Sensor Localization with Ring Overlapping Based on Comparison of Received Signal Strength Indicator

Chong Liu
Computer Science Dept.
University of Victoria
BC, Canada V8W 3P6
chongliu@cs.uvic.ca

Kui Wu
Computer Science Dept.
University of Victoria
BC, Canada V8W 3P6
wkui@cs.uvic.ca

Tian He
Computer Science Dept.
University of Virginia
Charlottesville, Virginia 22904-4740
tianhe@cs.virginia.edu

***Abstract*—**

Sensor localization has become an essential requirement for realistic applications over Wireless Sensor Networks (WSNs). Radio propagation irregularity and the stringent constraint on hardware cost, however, make localization in WSNs very challenging. Range-free localizations are more appealing for range-based ones, since it does not depend on received signal strength to estimate distance and thus needs simple and cheap hardware only. In this paper, we propose a ring-overlapping, range-free approach using Ring Overlapping based on Comparison of Received Signal Strength Indicator (ROCRSSI). Simulation results have verified the high estimation accuracy achieved with ROCRSSI.

***Key Words*—**

Range-Free Localization, Wireless Sensor Networks

I. Introduction and Background

Wireless Sensor Networks(WSNs) become the current hot spot of networking area and have been used for various applications, such as habitant monitoring, environment monitoring, and target tracking. Location information plays a crucial role in understanding the application context in WSNs [5] [6], and many localization algorithms for WSNs have been proposed to provide per-node location information. They can be divided into two categories: ranged-based methods [1] [3] and ranged-free methods [2] [7] [4]. Range-based localization depends on the assumption that the absolute distance between a sender and a receiver can be estimated by received signal strength or by the time-of-flight of communication signal from the sender to the receiver. The accuracy of such estimation, however, is subject to the transmission medium and surrounding environment and usually relies on complex hardware [8]. In contrast, range-free localization never tries to estimate the absolute point-to-point distance based on received signal strength. As such, the design of hardware can be greatly simplified, making rang-free localization very appealing for WSNs.

In this paper, we propose another range-free localization approach, Ring Overlapping based on Comparison of Received Signal Strength Indicator (ROCRSSI), that uses ring-overlapping to estimate nodes' location. This approach has the following prominent features. First, it does not require sensor nodes to send out control messages, and the communication cost is light and on anchor nodes only. Second, ring-overlapping, compared to triangle-overlapping in APIT [4] that is demonstrated to perform best for randomly deployed WSNs among existing range-free localization approaches, generates small intersection area and results in more accurate location estimation. Finally, the proposed ring-overlapping method is robust under irregular radio propagation patterns.

II. Ring Overlapping based on Comparison of Received Signal Strength Indicator (ROCRSSI)

A. Introduction of ROCRSSI

The motivation of ROCRSSI is to get accurate estimation and reduce communication overhead with small number of anchors. Anchors, which is generally required to deploy with sensor nodes by most of range-free localization methods [2] [7] [4], are those nodes who know their locations and usually have larger transmission power than normal sensor nodes. The general idea of ROCRSSI is that each sensor node uses a series of overlapping rings to narrow down the possible area in which it resides. As the example shown in Fig. 1(b), if S can determine that its distance to A is larger than the distance between A and B, but less than the distance between A and C, it can conclude that it falls within the ring center at A with the inner radius equal to the distance between A and B and the outer radius equal to the distance between A and C. Similarly, S can figure out another ring centered at anchor B, and a circle centered at anchor C. Then it calculates the intersection area of these rings (or circles) and takes the gravity of this area as its estimated location.

The rings can be generated by comparison of the signal strength a sensor node receives from a specific anchor and the signal strength other anchors receive from the same anchor. For example, in Fig. 1(a), assume that A, B, and C are three anchor nodes and S is a sensor node. Assume that anchor A sends out beacon messages and the signal strength received by anchor B, anchor C, and sensor S is $RSSI_{AB}$, $RSSI_{AC}$, and $RSSI_{AS}$ respectively. If $RSSI_{AB} > RSSI_{AS} > RSSI_{AC}$, then S is likely to fall within the shadowed ring area if anchor B, anchor C, and node S are roughly in the same direction from anchor A. Since ROCRSSI does not try to map the received signal strength to absolute point-to-point distance, it belongs to range-free localization approaches. Notably, ROCRSSI only compares the relative strength of RSSI and does not depend on absolute RSSI values.

The correctness of ROCRSSI is based on the assumption that in a certain range of direction, with the increase of distance between a sender and a receiver, the signal strength at the receiver decreases monotonically. This assumption is usually true for

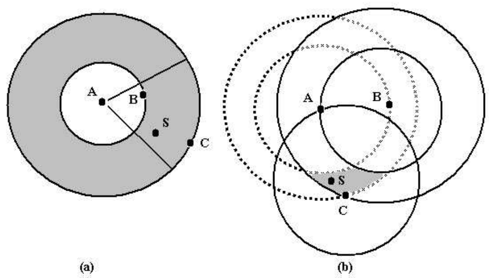

Fig. 1. Examples of ROCRSSI

```
// Assume that sensor node S wants to calculate its location
// Input:
//        S_n denotes the set of neighbouring anchors of sensor S.
//        S_A denotes the set of neighbouring anchors of anchor A,
//        where A is one of neighbouring anchors of sensor S.
//        RRSI_AB denotes the signal strength recorded from node A to node B.
Process LocationEstimation( )
{
    RingSet R = {};
    While(S_n has more elements){
        step 1: Anchor A= S_n.nextElements();
        step 2: Split S_A into two parts: S_A1 and S_A2, such that
                each element I in S_A1 has larger RRSI_AI than RRSI_AS and
                each element J in S_A2 has smaller RRSI_AJ than RRSI_AS.
        step 3: if ((S_A == null) or (S_A2==null)) goto step 1.
                J = the element with the largest value in S_A2;
                d_2 = distance between J and A;
                if (S_A1 ==null) { d_1 = d_2;}
                 else {
                        I = the element with the smallest value in S_A1;
                        d_1 = distance between I and A;
                 }
                Generate a ring r centered at A with inner radius d_1 and outer radius d_2;
                R = R + {r}; // insert r into R.
    }
    step 4: Calculate the intersection area of all rings in R;
    step 5: return {the gravity of this intersection area};
}
```

Fig. 2. Algorithm for Location Estimation

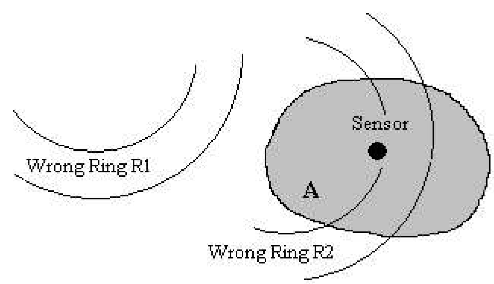

Fig. 3. Grid scan algorithm alleviates the influence of wrong rings

realistic sensor networks [4]. If omni-directional antennas are used in a homogeneous environment, we can assume isotropic radio attenuation model and ROCRSSI can get the best estimation accuracy. Note that although ROCRSSI depends on the homogeneity of radio transmission in a large range of direction, the estimated location errors by ROCRSSI are generally small even under circumstances with very irregular radio propagation. Briefly, this is because we introduce extra constraints on usable RSSI information. The detailed reasons will be illustrated in Section II-D.

ROCRSSI works in a purely distributed fashion. In ROCRSSI, the received signal strength from a certain anchor, say anchor A, can be measured by neighbouring nodes (anchors and sensors) that fall within the radio transmission range of anchor A. All neighbouring *anchors* will broadcast the measured signal strength from anchor A. In this way, each sensor node will be able to collect enough information to generate a series of overlapping rings that it believes itself falls within. Note that *only* anchor nodes are required to send out control messages.

The ROCRSSI algorithm can be broken into two phases: RSSI propagation and location estimation, which are described in detail in the sequel.

B. RSSI Propagation

At initial period, each anchor broadcasts a specific number of beacon messages. During this period, each of its neighbouring anchors and sensors will constantly sample received signal strength. At the end of this period (for example, the number of broadcast beacon messages in each anchor have reached a predefined number), all neighbouring anchors and sensors will calculate the mean of the measured signal strength. For a sensor node, it will store the mean value for later use. For an anchor node, it will broadcast a RSSI message, including the mean value of the measured signal strength, its own ID, the ID of the reference anchor (the one who has been measured), and its own location information. Any sensor node that receives the RSSI message will record the related information.

C. Location Estimation

When sensor node S obtains enough information after the initial RSSI propagation stage, it can make use of the information to calculate its own location. The pseudo-code of the algorithm is shown in Fig. 2. The basic idea is to generate a series of rings, each of which S believes itself falls within. S calculates the intersection area of these rings, and takes the gravity of the final intersection area as its estimated location.

Note that in the algorithm, if the set S_A or the set S_{A2} is empty, then no ring will be generated. If the set S_{A1} is empty but the set S_{A2} is not, only one circle is generated. If both sets S_{A1} and S_{A2} are not empty, S will generate a ring.

In step 4, a grid-scan algorithm [4] is used to calculate the gravity of the intersection area. In this algorithm, the whole terrain is divided into small pieces of grids. Each grid maintains a counter which is initialized to 0. Every time a ring is generated by comparison of signal strength, the counter values associated with the grids within the ring are increased. Once all possible rings are calculated, we scan the whole grid array to find the area with the maximum counter value, then take this area as the final intersection area and calculate its gravity. It is easy to see that the size of the grids determines the possible smallest granularity of location error. Small grids are thus preferred but small grids need more calculation time.

D. Handling Radio Irregularity

According to the measurement results over real sensor devices, radio propagation is usually not homogenous in all directions [9], that is, different directions have different radio attenuation rates. So a good localization algorithm should accommodate radio irregularity by not assuming isotropic path losses. ROCRSSI does not exclude generating wrong rings and thus makes incorrect estimation because of the irregularity of radio propagation. Nevertheless, the grid-scan algorithm that sensor nodes use to calculate the gravity of intersection area helps reduce the influence of wrong rings. As mentioned before, grid-scan algorithm takes the area consisting of grids with maximum counter as the final intersection area. In Fig. 3, suppose *more than half* of the rings generated by RSSI comparison are correct, and the intersection area of all correct rings is the gray area labeled as A. The gravity of area A will be taken finally as the estimated location of the sensor, because even if all wrong rings have no intersections with area A and even if all wrong rings happen to overlap at one place, the counter value associated with the grids at that (wrong) place must be smaller than that of grids in area A. As a result, wrong rings will not be taken into consideration in the location calculation.

If there are some wrong rings overlap with area A, such as the wrong ring R_2 in Fig. 3, then the final intersection area may not contain the sensor node. But the final intersection area is a subset of area A and is thus within the area A. Since the size of area A is usually small if the number of audible anchors is large enough, the gravity of the final intersection area will be very close to the real location of the sensor. As such, even if ROCRSSI may generate some wrong rings, it can still yield fairly accurate location estimation.

III. Simulation results and analysis

In our simulation, we assume all the sensor nodes have the same maximal sensor radio transmission range R. Notably, R is used for normalization *only*. All distances including error estimation are normalized by R to ensure generally applicable results. Sensor nodes and anchor nodes are randomly deployed within a square area with each edge of length 10R. For each simulation scenario, ten runs with different random seeds were executed and the results were averaged. We define the location estimation error as the Euclidian distance between the real location of a node and its estimated location. We use average location error as the metric to evaluate the accuracy of location estimation. It is defined as the mean of location estimation errors collected over all determined sensor nodes in ten runs.

We implement three localization methods, ROCRSSI, APIT, an improved version of APIT, denoted as APIT+. APIT+ differs from APIT in that when a triangle is added, only those grid points within maximum range of all heard anchors are added. This method will improve the performance of APIT in the face of radio irregularity with extra checking for each grid point. In order to compare the performance of different methods under radio irregularity, we extend the DOI model in [4] so that it can calculate the possible received signal strength at any specific point within the maximal radio range of a sender. DOI value is used to adjust the degree of radio irregularity and large DOI values represent large variation of radio irregularity.

Fig. 4 demonstrates that ROCRSSI always outperforms APIT and APIT+ in terms of average estimation error, no matter whether the radio propagation is regular or irregular. This is because the intersection of rings usually has smaller size than the intersection of triangles. A simple example can be found in 1(b), where it is easy to see that the size of the shadowed ring intersection area is smaller than the size of $\triangle$ABC (if we assume that S falls within $\triangle$ABC).

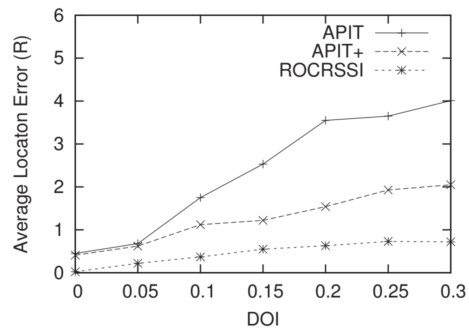

Fig. 4. The approximate comparison of APIT and ROCRSSI

IV. Conclusion and Future Work

Range-free localization presents a promising solution for the localization problem in WSNs. This paper proposes a ROCRSSI method which achieves more accurate location estimation than existing high performance APIT method. The ROCRSSI method has the following nice features:

1) It does not require sensor nodes to send out control messages and thus poses very little overhead on sensor nodes.
2) It generates small intersection area and results in accurate location estimation.
3) It is robust under irregular radio propagation patterns.

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