RSSI-based Localization for Wireless Sensor Networks with a Mobile Beacon

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***Abstract*—Localization is one of the fundamental issues in wireless sensor networks. Many approaches including range-based and range-free categories have been proposed to determine sensor node locations. The range-based algorithms often achieve higher accuracy, but they are easier to be interfered and an additional hardware is required. In this paper, we present a fast and simple localization scheme for wireless sensor networks, which is computed by simple operations with the specific approximate RSSI value on an accelerative signal attenuation model. Simulation results show that our scheme is very efficient and that the node positions can be determined accurately.**

I. INTRODUCTION

Wireless sensor networks (WSNs) have wide application in fields such as military and disaster relief [1]. Recent advances in wireless communications and electronics have enabled the development of small low-cost sensor nodes. Wireless sensor networks are comprised of several sensor nodes that communicate via wireless technology.

Localization is one of the most important topics in WSN research. So far, many localization methods have been presented that could be implemented using one or a few powerful nodes with Global Positioning System (GPS). A feasible solution is to designate a small number of sensor nodes as anchor points or beacons and equip them with GPS. So we present a RSSI-based geometric localization scheme called RGL based on a self-propelled device equipped with GPS.

II. RELATED WORK

Recently, many localization schemes for WSNs have been presented. These localization algorithms fall into two categories: range-based and range-free schemes.

Range-based schemes are usually supported by additional sensor hardware that measures the distances or angles of the signals being transmitted between the nodes such as Time of Arrival (TOA) [7], Time Difference of Arrival (TDOA) [8], and Received Signal Strength Indicator (RSSI) [2]. The drawbacks are easier to be interfered by multipath, fading, and noise and an additional hardware is required.

On the other hand, range-free schemes avoid costly hardware by exploiting inter-node communication and the sensing range of the node to estimate the positions of the sensor nodes such as Centroid [3] and DV-HOP [6]. These approaches typically need a large amount of stationary anchor points involved a heavy computation for achieving higher accuracy.

Mobile localization exploits moving beacons to avoid the problems of static range-free localization schemes. Guo’s [4] scheme utilizes the geometric relationship of a perpendicular intersection to compute node positions. Ssu introduces scheme [9] that the location of a sensor node is estimated using the intersection points of two perpendicular bisectors of the chords obtained by three beacon points. To improve the localization accuracy of Ssu’s scheme, an efficient scheme is suggested to estimate sensor locations from possible areas by using geometric constraints [5].

III. RGL SCHEME

In this section, we propose a fast and simple localization scheme, called RSSI-based geometric localization (RGL), to locate sensor nodes efficiently using the receiving RSSI value from a mobile beacon equipped with GPS. Each sensor node receives the messages but does not interact with other nodes for localization. Distributed computation of node position involving elementary operations allows the system to operate in a low power consumption mode..

A. The Model of the RGL Scheme

We assume that the transmission range of each sensor node is a circle with radius r. We assume that the sensor nodes are deployed in a square of side Range. We set the coordinates of the upper left corner at (0, 0) and those of the lower right corner at (Range, Range). Besides, the mobile beacon adopts the trajectory of random waypoint model.

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B. Observations on RSSI

However, the existing RSSI signal propagation models are far from perfect because of outer uncertain influences. In ideal sense, the distance between a sensor node and the mobile beacon with the RSSI values can be calculated by the log-normal shadowing model that is described as

$$P_T = P_L(d_0) - 10\eta \log\frac{d}{d_0} + X_\sigma ,$$

where P_T is the transmission power, $P_L(d_0)$ is the path loss for a reference distance of d_0, and η is the path loss exponent. The random variation in RSSI is expressed as a Gaussian random variable $X_\sigma = N(0, \sigma^2)$. All powers are in given in decibels relative to 1 mW, and all distances are given in meters. Let η be between 2 and 5 and σ between 4 and 10, depending on the specific environment.

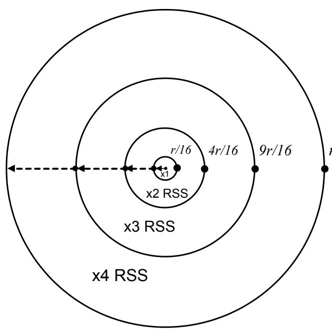


Figure 1. An accelerative signal attenuation model of RSSI.

In fact, the receiving strength signal value is reciprocal proportion with the square of the distance between two nodes. Instead of directly mapping RSSI values into physical distances, we propose an accelerative signal attenuation model based on the inverse-square law. We divide the transmitting range of the mobile beacon with radius r into n regions. Fig. 1 illustrates the four rings located position are $r/16$, $4r/16$, $9r/16$, and r for the case of $n = 4$. If the receiving power signal is in the kth ($1\leq k \leq 4$) region, we obtain an estimated distance between the mobile beacon and a sensor node by

$$\frac{r}{32}(2k^2 - 2k + 1) \cdot$$

C. Preliminaries

The mobile beacon broadcasts periodically the packet contain the localization information, where are path number, sending time, GPS position and moving velocity, to the sensor nodes when it traverses.

As the sensor nodes receive the packet from the mobile beacon then those fields will be stored in its local storage. These fields are similar to the transmitting packet but the packet number field is recorded the sequence of receiving the packet by the mobile beacon and the field of RSSI strength is recorded.

D. The Description of the RGL Scheme

The mobile beacon broadcasts messages periodically as it traverses at a constant velocity v and transmission interval is the time between two consecutive beacon messages denoted as Δt. Each phase involves the beacon moving a fixed distance d, which means $v \Delta t$.

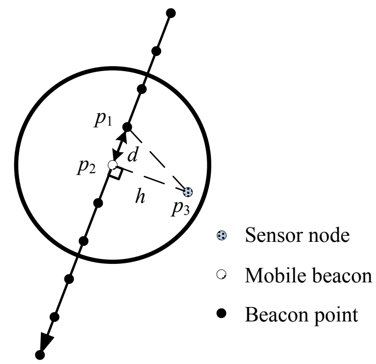


Figure 2. The process of the mobile beacon locating the sensor node

As shown in Fig. 2, we suppose the sensor real position is p_3**.** The sensor node will acquire and store a series of different mobile beacon position and RSSI signal information after receiving packet from mobile beacon when sensor nodes are in the transmitting range with radius r. Then the sensor node will find the maximum strong RSSI signal from local storage and is denoted $RSSI_{MAX}$ at position p_2 as shown in Fig. 2.

The other important RSSI signal information is the previous position of the mobile beacon at position p_2 related $RSSI_{MAX}$ denoted $PreRSSI_{MAX}$ at position p_1. Thus, the distance d value is from p_1 to p_2 and the distance h derived from the maximum strong RSSI signal is from p_2 to p_3. Those of three nodes, p_1, p_2 and p_3, will construct a specified right triangle. It reveals when a sensor node find the maximum strong RSSI signal implies the closest distance from mobile beacon. In an ideal model, we can identify the point p_2 as the perpendicular intersection point of moving distance d and the distance h related the maximum strong $RSSI_{MAX}$ signal.

By these describes, we can derive an bivariate quadratic equation as

$$\begin{cases} h^2 = (x_2 - x_3)^2 + (y_2 - y_3)^2 \\ d^2 + h^2 = (x_1 - x_3)^2 + (y_1 - y_3)^2 \end{cases} . \quad (1)$$

Because these variables (x_1, y_1) and (x_2, y_2) are known, we just solve the solutions of equation (1) for variables (x_3, y_3). Thus there are two solutions are represented (x_3, y_3) and (x_3', y_3') that one of them is the correct estimated position. If a sensor node can receive different path information twice by the mobile beacon, an estimated position can be identified. Consider the scenario of a sensor node p in Fig. 3. We can obtain four solution s_1, s_2, s_3 and s_4 by solving two related bivariate quadratic equations. These two points s_1 and s_2 can construct an isosceles triangle and s_3 and s_4 do. Theoretically, these two isosceles triangles will have an intersection point which is regarded as the estimated position of a sensor node.

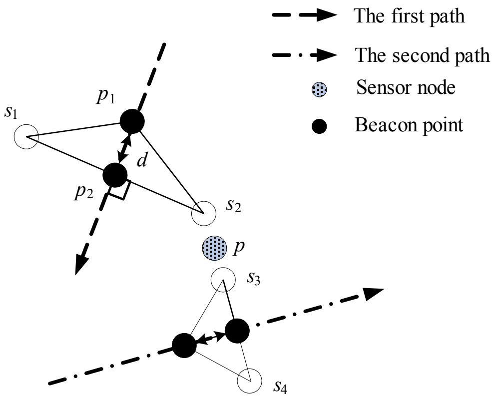


Figure 3. The sensor node passing by twice moving path of mobile beacon

By minimizing the comparison of the distances of any two solutions each other as

$$Min\{\ |s_1 - s_2|,\ |s_1 - s_4|,\ |s_2 - s_3|,\ |s_2 - s_4|\ \},$$

we can acquire a pair of estimated positions.

Finally, we treat the average values of the two possible estimated positions in the pair solution as the real position of a sensor node. In general, a sensor node will receive many packets from the mobile beacon. For getting more accurate, a sensor node must choose the greater $RSSI_{MAX}$ value than previous one implies the sensor node is closer the mobile beacon to reduce the distance error. So the table maintained by a sensor node will keep a maximum $RSSI_{MAX}$ value.

The RGL scheme is described in the following.

Localization Algorithm in Wireless Sensor Network

***Input*:**
***node$_i$* :** ith sensor node
***RSSI* :** Received signal strength indicator between sensor and beacon
***BBI* :** beacon broadcast interval
***Output*:** The estimated position of *node$_i$*

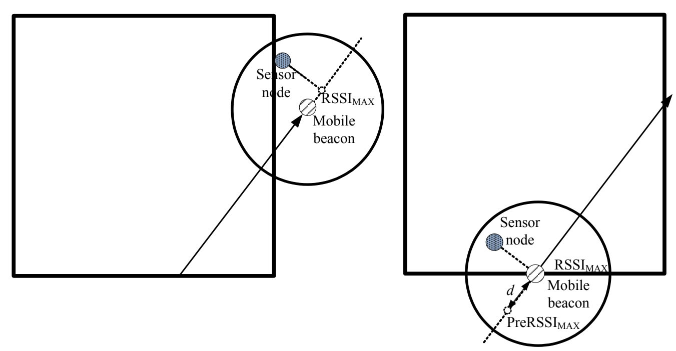
while (beacon packets are received **)**
  if (the *RSSI* is greater than the last *RSSI* **)**
    Update the *RSSI* values of *node$_i$*
  else if (the *RSSI* is maximum**)**
    RSSImax ←The position that the maximum *RSSI* value appears
    PreRSSImax ←The *RSSImax* of the previous beacon point
    RSSI _to_dist ← Transfer *RSSI* value to distance
    Calculate(i , *BBI* , *RSSImax$_x$* , *RSSImax$_y$* , *PreRSSImax$_x$* , *PreRSSImax$_y$* , *RSSI_to_dist*)
    if (beacon for the first time through the sensor **)**
      pos1[1].point← *Solution_A* : *pos1*[2].point← *Solution_B*
    else if (beacon for the second time through the sensor **)**
      pos2[1].point ← *Solution_A* : *pos2*[2].point← *Solution_B*
      find the shortest distance between *pos1*[m] and *pos2*[n],where m, n = 1~2 ,
      estimated position P of *node$_i$* ← (*pos1*[m] .point + *pos2*[n] .point) / 2
    else if (beacon for the third time or more through the sensor **)**
      P' ← find the shortest distance between P and two solutions
      real estimated position P of *node$_i$* ← $(P + P')$ / 2
    end if
  end if
end while
Calculate (i , d , x_2 , y_2 , x_3 , y_3 , h)
  [*Solution_A*, *Solution_B*] = Solve Bivariate Quadratic Equation

$$\begin{cases} h^2 = (x_2 - x_3)^2 + (y_2 - y_3)^2 \\ d^2 + h^2 = (x_1 - x_3)^2 + (y_1 - y_3)^2 \end{cases}$$

  Solution_A =(x_3 , y_3) : *Solution_B* =(x_3' , y_3')
End Calculate

E. The refinement of RGL scheme

In our scheme, there are some issues that might affect localization accuracy. For example, sensor nodes in the vicinity of the boundary occurs the error localization easily. As shown in Fig. 4(a) and Fig. 4(b), some sensor nodes have a problem which the perpendicular intersection $RSSI_{MAX}$ or $PreRSSI_{MAX}$ positions falls outside the deployed range when the mobile beacon reaches the deployed boundary and then turns another direction boundary. We solve the problem by exploiting the deployed region to expand the boundary with transmitting radius r and then the nodes in the vicinity of the boundary will not miss the $RSSI_{MAX}$ or $PreRSSI_{MAX}$.



(a) (b)

Figure 4. Falling outside range (a)$RSSI_{MAX}$ (b) $PreRSSI_{MAX}$

IV. PERFORMANCE EVALUATIONS

In this section, we verify the accuracy of our scheme by simulation and comparison the performance with several well-known schemes.

A. Simulation Environment and Parameters

Our simulation is built on the MATLAB simulator. The nodes are deployed in an effective space range of 300m × 300m without obstacles and 100 sensor nodes are randomly deployed as a Gaussian distribution. These dataset of sensor nodes are changed if the parameter settings are not.

B. Metrics

We evaluate the simulation results of these discussions in terms of ME (Mean Error) to estimate the average localization errors. ME is defined as the average difference between estimated location (x' , y') and actual location (x , y) of all sensor nodes, where

$$\Delta E_{ME} = \frac{\sum_{i=1}^{N} \sqrt{(x-x')^2 + (y-y')^2}}{N}$$

C. Simulation Results

In reference to our scheme, there are some important values with mobile beacon like, the sensing range of a circle with radius r, the moving speed v and the period time of each transmitting packet Δt. These constraints influence our scheme so much and we will discuss the simulation results by these constraints later.

The Ssu's scheme [9] is popular and served as a benchmark program in the field of sensor localization. We compare with another two localization schemes, Guo [4] and Lee [5] which improved Ssu's scheme. So we evaluate the performance and compare our scheme with these schemes.

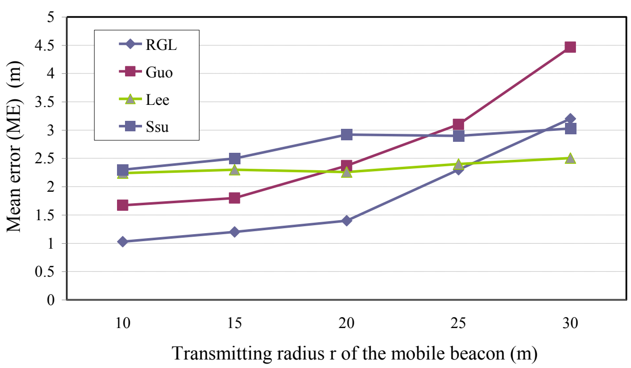


Figure 5. Mean error versus $v\Delta t$ =3m for different schemes

We explore the results of simulation are shown in Fig. 5 when r = 10m~50m and $v\Delta t$ = 3m. The results of the simulation show that the average location errors of our proposed scheme are below 2 in general and outperform those of the other three schemes. The most effective is up to 80% than Ssu's scheme.

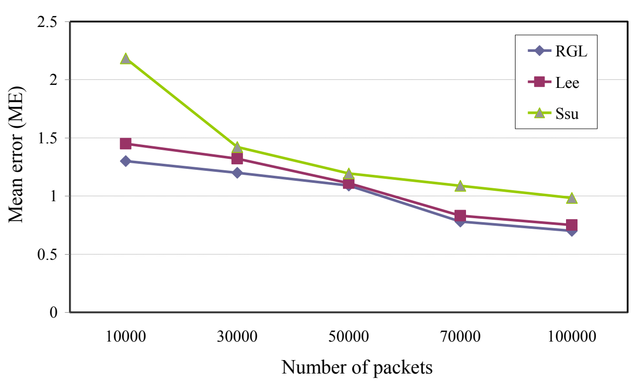


Figure 6. Average execution time versus r = 30m and $v\Delta t$ =3m

Next, we focus on the average execution time for the different schemes depend on the numbers of packets by the mobile beacon. We explore the results of simulation are shown in Fig. 6 when r = 30m and $v\Delta t$ = 3m. The mobile beacon of these three schemes moving path are not the same, Guo is fixed path and the others are RWP model, so we do not discuss the Guo's scheme in this simulation.

The results of the simulation show that the average location errors are lower than other schemes when the numbers of packets received increase. If each sensor node receives more packets, the estimated position can be modified by itself with receiving packets from the mobile beacon.

V. CONCLUSION

In this paper, we presented an efficient range-free localization scheme RGL that can locate sensor nodes and achieve fine-grained accuracy without any distance devices. All computation is performed locally, so the mechanism is distributed, scalable, effective, and power efficient. The proposed technique is supported by a mobile beacon with a GPS. The beacon moves along random traverse trajectories and broadcasts its current information periodically. Each sensor node receives the messages but does not interact with other nodes for localization. Distributed computation of node position involving elementary operations allows the system to operate in a low power consumption mode. To avoid outer uncertain influences of the RSSI signal, we adopt our accelerative signal attenuation model and obtained accuracy improvement. Simulation results show that our mechanism outperformed previous range-free localization schemes.

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