RSS Self-calibration Protocol for WSN Localization

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***Abstract*— In wireless sensor network (WSN) localization system, received signal strength (RSS) is one of the simplest ranging methods. However, in real situation, a RSS is affected by some errors which are caused by multi-path channel and dynamic environment. In this paper, we propose RSS self-calibration protocol to attack the errors. The RSS self-calibration protocol can adopt the calibration parameters according to environment as time goes by.**

I. Introduction

If we don't know the location of sensor, it is very hard to say the exact status of the sensing field. We need a localization system for WSN. There are many ranging methods for localization. They are Time of Arrival(TOA), Time Difference of Arrival(TDOA), Received Signal Strength(RSS), Near Field EM Ranging(NFER), and so on[2]. Especially, Received Signal Strength(RSS) is one of the simplest ranging methods. If we well model the path loss of the signal, the RSS can successfully depict the relationship between a distance and the signal strength decrement along with the distance. However, there are two problems. One is that every time when sensor network is installed, the system needs a RSS calibration because according to environment, the path loss model can be changed. The other is that RSS is very unstable. It can be affected by not only environment but also moving objects, or people. If the user calibrates all the nodes one time, no one guarantees first parameters well fit to a changing environment. Therefore, in this paper[1], we suggest a self-calibration protocol. By using the protocol, a user doesn't need to calibrate all nodes manually, and the calibrated parameters can be changed over time according to affect the new environment.

II. Radio Propagation Model

The radio propagation model can be represented to equation (3)[3] as shadowing model. The free space model and two-ray model assume the radio range is a ideal circle, oh the other hands, the shadowing model can represent a random variable which is caused by multipath propagation effect. The shadowing model can be divided to two parts.

The first one is a path-loss model. Equation (1) is the path-loss model of shadowing model. $\overline{P_r(d)}$ is the average path-loss at distance d. $P_r(d_0)$ is the path-loss at reference distance d_0, generally 1m. β is the path-loss exponent which depends on the surroundings. Table I shows typical value of the path-loss exponent according to environments.

Environment		β
Outdoor	Free Space	2
	Shadowed urban area	2.7 to 5
In building	Line-of-sight	1.6 to 1.8
	Obstructed	4 to 6

TABLE I
PATH-LOSS EXPONENT

$$\frac{\mathrm{P}_r(d_0)}{\overline{P_r(d)}} = \left(\frac{d}{d_0}\right)^{\beta} \tag{1}$$

The path-loss model is usually measured in dB. From equation (1) we can get equation (2) in dB scale.

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d0}\right) \tag{2}$$

The second part is the variation of received signal strength. It is a random valuable which follows Gaussian distribution. Therefore, we have the shadowing model to add equation (2) to equation (1).

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d0}\right) + X_{dB} \tag{3}$$

where X_{dB} is Gaussian random variable which has zero mean and standard deviation σ_{dB}.

In our self-calibration systems, we will use equation (2) as radio propagation model because X_{dB} has a zero mean and we will average some RSS samples for removing randomness and some errors.

III. RSS Calibration

Based on Radio Propagation Model, a sensor node needs to calibrate its path-loss model. If we use dB scale model, the relationship between RSS and distance can be represent linearly. Therefore, if we find out best fitting line of the relationship, that is a calibration of RSS. Traditionally, the calibration can be done by an empirical method. The method is that putting two sensors which have the known distance between them, recording several RSS sample data. After that, changing the distance between the two sensor nodes, and recording RSS data again. The next step is plotting the

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recorded data to a graph which has the distance in the x-axis and the path loss in the y-axis. Finally, finding the best fitting line of the graph. The $P_r(d_0)$ of (1) is y-axis intercept point and β of (1) is the slope of the line.

Reminder explains the way of finding the best fitting line. General equation of a line is

$$y = a + bx \tag{4}$$

The line above should be fitted through the recorded points so that the sum of the squares of the distances of those points from the straight line should be minimum, where the distance is measured in the vertical direction. The sum of the squares of the distance can be expressed to

$$q = \sum_{i=1}^{n} [y_i - (a + bx_i)]^2 \tag{5}$$

And at the minimum point, the first differentiation of q of (5) depending on a and b is zero. We can get two equations:

$$\begin{aligned} \frac{\partial q}{\partial a} &= 2\sum_{i=1}^{n}[y_i - (a + bx_i)] = 0 \\ \frac{\partial q}{\partial b} &= 2\sum_{i=1}^{n} x_i [y_i - (a + bx_i)] = 0 \end{aligned} \tag{6}$$

From (6), we can easily get the parameters a and b.

$$\begin{aligned} a &= \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n\sum x^2 - (\sum x)^2} \\ b &= \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2} \end{aligned} \tag{7}$$

where $\sum$ is $\sum\limits_{i=1}^{n}$.

IV. Self-calibration Protocol

A localization system which we concern consists of a anchor and a tag. An anchor is a sensor node which has its own position information. The position of the anchor can be set statically when the compile time or dynamically done by GPS or a position setting packet. And, the anchor periodically sends a beacon packet which includes its own position information and calibration parameter a and b of (7). The tag is the sensor node which doesn't have its own position. The tag will receive several beacons to calculate its own position.

The remaining explains the self-calibration idea. An anchor already knows its own position and the anchor can insert the position information to the beacon. Another anchor node which can receive the beacon can calculate the distance between beacon's originator and itself. So, the anchor which can receive at least two different anchors' beacon can plot distance-path loss graph and find best fitting line by (7) without any manual setting. Finally, the anchor which calculates a and b of (7) inserts the parameters in beacon, and then tag can calculate its position by the information which is included in beacons.

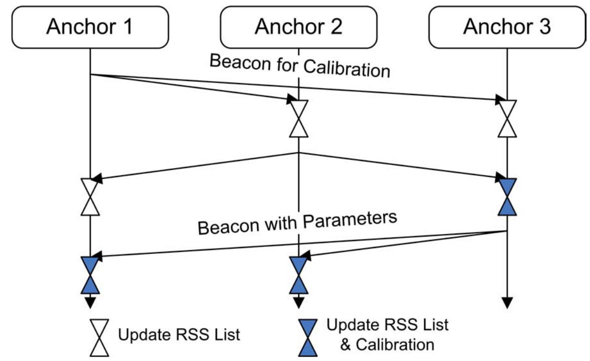

Fig. 1. Message Sequence for Calibration

A. Anchor Protocol

The basic roles of an anchor are calculating RSS calibration parameters and sending beacons for a tag's position calculation. Figure 1 shows a anchor's self-calibration protocol. An anchor sends a beacon periodically for a tag's localization. In the beacon, there is the sender's absolute position before calculating a calibration parameter. So, the other anchor which receives the beacon can calculate the distance between the anchor which sends the beacon and the anchor which receives. And then, the receiver records a RSS of the beacon and the distance for calibration. After receiving some beacons from more than different two anchors, the anchor calculates the calibration parameters. Finally, the anchor adds the calibration parameters to its own beacon for tag. As time goes by, an anchor updates RSS lists whenever a beacon is received. Even if an environment is changed over time, the system successfully reflects the changed environment in the calibration parameters.

B. Tag Protocol

A tag receives some beacons from at least three anchors for localization. Figure 2 shows the protocol for localization. If calibration parameters aren't set yet and there is no calibration parameter in the beacon, a tag ignores the beacon until a calibration parameter is embedded in the beacon. Because at least three different kinds of beacon are needed for localization, the tag definitely has more than three different kinds of calibration parameters. The tag can average the calibration parameters for calculating range between each anchor and the tag or use different parameters for different anchors, after then the tag calculates the current position by triangulation or other methods.

V. Simulation

Figure 3 shows the simulation result. We used MATLAB for the simulation, and we assumed nodes are randomly deployed. Wireless communication channel is Rayleigh multi-path fading channel and 0dB AWGN is added to original signal. The path delay is set to 10ns and maximum doppler shift is set to 10Hz. The simulation result which uses the self-calibration has better range accuracy than the one doesn't. 'With self-calibration' case, the fist 10 samples have the same values with 'without'

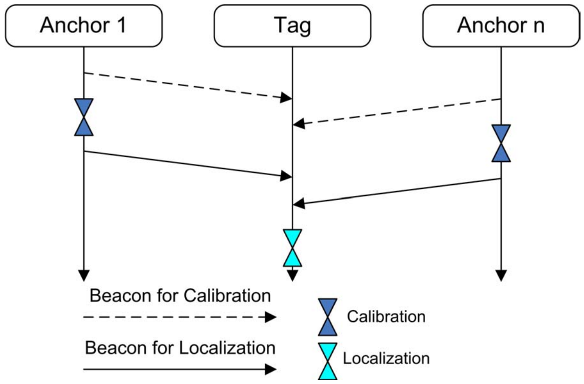

Fig. 2. Message Sequence for Localization

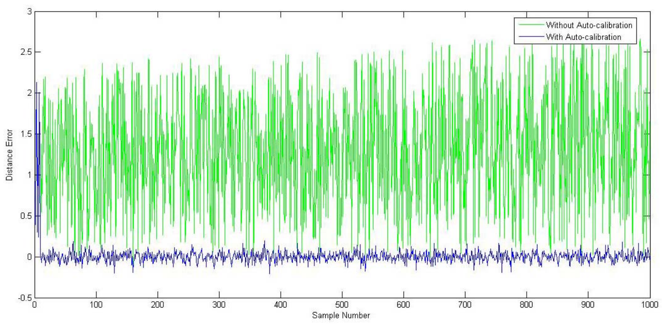

Fig. 3. Simulation Result for both with and without Self-calibration

case because the self-calibration used 10 samples for finding the calibration parameters.

VI. Experiments and Analysis

A. Experiments

Field experiment was conducted in indoor environment(Figure 4) to evaluate the performance of the whole system for localization of sensor node. Four anchor nodes were deployed to the field, and one blind node was deployed to test point which figure 4 shows. We used Chipcon's CC2431 SoC-BB as the experiment hardware. CC2431 SOC-BB has 8051 architecture and CC2420 architecture as microcontroller and RF transceiver, respectively. Figure 5 shows CC2431 SoC-BB.

We had conducted the experiment during about 1 hour at the day time because we want to see the change of RF signal's environment of 4. We set the anchors that anchors sends 8 beacons every three seconds. Normally, over 20 people are working at the sensing field during day time.

Figure 6 shows changing of RSS value of anchors over time. RSS is acquired by node 1 from node 2, 3, and 4. There are some fluctuations according to signal environment's change.

The calculated parameters are shown on figure 7. We used 10 RSS samples for calculating the parameters. As you can see, the system successfully reflects the change of radio signal's environment.

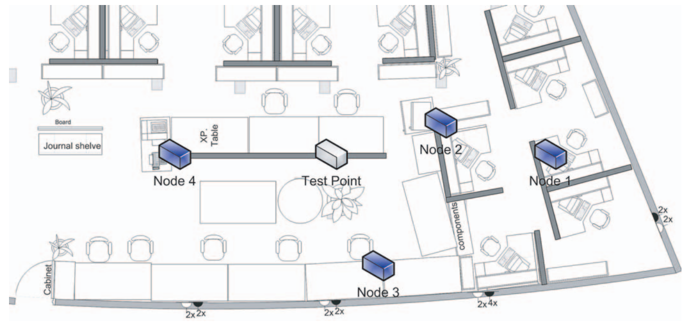

Fig. 4. Experiment Environment

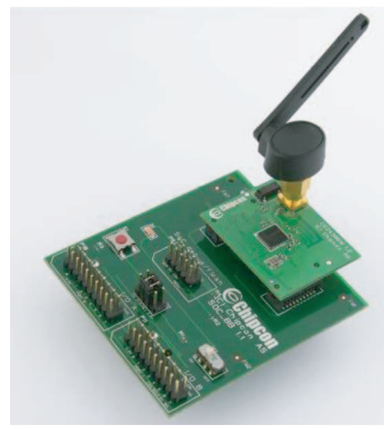

Fig. 5. Hardware for Experiments

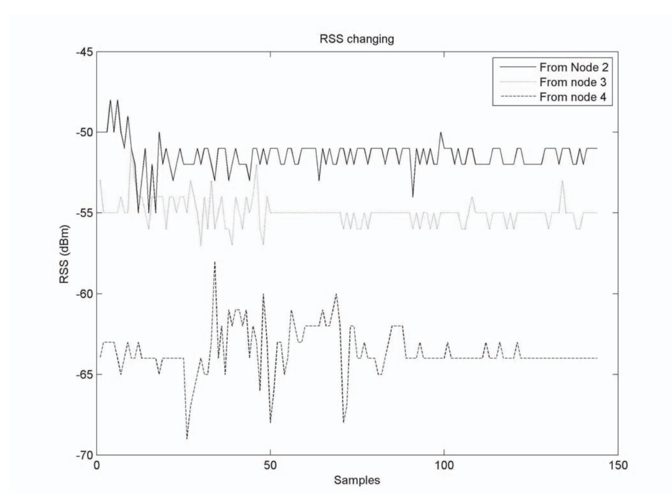

Fig. 6. RSS changing over time

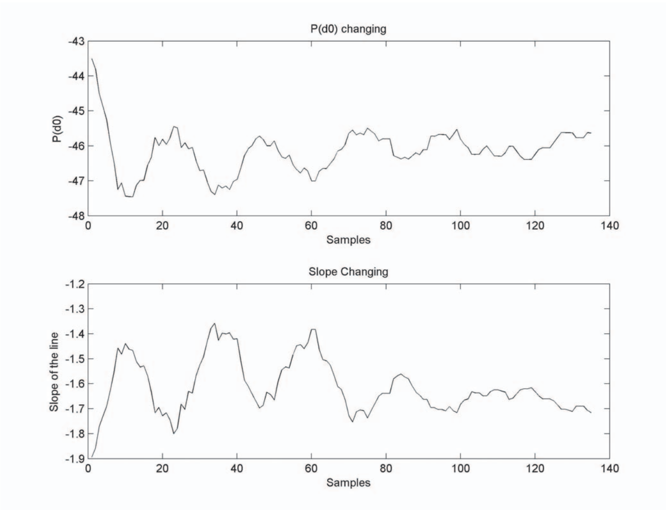

Fig. 7. Parameter values changing over time

B. Analysis

Figure 8 depicts the measured ranging error with self-calibration protocol and without self-calibration protocol between node 1 and test point.

In 'without' case, because the calibration parameter is fixed and not calibrated, the average ranging error is larger than 'with' case (Mean was -1.889, and standard deviation was 0.1059). However, in 'with' case, the average ranging error is not that big (Mean was - 0.2065, and standard deviation was 0.3573).

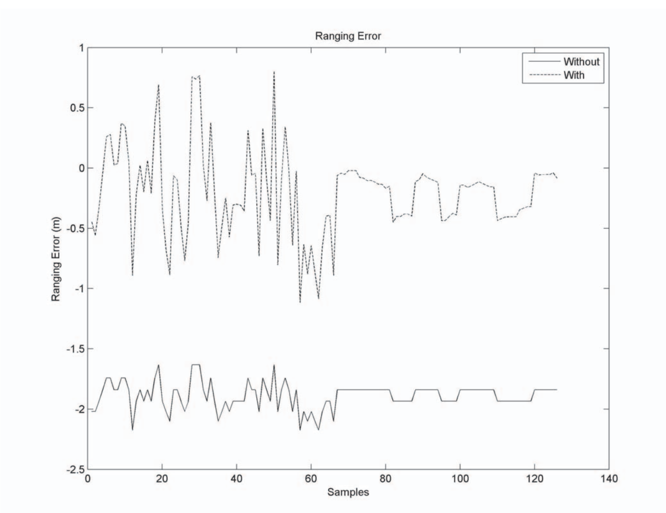

Fig. 8. Ranging Error

In 'without' case, because it is not calibrated, there is some shift from ranging error zero, but in 'with' case, because the systems always monitor signal environment, there is less shift than 'without' case. However, the ranging error is still shifted about 0.2m. It disagrees with simulation result. And the standard deviation of 'without' case is smaller than 'with' case.

The high frequency of change of RSS is caused by change of the path-loss exponent. Because the exponent is the divisor of mapping function between RSS and distance and the ranging result which is calculated from RSS and distance mapping is so sensitive against changing of RSS, these cause variation of distance error.

VII. Future Works

As we already mentioned at the previous section, the variation of ranging error is larger than 'without' case, even the average of ranging error is smaller. Therefore, for reducing the variation of ranging error, we have studied about smoothing of variation of path-loss exponent.

In this paper, we only concern one-hop calibration. However, if the ratio of anchor nodes and blind nodes is small, between the anchors and blinds should be multi-hop. Therefore, we have a plan to apply the RSS self-calibration to multi-hop environment.

VIII. Conclusions

We proposed the RSS self-calibration method for WSN localization system. The self-calibration is very simple, but can enhance a average ranging accuracy. By the RSS self-calibration, a RSS can be more attractive than the other ranging method.

References

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