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STATISTICAL ANALYSIS OF WSN BASED INDOOR POSITIONING LOCALIZATION SCHEMES WITH KALMAN FILTERING

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Abstract - Wireless Sensor Network (WSN) is used for determining the Indoor Positioning of objects and persons since recent years. WSN has been implemented in indoor positioning applications such as real time tracking of humans/objects, patient monitoring in health care, navigation, warehouses for inventory monitoring, shopping malls, etc. But one of the problems while implementing WSN in Indoor positioning system is to ensure more coverage large number of sensors must be deployed which increases the installation cost. So in this paper, we have used MATLAB GUI named Sensor Network Localization Explorer to analyze the impact of node density on indoor positioning localization schemes. Later we have integrated the Kalman filter with the indoor positioning system to increase the reliability and reduce the localization error of the system with lesser number of nodes.

Keywords- *Kalman Filter, Indoor Positioning, Wireless Sensor Networks, Time of Arrival, Angle of Arrival, Node density*

I. INTRODUCTION

Global Positioning System (GPS) plays a dominant role in localization of objects or persons in outdoor environments. Even though lots of GPS devices are developed to provide sufficient precision for outdoor use, GPS is not efficient for localization in indoor environment because in indoor environment the GPS signal can't penetrate most of the building materials and also the signal gets weakened due to obstacles. Since people spend most of their time in indoor environments, indoor positioning and tracking is in great demand. Hence in order to enable localization in indoor environments, development of special indoor localization techniques were needed. Several indoor positioning localization technologies have been developed based on Infrared, ultrasonic, RFID, Wireless Sensor Network (WSN), Wi-Fi, WLAN, etc. [1] The proliferation of wireless localization technologies offers large number of applications in indoor environments including patient monitoring, health care, navigation, real-time tracking of persons or objects, rescue purposes in fire extinguishers, monitoring elderly persons, etc.

Wireless Sensor Networks (WSN) is used for indoor positioning operations since recent years. The deployment of tiny, cheap, low power sensor nodes which are capable of sensing, processing and wireless communication has found many applications in the field of agriculture for irrigation purposes, surveillance, military purposes, etc. [2] Each sensor node consists of a processing unit such CPU or processor, a memory unit to store program and data, a radio transceiver for communicating with base station and other nodes, sensing unit for monitoring the given physical environment i.e. pressure, temperature, moisture, etc. and a power source.

The sensor networks, the nodes can be deployed either in location aware infrastructure or into an unplanned infrastructure where there is no a priori knowledge about location[3].

The rest of this paper is organized as follows. Section II will give information regarding the steps involved in indoor positioning localization. Section III explains the signal measurement phase of indoor positioning system. Section IV and V discusses the problem statement and the simulation environment. Section VI shows the outputs obtained using the senelex tool without Kalman filter. Section VII explains application of Kalman filter in indoor positioning system. Section VIII and IX concludes the paper with a discussion on open issues.

II. INDOOR POSITIONING SYSTEM

Dempsey [4] has defined indoor positioning system is a system that is capable of determining the position of an object or person in a physical environment and in real time.

In any indoor positioning system, at first the reference nodes are placed in the indoor environment. The reference nodes may be either aware of their location or in some cases they may be placed in an unknown infrastructure.

Now let us consider a typical indoor positioning scenario in which the reference nodes are placed. The reference sensor node sends out beacon signals at particular interval of time. When any unknown node i.e. target comes under the range of a reference node, the reference node sends out a request signal to the unknown sensor node. This unknown sensor node will perceive the incoming request signals and issues a ranging reply to the sensor node. By this time, the reference node would have calculated the transmission time between the reference node and the unknown node i.e. target. Then the reference node forwards the calculated time to base station where the original position of the target will be calculated based on the various position calculation schemes such as trilateration, triangulation, etc.

Thus in any indoor positioning system, in order to determine the position of a target, there are two important steps. First one is the signal measurement phase and second one is position calculation phase. In the signal measurement phase, some signals are transmitted between a number of reference nodes and the target node. During this process, some of the signal parameters such as Time of Arrival (TOA), Received Signal Strength Indicator (RSSI) and Angle of Arrival (AoA) are measured.

The second phase is the position calculation. In this phase, the physical position of the target node will be determined based on the signal parameters obtained in the first phase. Trilateration and triangulation are two most popular geometric approaches which are used for range based localization schemes position calculation. However the measured signal parameters in real time are prone to indoor noise, hence the accuracy is only up to a certain extent. So we need optimization techniques such as filters which are often used to suppress the indoor positioning measurement noise and increase the accuracy of the output.

III. LOCALIZATION SCHEMES

The problem of estimating the spatial coordinates of an unknown node (target) is known as localization. Broadly localization techniques can be classified in two main categories i.e. Fine-grained (range-based) and Coarse-grained (range-free). In range-based localization scheme distance, time of flight, angle information is noted to determine the position of target from the sensor node. Range-based localization schemes require more sophisticated hardware to measure the signal parameters such as Time of Arrival (TOA), Angle of Arrival (AOA) and Received Signal Strength Indicator (RSSI).[6] The accuracy of such estimation, however, is subject to the transmission medium and surrounding environment. On the other hand, the Range-free localization uses only proximity (connectivity) information to measure the distance of the target from reference node. [7] Now let us see the two phases of indoor positioning system with various range based localization schemes.

A. *Time of Arrival (TOA)*

Time-of-Arrival (TOA) is the time measured at the receiver end at which it receives the signal. The measured TOA is actually the time taken for the transmission plus the time delay. Thus the distance between the receiver node and a reference node is determined by time of flight of the transmitting signal. In TOA measurement, the speed of the transmitted signal is known. At the receiver end, on receiving the signal, in turn, each receiver node will send a signal back to transmitting node which is the reference node.

Once the time of flight of the signal is calculated, the distance between the nodes can be determined using the formula:

$$R = \text{time} \times \text{speed} \tag{1}$$

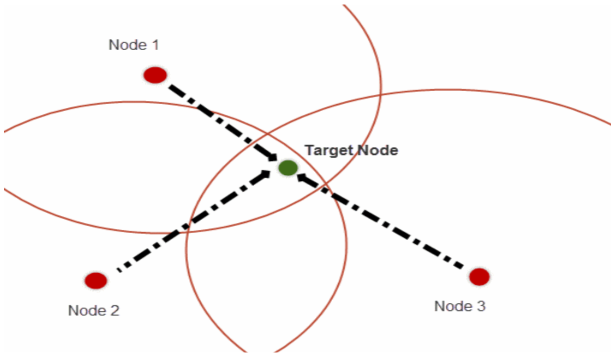

Fig.1 Time of arrival method[9]

After measuring the distance the usual method of trilateration is used for finding the position of the sensor.

B. *Angle of arrival (AOA)*

The Angle of Arrival (AoA) technique is another range-based localization scheme which requires directional antennas with rotating capability. It estimates relative or absolute angles between the reference nodes and the target node. AoA is defined as the angle between the propagation direction of an incident wave and some reference direction, which is known as orientation. Usually directional antennas or array of antennas are used for measuring the AoA. For proper AoA measurement, the array geometry must be known. With AOA, no time synchronization between nodes is required. But AoA requires directional antennas with rotation capabilities which make the hardware complex.

However, If the AoA signal parameter is available, triangulation can be used to determine the position of the target node. Unlike trilateration method, in triangulation only two reference nodes are enough to predict the position of the target. Thus it reduces number of reference nodes required to detect a target

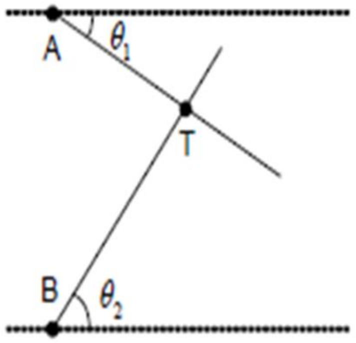

Fig.2. Angle of Arrival

As shown in Fig. 2, the reference nodes are represented by A and B. Once the angles $\theta1$ and $\theta2$ between the reference nodes and the target node is known, the physical position of Target T can be calculated based on the predetermined co-ordinates of the reference nodes.

C. Received Signal Strength Indicator (RSSI)

In RSSI, the distance is measured based on the attenuation introduced by the propagation of signal from the transmitting node (reference node) to the receiving node (target node). [8]The basic principle in RSSI measurement is that the signal strength is inversely proportional to distance travelled by the signal. That means the signal strength decreases as the signal travels greater distance, this decrease in signal strength is inversely proportional to the square of the distance travelled. It is given by

$$\text{Signal Strength} \propto \frac{1}{d^2}$$

The main advantage of RSSI localization scheme is its lower configuration cost than the other range-based localization schemes. At the same time, RSSI measurement has larger error because of the variation of RSSI by the environment (Radio interference, Obstacles (persons, walls), Individual differences of transmitters and receivers (antenna type, transmission power etc.). Multi-path fading, background interference, irregular signal propagation makes estimates inaccurate.

IV. PROBLEM STATEMENT

If we take a closer look at the localization schemes, each one of them have their own advantages as well drawbacks. Either the hardware complexity increases or the accuracy gets reduced. So to maintain accuracy, the node density needs to be increased. So we have tried to analyze the node density effect on the localization schemes such as TOA, AOA and RSSI. Then we applied the obtained estimated position of the target by each localization scheme to the Kalman filter to improve the accuracy of lesser node density network up to the level of higher node density network.

V. SIMULATION ENVIRONMENT

We have used a MATLAB GUI called Senelex i.e. The Sensor Network Localization Explorer which is provided by OHIO STATE University [9].The Localization GUI requires MATLAB version 7.x and greater and the Optimization Toolbox to run properly. The sensor network self-localization GUI enables the user to determine the localization of arbitrary sensor networks through simulation. We kept the network size to be constant as 300x200 m^2 and array node density to be 18. At first the localization error is calculated for all signal parameters such as TOA, AOA and RSSI. Then the array node density is increased to 36 keeping the network size to be constant. Now again the simulation is run and the localization error parameter is calculated for all signal parameters.

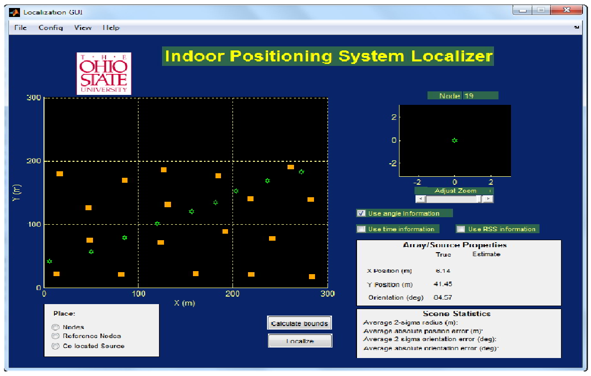

Fig.3. Sensor Network before Localization

Fig. 3 shows a network of sensor node in which 18 anchor nodes representing the orange boxes and rest other are target node position are placed within the area 300m x 200m.

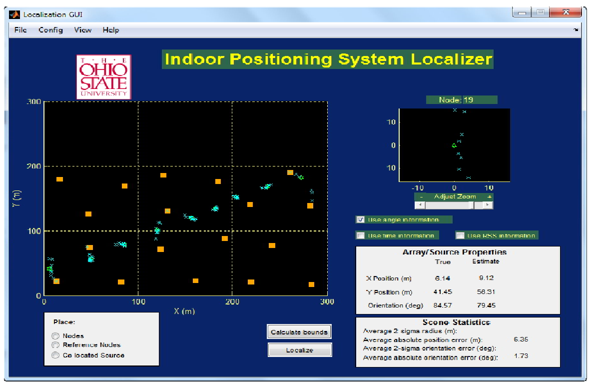

Fig.4. Sensor Network after Localization

Fig. 4 shows the localized result of the same network after applying range-based RSS scheme.

The simulations of each range-based scheme are done on each network parameters. The output of each simulation is stored into a MATLAB .m file. Then on each .m file the performance metrics is applied and the result is calculated.

The standard deviation is calculated using the following procedure:

$$LE(X) = (X - X_{est}) \quad (3)$$

$$LE(Y) = (Y - Y_{est}) \quad (4)$$

$$Mean(X) = \sum_{i=1}^{N} \frac{LE(X)}{N} \quad (5)$$

$$Mean(Y) = \sum_{j=1}^{N} \frac{LE(X)}{N} \quad (6)$$

$$\Delta X = LE(X) - Mean(X) \quad (7)$$

$$\Delta Y = LE(Y) - Mean(Y) \quad (8)$$

$$\sigma^2_{Xk} = (\Delta X)^2 \quad (9)$$

$$\sigma^2_{Yk} = (\Delta Y)^2 \quad (10)$$

VI. RESULTS

Keeping the network size constant, the network is simulated with each signal parameter such AOA, TOA and RSSI one by one. The following represents the results of the simulations.

From the exported Matlab file, the performance metrics are applied and the results are plotted versus the original position of the target node.

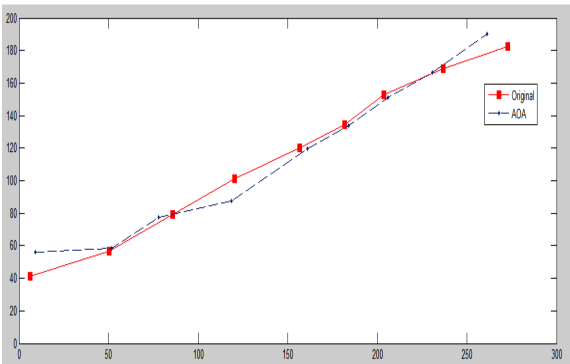

Fig.5. Angle of Arrival Estimated Position Vs Original Position

In figure 5, we can notice that the original position of the target and the estimated position of the target are not the same. The localization error between the original position and the estimated position using the Angle of Arrival parameter is found to be 14.6 and 8.3

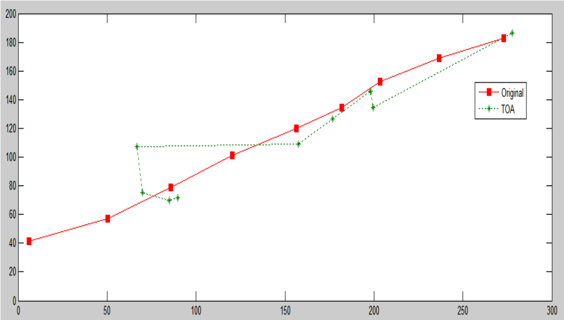

Fig.6. RSSI estimated Position vs. Original Position

In figure 6, we can notice that there is large difference between the original position of the target and the estimated position of the target.

The localization error between the original position and the estimated position using the Angle of Arrival parameter is found to be 23.6 and 16.2 respectively for two different node densities.

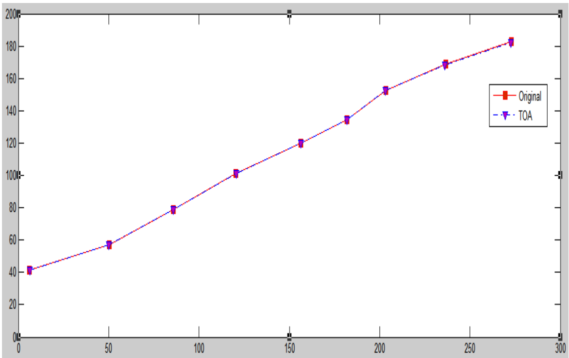

Fig.7. TOA Estimated Position vs. Original Position

In figure 7, we can notice that there is only small difference between the original position of the target and the estimated position of the target.

The localization error between the original position and the estimated position using the Angle of Arrival parameter is found to be 3.6 and 1.2 respectively for two different node densities.

VII. KALMAN FILTER

Kalman filter is a parametric filter which is used to suppress the indoor noise from the estimated position and to predict the future position. In this paper, we have considered only the noise suppression phase of the Kalman filter[10].

Kalman filter is used for filtering the measurement noise, and predict the next position of the person using system model. The KF uses the current position of the person to predict his next position for a uniform sampling period. We have assumed that the target is moving with constant velocity of .5m/s.

A. System model:

This model provides the present state of the system at any time step,

$$X_k = A^* X_{k-1} + w_k \qquad (3)$$

Where A- Represents the state transition matrix

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ x_v \\ y_v \\ z_v \end{bmatrix}_k = \begin{pmatrix} 1\,0\,0\,T\,0\,0 \\ 0\,1\,0\,0\,T\,0 \\ 0\,0\,1\,0\,0\,T \\ 0\,0\,0\,1\,0\,0 \\ 0\,0\,0\,0\,1\,0 \\ 0\,0\,0\,0\,0\,1 \end{pmatrix} * \begin{bmatrix} x_p \\ y_p \\ z_p \\ x_v \\ y_v \\ z_v \end{bmatrix}_{k-1} + W_k$$

The state vector X_k has positional components in x, y & z coordinates represented as x_p, y_p & z_p and their velocity counterparts, represented as x_v, y_v & z_v respectively.

The initial estimates are passed to the Kalman filter and the Kalman filter suppresses the noise caused to multi path and additive white Gaussian noise[11]. Thus the measurement noise is reduced in the Kalman filter.

Now again the localization error is calculated for all localization schemes such as TOA, AOA and RSSI. This time it is found that, the standard deviation in estimated position and the original position of the target is lesser.

The respective outputs for TOA, AOA and RSSI for network size with 18 nodes are found to be

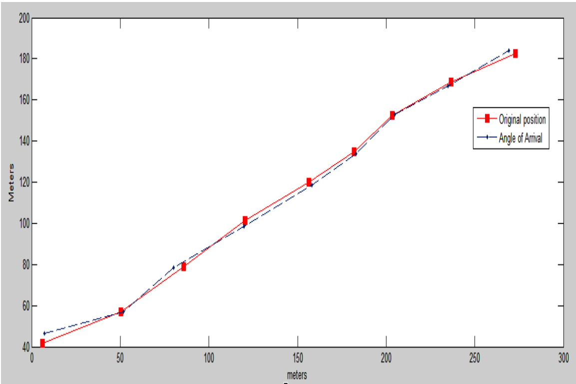

Fig.8. Angle of Arrival with Kalman Filter

Figure 8 shows that, the estimated position obtained after integrating Kalman filter is better than before. And also the localization error i.e. the standard deviation now is found to be 9.3 which are closer to network with higher node density.

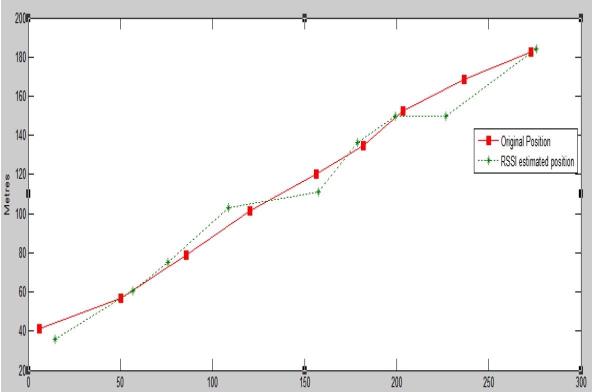

Fig.9. RSSI with Kalman Filter

Figure 9 shows that, the estimated position obtained from RSSI after integrating Kalman filter is better than before. And also the localization error i.e the standard deviation now is found to be 18.6 which is closer to network with higher node density.

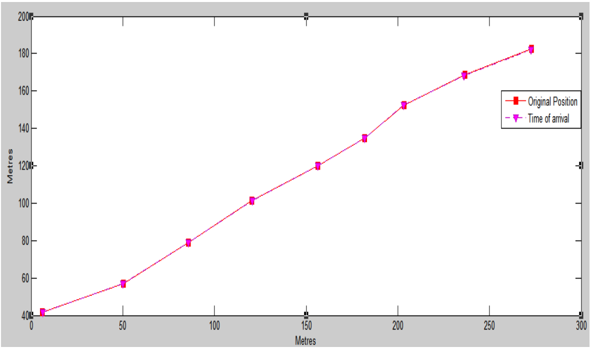

Fig.10. TOA with Kalman Filter

Figure 10 shows that, the estimated position obtained from TOA after integrating Kalman filter is better than before. And also the localization error i.e the standard deviation now is found to be 2.3 which is closer to network with higher node density.

VIII. CONCLUSION

Sensor networks are a collection of large number of low-cost, low-power, multifunctional, and small sensors and Localization is a fundamental problem of deploying wireless sensor networks for many applications. The localization can be mainly range-based or range-free according to the mechanism used for determination of location.

Simulations and experiments show the relationship between original position and the estimated position of target determined for each localization scheme. At last we would like to conclude that the range based Time Algorithm provides the lowest deviation from the mean localization error. This means lower the SD better the accuracy. So in comparison to RSS and Angle one should use Time Algorithm for localization purpose.

Similarly, with the help of Kalman Filter, the localization error of the indoor positioning system can be further reduced and also the accuracy of higher node density system can be obtained in the system of same network size but with lesser node density. Thus by integrating Kalman filter with exiting indoor positioning system, we can reduce the cost of node deployment and can improve the accuracy.

IX. FUTURE WORK

We are looking forward to implement Particle filter in indoor positioning system to track more than one target at the same time. And also Particle filter uses iterative prediction method in which we can define a preset threshold for any environment based on the noise present there.

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