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RSSI-based Indoor Localization Using RSSI-with-Angle-based Localization Estimation Algorithm

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Abstract

For the scenarios of indoors localization and tracking, the solutions generally need complex infrastructure because they would require either a grid of antennas, each having a well-known position (proximity based approach), or a sophisticated algorithm that uses scene fingerprint to estimate the location or the zone of an object by matching the online measurement with the closest offline measurement. Those techniques may not be available in unknown zones, which will make it difficult to locate a lost node. In this paper, with no additional hardware costs, we propose a new RSSI-based approach in order to find a lost node using a known node. By rotating the known node at the same spot we can collect different RSSI for different polar angles. Two pairs of angles with the strongest RSSI will indicate the main lobes of the radiation pattern, namely, zone of the unknown node. Experimental results illustrate a very close estimation of the unknown node zone, reducing up to 84% of the zone uncertainty.

Keywords: RSSI; Node; Polar angles; Rotation; Localization

Introduction

The Received Signal Strength Indication (RSSI) is the measurement of the power present in a received radio signal. It has commonly been used to estimate the distance between nodes. Techniques have been discussed, using distance estimation from multiple reference points to determine the position of a node. The distance estimation is processed through the radio signal velocity and the time spent by the signal to reach its target. This method uses the concept of Time of Arrival (TOA) [1] and Time Difference of Arrival (TDOA) for estimating distance. Two main issues are encountered in TOA: first transmitters and receivers in the system must be perfectly synchronized in order to get a meaningful estimation, then a timestamp must be embedded in the transmitting signal in order for the measuring unit to more accurately estimate the corresponding distance. These two issues may lead to errors or even meaningless estimation. RSSI is widely adapted in wireless communication protocols such as Bluetooth, ZigBee [2,3] and other wireless techniques, because it indicates the strength of the signal transmitted. Furthermore, this signal strength can be measured without connecting or setting up devices. And this makes things easier since neither synchronization nor timestamp is required.

We mostly use antennas for signals transmission. The zone where we can possibly get a signal is a radiation pattern. The main lobe or main beam is the zone containing the maximum power of the signal. This is the lobe that exhibits the greatest strength. The radiation pattern of most antennas shows a pattern of "lobes" at various angles, directions where the radiated signal strength reaches a maximum, separated by "nulls" [1-5], angles at which the radiation falls up to zero. For dipole antennas, we have two main lobes, usually opposite. Because of the canonical form of the pattern radiation, we will assume that we may get at least 90° between two main lobes [4].

In this paper a new approach for unknown node location is proposed. It consists of determining the zone of an unknown node using the angles associated to the strongest RSSI transmitted by that node. This paper is arranged as follow: In Section 2 we will review the related work, in Section 3 we will propose the RALE approach, in Section 4 we will show the experiment results and their analysis and finally in Section 5 we will give a conclusion.

Related Work

Various studies have proposed different localization algorithms which vary on whether the algorithm depends on known nodes or not. The anchor-based algorithms use some nodes with known position. The higher number of known nodes guarantees a better location accuracy of the unknown node that has an unknown position. Those algorithms may need at least 3 anchor nodes, with the TOA and the Angle of Arrival (AOA) of the signal [1] respectively, in order to estimate the distance between known nodes and the unknown node. This technique requires a very large and complex hardware set up and many reference points. In addition, a big number of nodes can affect noisily the location of the unknown node [5].

The proximity approach requires in getting location using antennas [6]. The AOA and the signal strength of those antennas will help determine the zone of the unknown node. Sometimes the blind node can calculate its position because the AOA and signal strength information are transmitted in the signal received by the blind node.

Several methods have been used for indoor positioning, such as trilateration [1,5], triangulation [1], proximity approach [7], radio map [8], and fingerprinting [9]. The results reported in ref. [5] shows the trilateration has an accuracy of 50% and it needs extra hardware to send two types of data simultaneously; further confirmations of the accuracy of trilateration in ref. [10] shows that it can attain a better accuracy

Some literature, tells us that signal strength and its fluctuation may differ according to antenna angle variation [11]. Particularly, it is also observed that, human movement from slower to faster paces increases

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the fluctuations of the RSSI. However the height between the receiver and the transmitter has less effect on the RSSI values [12].

A technique using radio map's data, accelerometer and magnetic sensor has been discussed. It enables somebody whose initial position is known to be located on a radio map through the compass and the signal strength read in his mobile phone. The algorithm then consists of comparing his current data with the one attached with the nearest radio map's data [8] saved in a server. The compass measures the polar angle which is one of the coordinate components defining the user location, the other component of the user coordinate is the radius which corresponds to the distance between the initial point and the current point, and this is where the accelerometer will be useful. This distance is compared with the distance calculated using the maximum distance estimation made through the RSSI values. Indeed there are ranges of RSSI values that correspond to maximum distance estimations. Factors such as diffraction, reflection and scattering can deeply affect the RSSI.

Every node use an antenna to transmit its signal; but the signal radiation depends on the type of antenna it has and this can deeply affect the value of the RSSI [13]. Mobile phones for the most part have a broad bandwidth and circular polarized antennas that make them very reliable and efficient when it comes to receive signals [14]. Most of the time the issue encounter in signal reception is to know the type of antenna the transmitter used and its signal radiation mode: methods of radiation calculation based on directional function calculation are also found in the literature [4]. These methods reveals that transmitters antennas build radiation lobes which have different, and sometimes almost opposite directions.

RALE Approach

This section describes the RSSI-with-Angle-based Localization Estimation (RALE) approach in order to determine one unknown node. RSSI value can increase as we get close to the unknown node; in order to avoid fluctuant RSSI due to angle variation [11], we assumed that both nodes are stable and on the same horizontal plane.

We collected the pair (RSSI, angle) for every random direction during the rotation, with a short pause in many directions as shown in Figure 1; we averaged the RSSI values for each direction in order to get more meaningful RSSI values.

The meaningful RSSI ($RSSI_i$, $i=1, 2,\ldots, n$) and its corresponding angle (θ_i) will be considered as weighted point for our approach. In the database, we searched the two maximum RSSI values, $RSSI_{m1}$ and $RSSI_{m2}$ with $RSSI_{m1} > RSSI_{m2}$ and we read the corresponding angles θ_1 and θ_2.

We required two pair belonging to different lobes of the antenna radiation thus we proceeded to a test in order to separate measurement from the same lobe. Because of the canonical form of the antenna's pattern radiation we defined that $|\theta_1 - \theta_2| > 90^\circ$. When that difference doesn't match the condition we consider that those two angle values are associated to RSSI belonging to the same lobe. We then have to change $RSSI_{m2}$ with the next strongest RSSI saved in the database ($RSSI_{m3}$) and proceed the same condition. Then the fourth pair will then be regarded as $RSSI_{m3}$ .we can repeat this process till the conditions are respected as illustrated in Figure 2.

From this we get two directions that divide the plane in four zones. Our target is to determine the zone containing the unknown device and for that we have to make a choice. The third greatest RSSI ($RSSI_{m3}$) will be used to identify the zone and its associated angle θ_3 should be greater or equal to $\theta_1 \pm 90°$. The third strong RSSI ($RSSI_{m3,}\ \theta_3$) will help us decide in which zone the node might be located because now we get four possible zones of interest: $[\theta_1; \theta_2]$ $[\theta_1; \theta_2 -\pi]$ $[\theta_1 -\pi; \theta_2]$ $[\theta_1 -\pi; \theta_2 -\pi]$ and thus θ_3 should belong to one of these 4 zones. We called this process zone determination

RALE has four main advantages:

- It doesn't require a survey of the scene (like in the fingerprint method), and can be implemented in every indoor environment: this is one of the common requirement in indoor positioning location, for new scene and less time it' an indoor localization.
- It doesn't require heavy or sophisticated infrastructure for his implementation like in trilateration or triangulation, no need TOA or DOA. Indeed in TOA or DOA techniques we need to be able to measure the angle of arrival and the time of arrival of the signal. This requires special tools that most of time can be difficult to get.

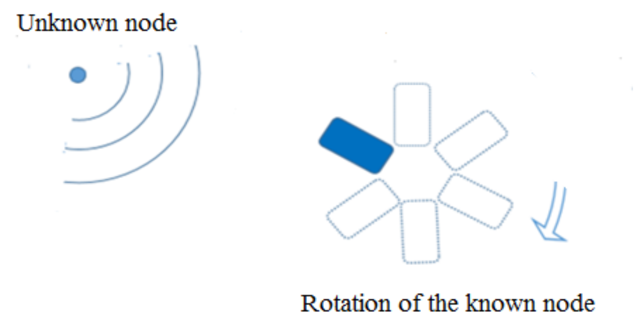

Figure 1: Rotation of the known node, collecting both RSSI values received and polar angles.

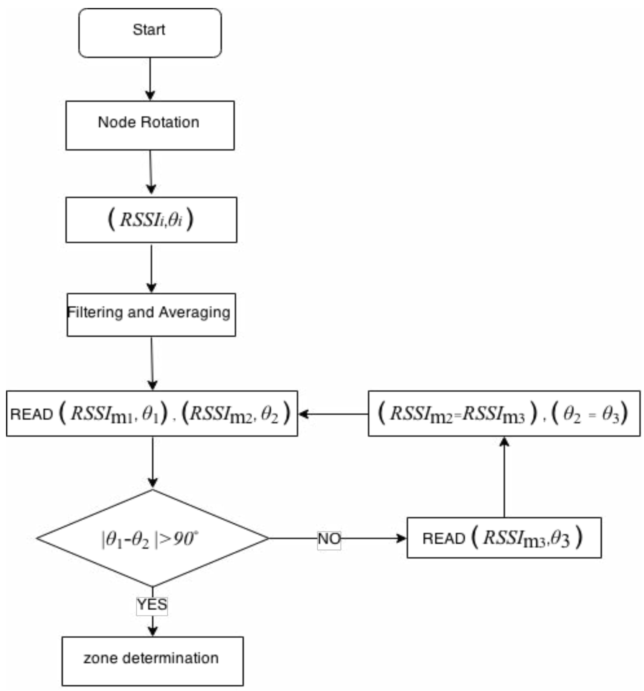

Figure 2: RALE approach flow chart

- It is low cost, we just need 2 nodes and the algorithm is simple to execute. Basically a mobile phone and a BLE device can do the job; those are not expensive and are accessible to everybody. Beside an app can execute the algorithm in the phone.
- We just need the values of RSSI during the rotation. A key is to record RSSI during the rotation we don't need other measurement to estimate the location of the node.

RALE analytically interpreted the data stored during the rotation of the node. Its efficiency was guaranteed by a huge amount of data. In the next section we will describe how experimentally we were able to implement this approach.

Experiments

The rotation of a Bluetooth sensor (known node) has been performed in 4 different positions. We put, during the whole experiment the Bluetooth sensor and a Bluetooth Low Energy (BLE) device (unknown node) on the same flat ground as shown in Figure 3.

The BLE device is made on the CC2541 chip from Texas Instrument, working on 2.4-GHz applications. During the rotation of our sensor we have collected and saved in a database the polar angles and RSSI values, and we could see the repartition of the pair point (angle, RSSI) in Figures 4-7: we noticed that the aligned points represent the data during the pause of the smartphone and we can see that for a fixed

(a) (b)

Figure 3: Experiment setup.

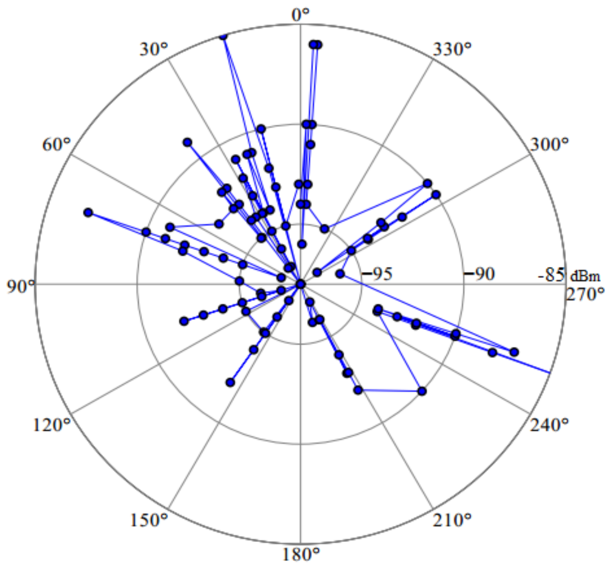

Figure 4: RSSI and angle at Position 1.

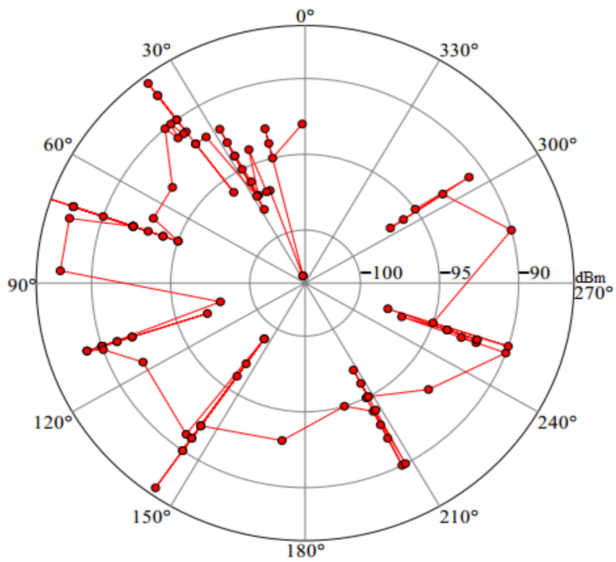

Figure 5: RSSI and angle at Position 2.

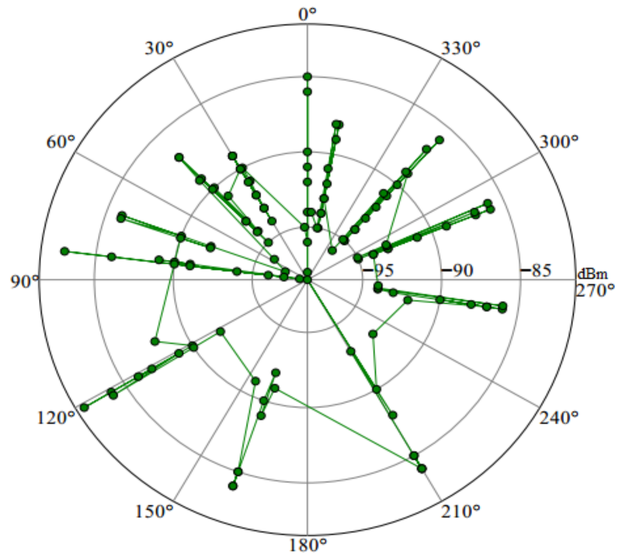

Figure 6: RSSI and angle at Position 3.

direction the RSSI fluctuates a lot, that's why we averaged those values and filtered the unaligned points in order to get weighted pair point as shown in Figure 8-11. The weighted points clearly showed the maximum RSSI, their angles and we observed for example Strong RSSI in Figure 9 belonging to the same lobe radiation (around 120° and 180°).

The angular velocity (Table 1) is determined by the angles covered by the rotation over the time used to cover them. The time is measured by the number of data times 0.5 s which is the period set up for every data collection.

In Table 2 we display the zone calculated by our algorithm and the angle measured with the Bluetooth sensor pointing the direction of the BLE devise. We come to the conclusion that sometimes the zone might not always contain the direction or angle measured, but can be very close to it. It's the case at Position 2; this can be explained by the

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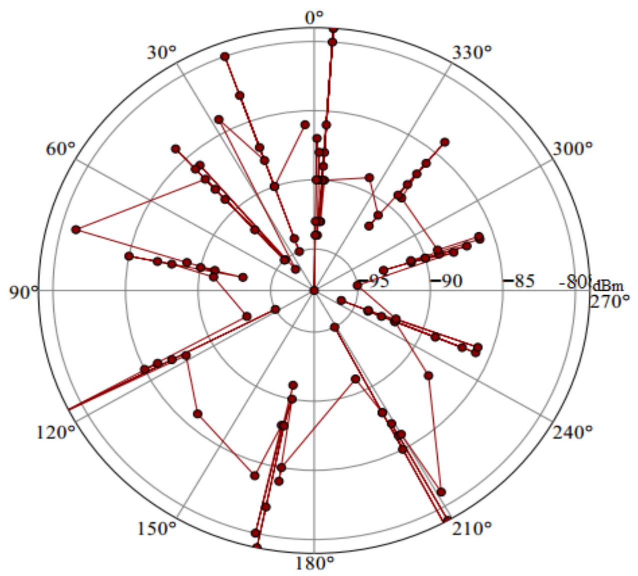

Figure 7: RSSI and angle at Position 4.

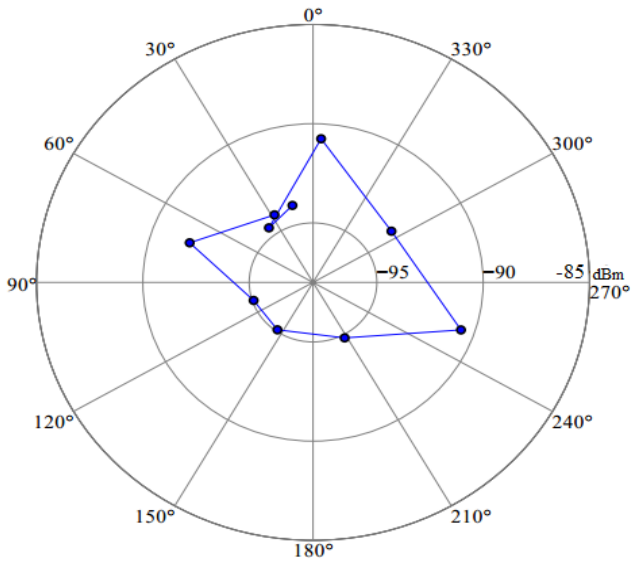

Figure 8: Average RSSI and angle at Position 1.

number of pause during the rotation of the smartphone. Indeed in Position 2 we counted 7 pauses during the rotation, when for the other positions we had at least 8 pauses.

As for techniques like trilateration, or triangulation the location accuracy is improved by increasing the number of reference points. So does our approach, but instead of adding reference points we increase the number of pause directions as we noticed at Position4 where we made 9 pauses direction.

The zone represents the area of certainty, where we may actually find the unknown node. The accuracy here represents the percentage of the remaining area over 360°.

It is calculated as follows Accuracy $\frac{(360-\partial Zone)}{360}\times 100, \partial$ zone is the angle difference between the zone intervals. When compared to our method, which has an accuracy of up to 84%, it can be shown that our method performs considerably well using limited resources. Also, our method implies that you can use only one device to obtain high accuracy.

Again, the results of triangulation, as reported in ref. [1] or fingerprint in ref. [9], or even proximity approach in ref. [7] show that it can have a pretty good accuracy but requires very expensive and complex infrastructure.

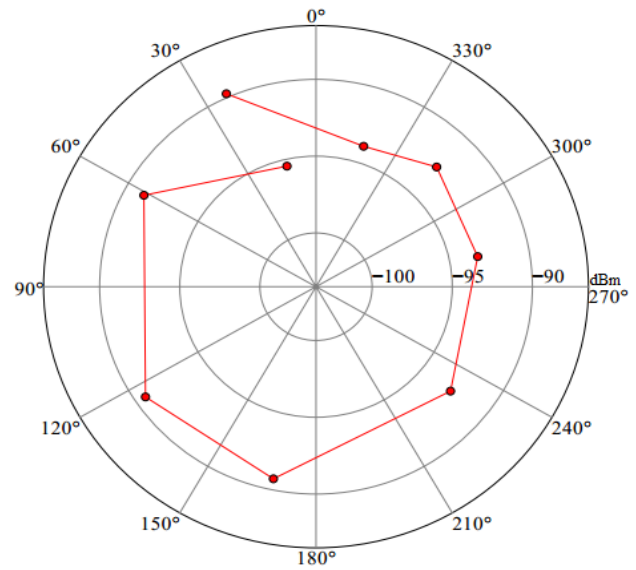

Figure 9: Average RSSI and angle at Position 2.

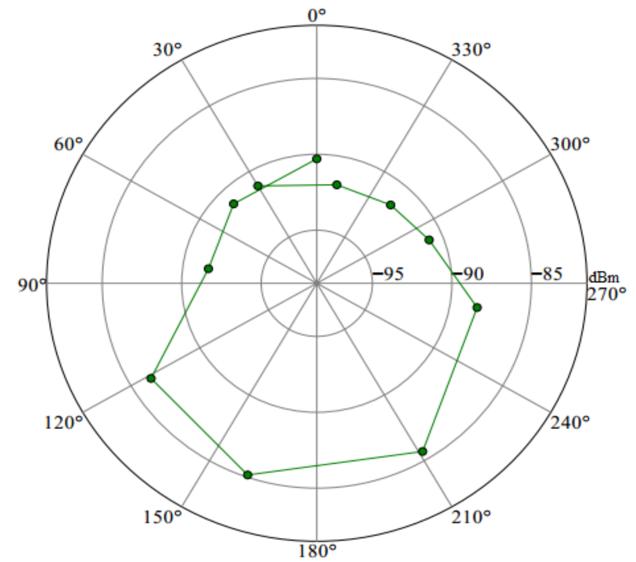

Figure 10: Average RSSI and angle at Position 3.

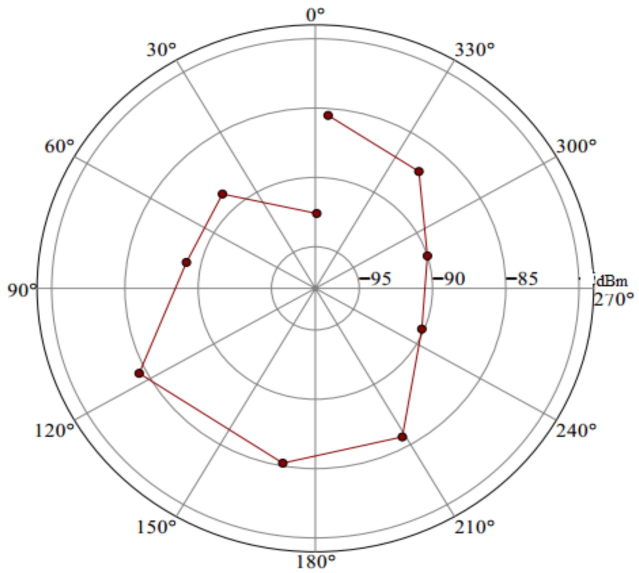

Figure 11: Average RSSI and angle at Position 4.

Position	Position 1	Position 2	Position 3	Position 4
Angular velocity	5.16°/s	5.42°/s	4.9°/s	6.3°/s

Table 1: Angular velocity of the Smartphone rotation.

Angles	θ_1	θ_2	θ_3	Zone interval	Direction measured	Accuracy
Position 1	357°	251°	71°	[357°;71°]	10°	79.45%
Position 2	24°	124°	61°	[24°;124°]	13°	72.23%
Position 3	161°	261°	0°	[-19°;81°]	0°	72.23%
Position 4	117°	356°	320°	[297°;356°]	356°	83.68%

Table 2: Example of Zone determination based on θ1, θ2, θ3.

Conclusion

In this paper we have implemented an algorithm that determined the location of an unknown device by using RALE approach. The experiment results give the zone where the unknown device is located. RALE just requires RSSI and angles, regardless of the technology used (Bluetooth, Wi-Fi…). It doesn't require also prior survey of scene or special map, sophisticated infrastructure or resources, not even complex algorithm. The accuracy of this method in locating the node depends on the number of pauses during the rotation of the node and also the type of antenna used. Further research may look in a way to get the node position dynamically at different heights and environment.

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