Design and Implementation of Zigbee Location System Based on Kalman Filter

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Abstract

In order to solve the problems of Zigbee location in wireless sensor network: low precision, poor real-time,the limition between localization algorithm,communication and the hardware cost, unmature on the dynamic node localization, this paper constructs the network architecture, sets up Zigbee network, propose the algorithm that rebuild the TDOA location algorithm based on Kalman filter.The idea of the algorithm is TDOA algorithm first estimates the initial position of the unknown node, and the estimation values are filtered by using Kalman filter algorithm, predicts the position of the next moment. Through analyzing the experimental results and comparing with the traditional TDOA location algorithms, the algorithm has advantages for dynamic node as follow: higher location accuracy, smaller error and better stability.

Keywords

Zigbee network, TDOA, Kalman filter, Location system.

1. Introduction

At present, wireless sensor network has a very good application in the field of environmental monitoring,target positioning[1]. Data with the location informations of nodes have only significant of research[2], and achieve specific location, and geographic information of analysis and target localization and tracking [3], so nodes localization has become a prerequisite for many applications in sensor networks.Therefore based on Zigbee wireless sensor networks the localization technology emerges as the times require.

Zigbee technology has its unique characteristics: low cost,low power consumption,high reliability,easy arrangement etc. Based on Zigbee localization technology has some features: protocol simple, reliable data transmission,CSMA/CD mechanism, self-organizing network ,multi-hop and self-healing ability, communication mode of the broadcast and unicast, convenient large-scale application. However, the proposed localization algorithms have their application conditions and limitations respectively, and have the following problems: algorithm will not meet the requirements on real-time positioning; complex degree of algorithm,communication spend and hardware resources restrict each other; node localization is not mature in the dynamic network structure.

According to above-mentioned, the Zigbee wireless sensor network localization have defects[4,5], this paper constructs platform architecture of the Zigbee network based on Zigbee protocol to realize the Zigbee network topology and setup. In order to improve the localization accuracy of dynamic nodes in Zigbee network, proposes the TDOA localization algorithm based on Kalman filter.

The remainder of this paper is organized as follows:Sec.2 describes the construction of Zigbee network platform;Sec.3 reconstruct the TDOA localization algorithm based on kalman filter;Sec.4 compares the reconstructed location algorithm with the traditional algorithm by simulation and analysis superiority on the reconstructed location algorithm;Sec.5 concludes with a summary and discussion.

2. The zigbee network platform

2.1 Zigbee protocol stack

From figure 1, Zigbee protocol stack[6] consists of the physical layer, medium access control layer, network layer, application layer from the bottom to the top.Each layer provides two entities to provide specific services for the upper layer: data entity provide the necessary datas for upper layer;management entity provides data management mechanism for the upper layer,and accesses to the internal layer parameters etc.Two entities provide service interface through the service access point (SAP).

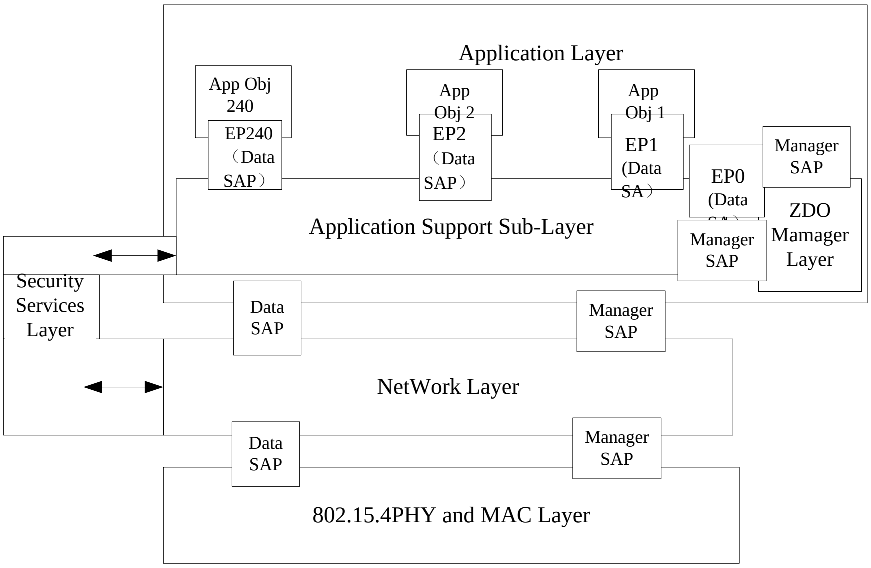


Figure 1. Framework of Zigbee protocol stack

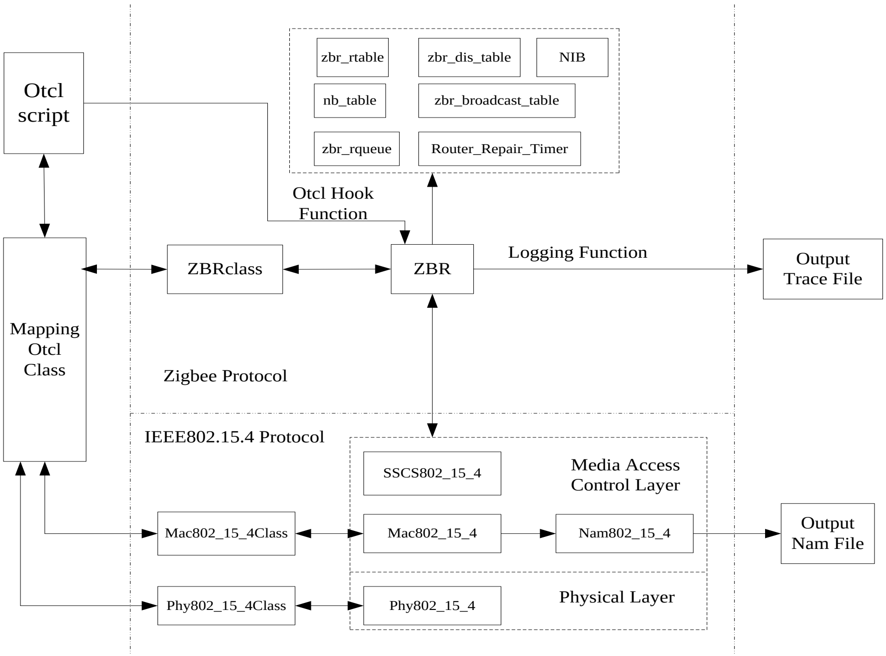


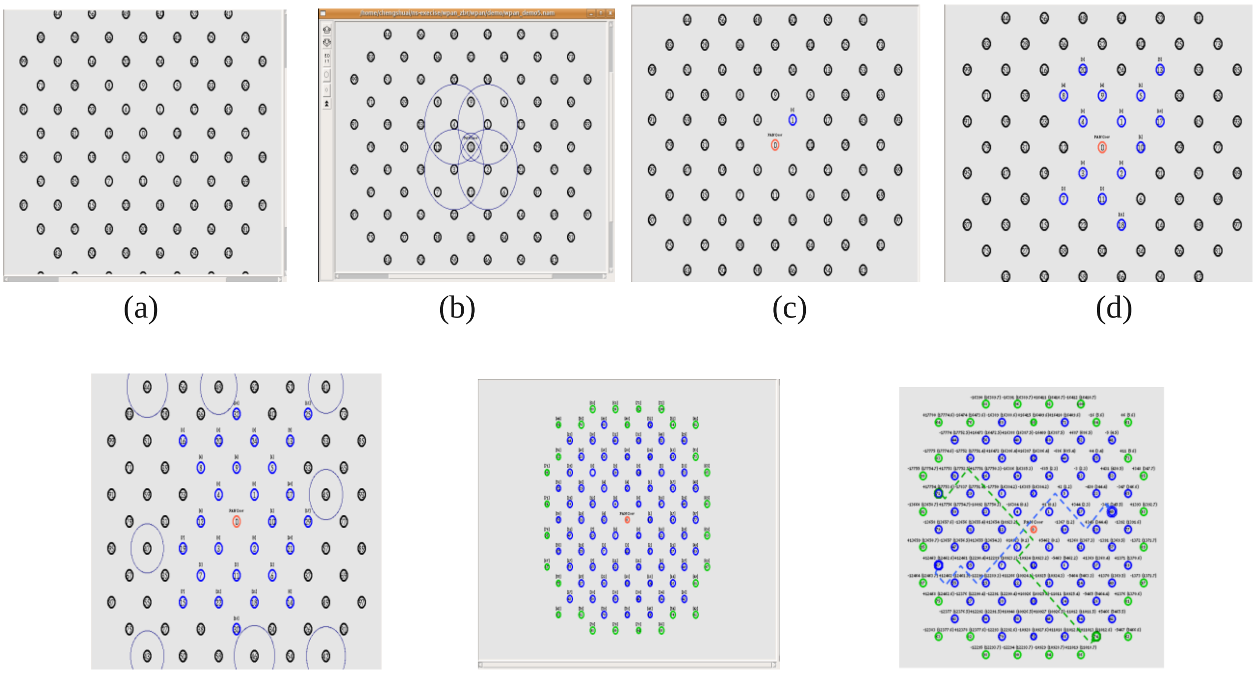
Figure 2. The basic framework of network simulation platform

2.2 Structure the Zigbee network platform

Based on protocol specification of IEEE802.5.4 and Zigbee, the function of every layer in the Zigbee protocol stack is abstracted, modeled, instantiaed[7], and add the Zigbee protocol component in NS2 simulation tools, build the platform architecture of IEEE802.5.4, Zigbee under NS2 environment in figure 2.

2.3 Structure the Zigbee network platform

In the section, in order to adapt to the harsh environment conditions ,we use tree topology in Zigbee network, since the of robust tree topology is better. In figure 3,we use Zigbee routing protocol to achieve the tree topology, complete the establishment of regional network, realize the data communication between nodes.


(a) (b) (c) (d)

(e) (f) (g)

Figure 3. (a):tree topology and node layout.(b):the coordinator node 0 establish network.(c):routing node 1 adds to the network.(d): multiple routing nodes add to the network.(e):multiple routing nodes join into the network and several nodes start to channel scanning.(f):all nodes add to the network.(g):data communication between nodes.

3. Kalman filter in the tdoa localization

Kalman filter is a recursive algorithm by estimator and linear unbiased minimum estimation, has the time-varying structure and is considered as be the optimal linear estimation theory [8]. In the [9]Measurements values(estimated values) by TDOA are filtered by the Kalman filter, then forecast the next time position and get the optimal value of nodes, in order to reduce the positioning error.

The principle of Kalman algorithm

Two basic equations of Kalman filter: the state equation and measurement equation:

$$s(k) = As(k-1) + w(k-1) \tag{1}$$

$$z(k) = Gs(k) + v(k) \tag{2}$$

Where in the time k , $s(k)$:state variables, A : the gain matrix of state variables, $w(k)$:the noise of the input signal, $Q(k)$:the covariance matrix of $w(k)$, $z(k)$:the observed data,: G :gain matrix between state variables and the output signal, $v(k)$:the measurement noise, $R(k)$:the covariance matrices of $v(k)$.

Prediction equation:

$$\begin{cases} \hat{s}(k/k-1) = A\hat{s}(k-1/k-1) \\ P(k/k-1) = AP(k-1/k-1)A^T + Q(k) \end{cases} \tag{3}$$

Where, $\hat{s}(k/k-1)$ is the prediction results of the previous state, $\hat{s}(k-1/k-1)$ is the optimal result of a previous state. $P(k/k-1)$ and $P(k-1/k-1)$ represent the covariance matrix of $\hat{s}(k/k-1)$ and $\hat{s}(k-1/k-1)$ respectively.

By formula 3,calculate the value of the optimal estimation $\hat{s}(k/k)$ and $P(k/k)$ at the current state,eg.estimation equation:

$$\begin{cases} \hat{s}(k/k) = \hat{s}(k/k-1) + K(k)e(k) \\ P(k/k) = [I - K(k)G]P(k/k-1) \end{cases} \tag{4}$$

Where, $K(k)$ is Kalman filter gain.

Implementation of the filtering algorithms

The motion model is predicted on the X axis based on Kalman filter, similarly available prediction to the Y axis. Moving object along the X axis can be described by the equation of state the following:

$$x(k+1) = x(k) + Tv(k) + (T^2/2)u_x(k) \tag{5}$$

$$v(k+1) = v(k) + Tu_x(k) \tag{6}$$

Where, $x(k), v(k), u_x(k)$ represent the position, velocity and acceleration of the target in the time k on the direction of the X axis, the T is interval for the current time and the next time.

With the matrix representation for:

$$X(k+1) = \Phi X(k) + \Gamma W(k) \tag{7}$$

Where, $X(k) = \begin{bmatrix} x(k) \\ v(k) \end{bmatrix}, \Phi = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}, \Gamma = \begin{bmatrix} \frac{1}{2}T^2 \\ T \end{bmatrix}, W(k) = u_x(k)$.

To account for the observations of wireless sensor network, the observation equation:

$$Z(k) = C(k)X(k) + V(k) \tag{8}$$

In the formula, $C(k)=\begin{bmatrix}1 & 0\end{bmatrix}$, $V(k)$ is the noise sequence that is zero mean, its variance is known. To predict the target, by the relevant theory obtains iterative formulation:

$$\hat{X}(k/k-1)=\Phi\hat{X}(k-1/k-1) \tag{9}$$

Where, $\hat{X}(k-1/k-1)=E\left[X(k)\,|\,Z^{k-1}\right]$, by before time $k-1$ the observation values estimates the current state.

Variance of the prediction error for:

$$P_{\hat{X}}(k/k-1)=\Phi P_{\hat{X}}(k-1/k-1)\Phi^T+\Gamma Q(k-1)\Gamma^T \tag{10}$$

For optimal filtering, iterative formula:

$$\hat{X}(k/k)=\hat{X}(k/k-1)+K(k)\left[Z(k)-C(k)\hat{X}(k/k-1)\right] \tag{11}$$

In the formula, $K(k)$ Kalman gain.

The covariance of filtering error for:

$$P_{\hat{X}}(k/k)=\left[I-K(k)C(k)\right]P_{\hat{X}}(k/k-1) \tag{12}$$

In the Kalman filter, we need the given initial value to use the formula above. In practical,the initial value of moving target can not be got, can establish the initial state estimate values by using the first few observation values, for example, uses two observations,

$$\hat{X}(2/2)=\begin{bmatrix}z_x(2) & \left[z_x(2)-z_x(1)\right]/T\end{bmatrix}^T \tag{13}$$

At this time, estimation error:

$$\overline{X}(2/2)=\begin{bmatrix}-v_x(2) & \dfrac{T}{2}\cdot u_x(1)+\dfrac{v_x(1)-v_x(2)}{T}\end{bmatrix}^T \tag{14}$$

And the error covariance matrix:

$$P_{\overline{X}\overline{X}}(2/2)=\begin{bmatrix}\sigma_x^2 & \sigma_x^2/T\\ \sigma_x^2/T & 2\sigma_x^2/T\end{bmatrix} \tag{15}$$

4. Simulation experiment and results analysis

In theory, the main error derives from wireless multi-path fading and NLOS in TDOA. In the literature of [10,11,12],the method is based on TDOA measurement error which is a Gauss variables of zero-mean without considering the influence of NLOS. Therefore, in the simulation of the localization algorithm, mainly consider the error of TDOA measurements introduced by multipath fading and NLOS.

To take into account the real effect of Kalman filtering, we use the Monte-Carlo method that takes the average of several test results[13] to compute the mean and variance of error estimation, the expression is:

$$\bar{e}_x(k) = \frac{1}{M}\sum_{i=1}^{M}\left[x_t(k) - \hat{x}_t(k\,|\,k)\right] \tag{16}$$

Mean square of error values can be expressed as:

$$\sigma_x = \frac{1}{M}\sqrt{\sum_{i=1}^{M}\left[x_i(k) - \hat{x}_i(k\,|\,k)\right]^2 - \bar{e}_x^2(k)} \tag{17}$$

Where, M is the number of Monte-Carl during the simulation, and K is the number of sampling value. The more the number of simulation, experiment results is more close to the actual trajectory, but it will have a certain influence on the speed of operation. Here we take M=500, the simulation results in figure 4.

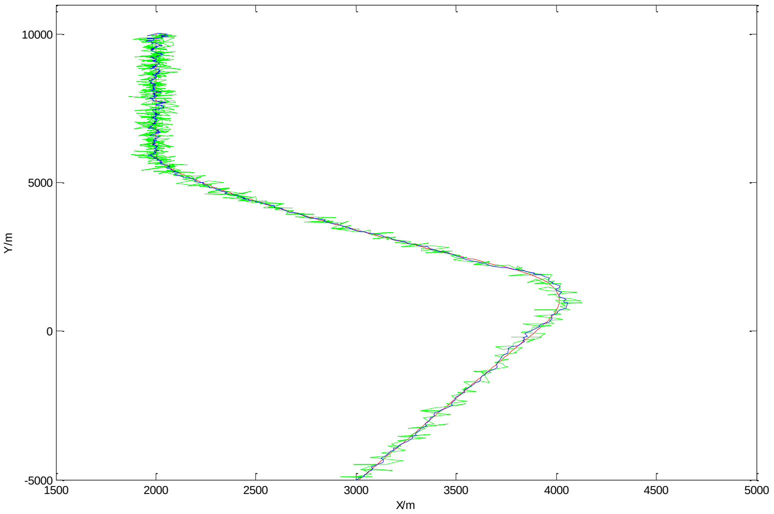


Figure 4. Comparison map of motion trajectory under NLOS. the ground truth(pink), traditional TDOA (green), TDOA + Kalman filter(blue).

In figure 4,pink curve represents the ground truth trajectory of a moving node. Green curve represents the motion trajectory which is obtained traditional TDOA algorithm. The blue curve represents the trajectory with filtering estimation for location algorithm.From the compared picture,the effect can be seen that when tracking the mobile node, due to the interference of external environment, the multipath propagation attenuation of signals and non-line-of-sight (NOLS) effect lead to the certain error which localization algorithm tracks the target node，so curve fluctuates greatly around the actual trajectory. However,the filtering algorithm has better effect on tracking, and the trajectory error and fluctuation are small compared with the actual trajectory, motion trajectory is more close to the actual trajectory.Thus verify the fact that the reconstructed location algorithm based on Kalman filter in dynamic target track has the better performance, and the position error is relatively reduced comparing with the traditional location algorithm.

In the next,we acquire 500 dataset in the above results that follow Gauss distribution and mean value is 0 in the measurement error, the standard deviation of measurement error are respectively 1m, 2m, 3m, 4m and 5m, under the condition NLOS, process the simulation for algorithm.

Figure 5 and figure 6 are the curve of root mean square error(RMSE)respectively in Y, X direction, the RMSE that the localization algorithm obtains is smaller than the RMSE that the unfiltered localization algorithm obtains. According to the analysis of the error, the filtered localization algorithm has better performance.

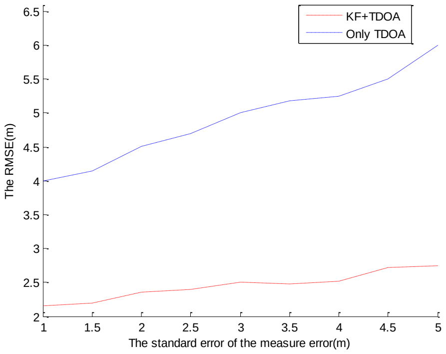


Figure 5. Comparative map of RMSE in Y direction

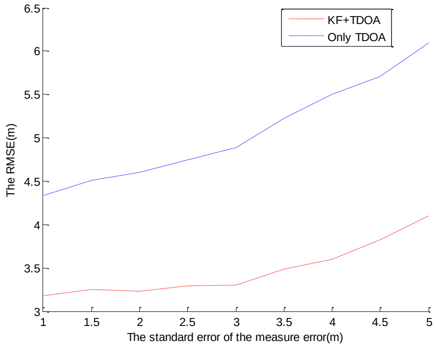


Figure 6. Comparative map of RMSE in X direction

In the figure 7, under the same localization errors, the RMSE of localization algorithm based on filtering (blue curve) is smaller than those without filtering algorithm (red curve), we can conclude that localization accuracy is improved by Kalman filter algorithm, reduces the influence of measurement errors on the localization accuracy.

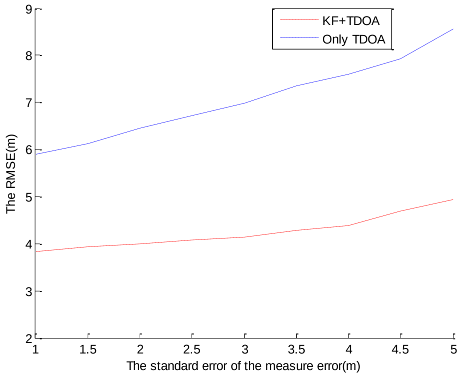


Figure 7. Comparative map of RMSE

5. Conclusions

From the above analysis, the paper will combines Kalman filtering with TDOA localization algorithm to resolve the current problem that the localization accuracy is not high in Zigbee wireless sensor networks, the simulation trajectory results of dynamic moving nodes in the network can be seen, TDOA localization algorithm based on Kalman filter has much better performance than the unfiltered algorithm. The filtered localization algorithm reduces the localization error, and improves the localization accuracy. In the fortune, we will improve the routing algorithm to reduce the consumption of the network and communication cost.

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