and observations. Correction is done after taking error between the predicted and actual observations.

$$x_k = f(x_{k-1}, u_k, k) + w_{k-1} \tag{1}$$
$$y_k = h(x_k, u_k, k) \tag{2}$$

where x_k is the state vector at point k, w_{k-1} is the additive Gaussian noise.
Extended Kalman Filter predictor and corrector equations as follows

$$P_k = F_{k-1}P_{k-1}F^T_{k-1} + Q_k \tag{3}$$
$$K_k = \bar{P}_k H^T_k (H_k P_k H^T_k + R_k)^{-1} \tag{4}$$
$$x_k = x_k + K_k (y_k - h(x_k, u_k, k)) \tag{5}$$
$$P_k = (I - K_k H_k)\bar{P}_k \tag{6}$$

where P_k is the covariance of the filter, F_k is the transition matrix, K_k is the Kalman gain matrix.

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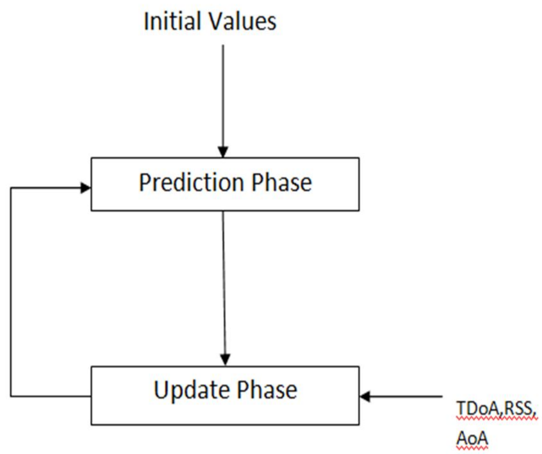

Figure 1: Flow chart for Extended Kalman Filter

III. SYSTEM MODEL

For the extracting the position of the target node, we required relationship between the location of the target node and the data which we are using to obtain the position. The scenario which we considered for the localization is that base station has the range of 100 metres, and the target and its neighbouring users are within this range: the target user and nearby user within the range of 25 metres to each other.

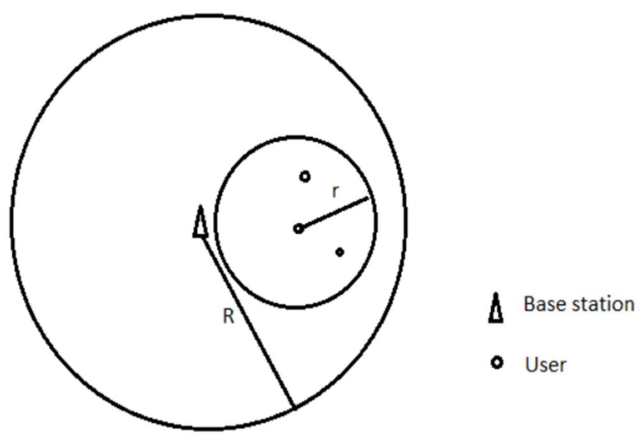

Figure 2: System model for Cooperative Localization

The data which we are using as observation data for the EKF is the angle of arrival(AOA), time difference of arrival(TDOA) and received signal strength(RSS), for cooperative localization nodes and the base station is communicating with each other. Nodes are communicating with each other in the form of RSS.

The equation of calculating the angle of arrival is:

$$AOA = tan^{-1}\{(y_i - y_j)/(x_i - x_j)\} \quad (7)$$

where i and j represents the i^{th} and j^{th} mobile user.

AOA is calculated by scanning the signal stength in every direction, then locating the angle at which maximum signal is received at the transmitter. TDOA is the time difference of the signal receiving from the base station between the nodes.The equation for calculating the TDOA is as follows:

$$TDOA= \sqrt{(a-b)}/c \quad (8)$$

where a and b is given as:

$$a = ((y_i - y_j)^2 + (x_i - x_j)^2 + (z_i - z_j)^2) \quad (9)$$

$$b = ((y_i - y_j)^2 + (x_i - x_j)^2 + (z_i - z_j)^2) \quad (10)$$

RSS is the strength of the signal received from the node to the transmitter. Nodes are also communicating with each other in the form of RSS. We have taken the log-normal shadowing
path for the channel effect. The equation for calculation of RSS in dB is as follows:

$P_r\ (dB) = P_t\ (dB) - 20\log_{10}(d/d_o)$

where P_r is the received power, P_t is the transmitted power, d is the distance between node and base station, d_o is the reference distance generally taken as 1.

For the Extended Kalman Filter state equation can be defines as:

$$x_k = Ax_{k-1} + w_k \qquad (11)$$

In the above equation the A is the state transition matrix, and wk is the Gaussian noise.

For localising the location of the target mobile user, we have considered the general case and one specific case. In the general case, we have considered that we don't know the exact positions of the neighbouring nodes, and in the particular case, we have considered that the adjacent nodes' locations are known to us. In both cases, we have communication between the neighbouring node and target node.

A. Base Station, 3 Unknown Nodes

In this case, we have a base station whose position is known to us. The base station is communicating with the nodes in the form of RSS, angle of arrival and time difference of arrival. Nodes are also communicating with each other in the way of RSS.

B. Base Station, 2 Known Nodes And 1 Unknown Node

In this case, we have a base station and two nodes whose position is known to us. The base station is communicating with the nodes in the form of RSS, angle of arrival and time difference of arrival. Known nodes are communicating with the unknown node in the way of RSS.

IV. NUMERICAL RESULTS AND DISCUSSION

The above mentioned system model is simulated using MATLAB. We have studied and tried Extended Kalman estimation algorithm tried to find the location of the node and the residues of TDoA, AoA and RSS for localization and cooperative localization also.

Table 1 System Parameters

Parameter	Value
Base Station radius R	100m
Observed data Noise Covariance	0.0001
Process Noise Covariance	0.1
Algorithm used	Extended Kalman Filter
Total nodes considered	3 or 4 nodes(including base station)
Number of iterations	100

The Figure 3(a) ,Figure 3(b) and Figure 3(c) shows the error in the positions of node 1, node 2 and node 3 respectively by using the localization method. The nodes are only communicating with the base station only not with each other. These error plots are in the case when we did not know the positions of the neighbouring nodes and the target node by using the simple localization technique for the given system model. We have also assumed that the node positions are random not fixed.

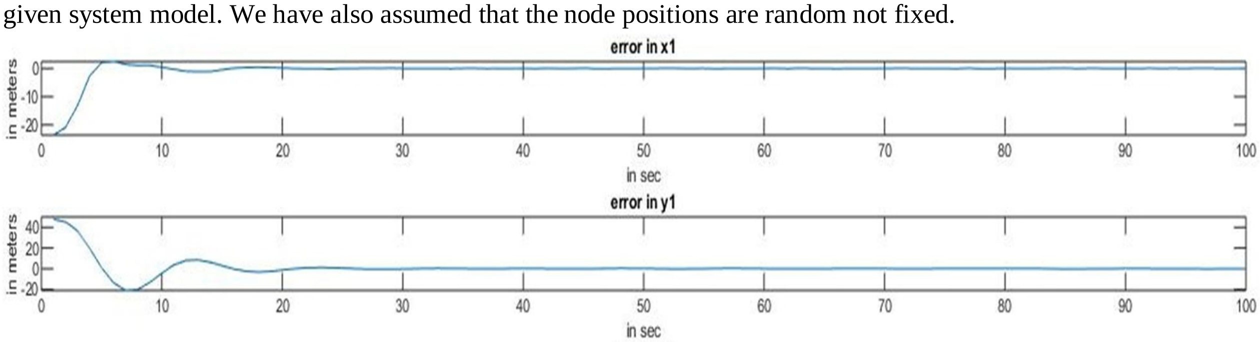

Figure 3(a): Error in node 1 when all 3 nodes are unknown

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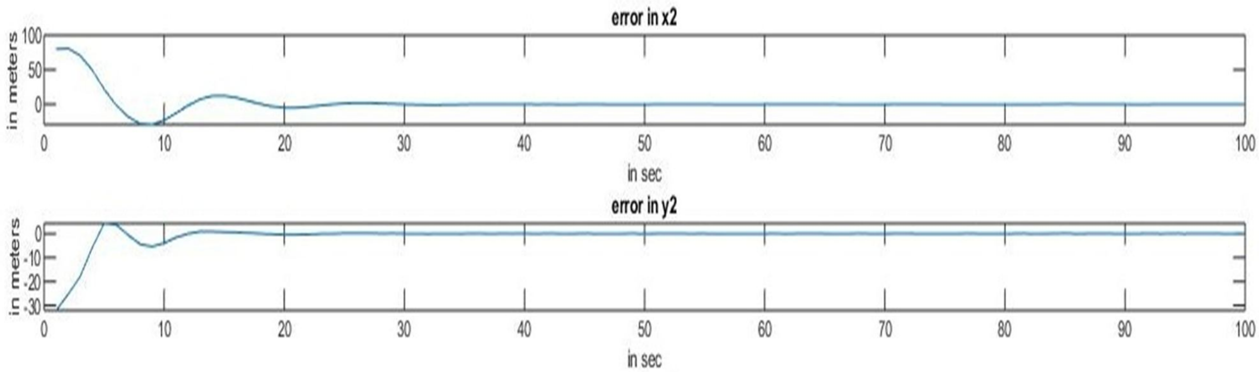

Figure 3(b): Error in node 2 when all 3 nodes are unknown

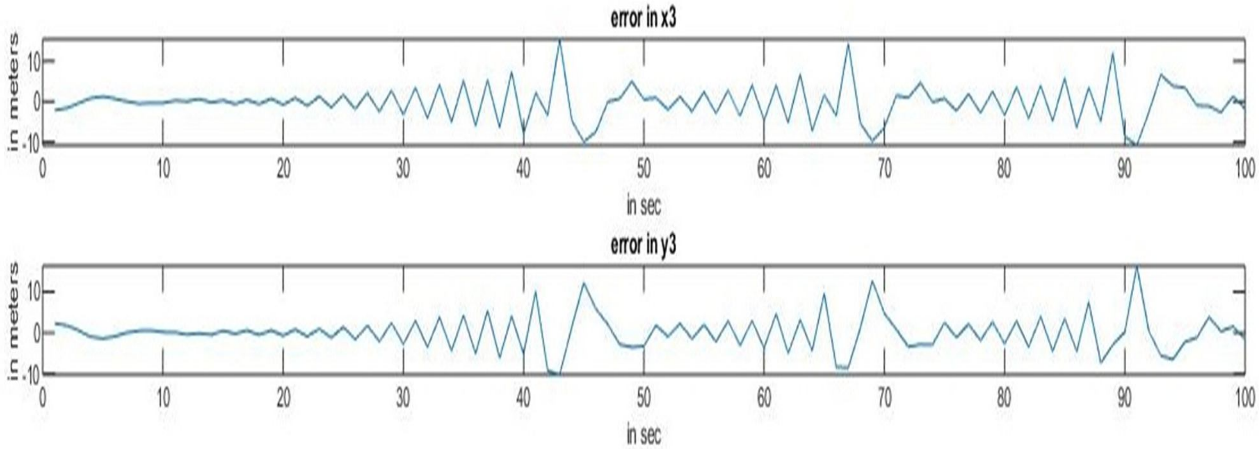

Figure 3(c): Error in node 3 when all 3 nodes are unknown

The Figure 4 shows the the error in the position of node 3 when the other 2 nodes are known by using the localization method.

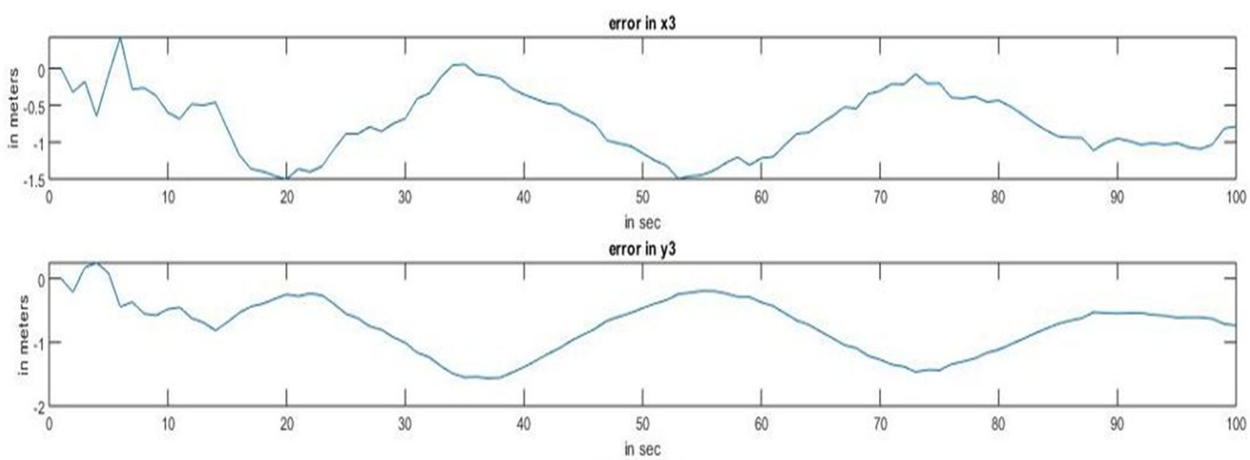

Figure 4: Error in node 3 when 2 nodes are known amd 1 unknown

The three figures Figure 5(a) ,Figure 5(b) and Figure 5(c) shows the error in the positions of node 1, node 2 and node 3 respectively by incorporating the cooperative localization technique. These error plots are in the case when we did not know the positions of the neighbouring nodes and the target node. We have also assumed that the node positions are random not fixed.

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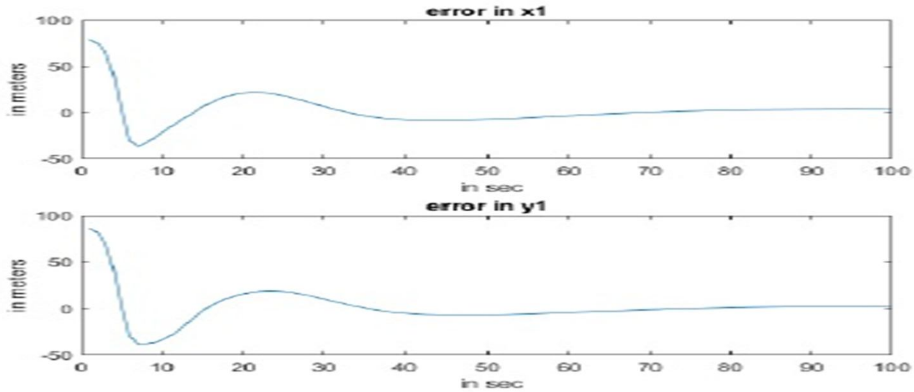

Figure 5(a): Error in node 1 when all 3 nodes are unknown.

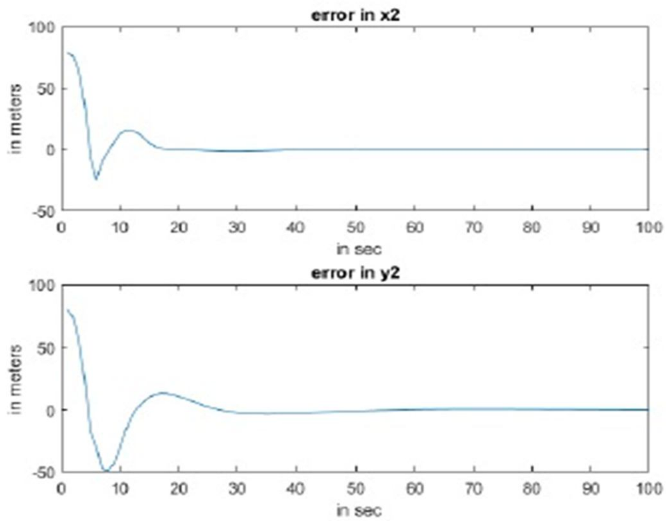

Figure 5(b): Error in node 2 when all 3 nodes are unknown

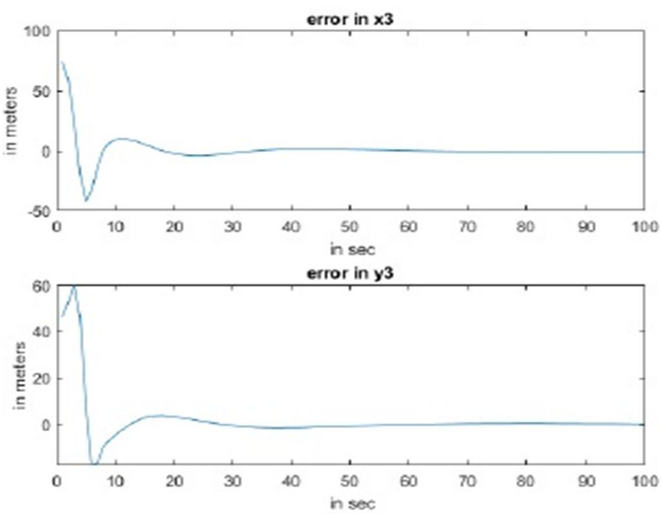

Figure 5(c): Error in node 3 when all 3 nodes are unknown

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The Figure 6 shows the error in the estimation of location of the target user under the assumption that we know the neighbour nodes exact positions and the nodes are also communicating with each other.

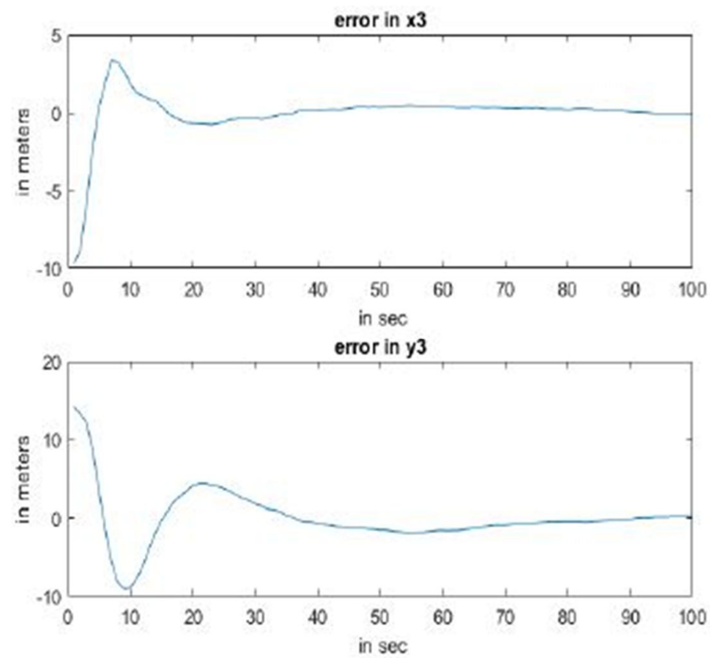

Figure 6: Error in node 3 when node 1 and node 2 are known and node 3 is unknown

Table 2. Comparison of errors in position coordinates of unknown nodes in both cases

SN.	Model Cases	Position coordinates	Error in position coordinates with localization (in metres)	Error in position coordinates with cooperative localization (in metres)
2	1 Base station and 3 unknown node	X1	0.229	0.1217
		Y1	0.8	0.4913
		X2	0.0972	0.1135
		Y2	-0.06	-0.0903
		X3	-1.75	0.1977
		Y3	-1.509	0.2301
1	1 Base station 2 known nodes and 1 unknown node	X3	-0.7876	0.02098
		Y3	-0.714	0.03891

V. CONCLUSION

We have shown the various conditions under which the estimation was done. We have calculated the position error for both localization and cooperative localization for the proposed model. Firstly we calculated the error for general case, i.e. when all the nodes are unknown. Then we have calculated the error and residue for specific cases, i.e. when the neighbouring nodes' positions are exactly known to us. As we can see from the comparison table that by incorporating the cooperative localization the position error is reduced for both the general and specific case.

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