Antenna Radiation Pattern Based 3D Localization Technique

Amarlingam M, P Rajalakshmi, Vinod kumar Netad
Department of Electrical Engineering
Indian Institute of Technology Hyderabad
Hyderabad, India
Email: ee13p1003, raji, ee13m1033@iith.ac.in

Masaya Yoshida, Kiyohito Yoshihara
KDDI R&D Laboratories Inc.
Green and M2M Application Laboratory
Iidabashi, Japan
Email: my-yoshida, yosshy@kddilabs.jp

***Abstract*—3D location knowledge of sensor node in a sensor network has many practical applications. This paper proposes a new algorithm for finding 3D location of sensor node in a sensor network by using radiation pattern of antenna with Received Signal Strength Indication (RSSI). Proposed localization algorithm is developed by considering target node equipped with half wave dipole antenna which has omnidirectional radiation pattern. The results show that proposed algorithm estimates 3D location of sensor node in a sensor network with low average error ($< 0.5m$), when compared to its actual location.**

***Index Terms*—Radiation pattern, RSSI, 3D localization.**

I. Introduction

Recent advances in micro-electromechanical systems, wireless communication technologies and digital electronics have brought us closer to the vision of pervasive Wireless Sensor Networks (WSN). Development in WSN enhanced smartness in controlling and monitoring sensors in a sensor network [1]. WSN have a number of potential applications such as sensing environment physical factors like temperature, humidity and also for monitoring and detecting chemicals, smokes etc. In most of application areas such as military, habitat sensing, target tracking, forest fire location detection and marine monitoring, knowledge of every sensor node location is very crucial to understand application context.

Authors of [2] discussed three basic advantages of having the sensor nodes location information. Firstly, location information is required to estimate the location of an event of interest for example intruder location. To deploy relief and rescue in a battlefield the location of enemy tanks is crucial. Secondly, knowledge of location information facilitates a number of application services, such as helping doctors by providing the location of nearby medical facilities in a smart hospital. Third, location information find its applications in geographical routing ([3] and [4]), network coverage checking [5] and location-based information querying [6].

For outdoor localization applications GPS is used, but in indoor environment GPS is inaccurate because of poor signal strength. Most of existing localization techniques are 2D localization techniques. In [7] and [8] RSSI based localization algorithms for 2D are discussed. In real world applications sensor nodes are deployed in 3D. To estimate 3D location of sensor node we need to develop 3D localization algorithm.

Existing localization techniques are broadly divided into two types. First one is range-based localization techniques and second one is range-free localization techniques. Range-based localization techniques are dependent on range measurement techniques (distance measurement, angle-of-arrival measurement techniques) for localization. The localization techniques which depends on RSSI and path loss modelling of environment ([9]) falls under category of range-based localization. The range-free localization techniques do not use range measurement techniques. They use topology, connectivity information for localization. Authors of [10] discuss basic centroid localization algorithm which falls under category of range-free localization algorithms.

Most of the 2D and 3D localization techniques which depend on RSSI and path loss model always consider antenna radiation pattern as isotropic i.e. antenna radiates uniform power in all directions [11]. In practice isotropic antenna does not exist. Omnidirectional antenna is used as isotropic antenna because it radiates uniform power in all azimuth directions, but it has a deep null in the orthogonal elevation direction. It radiates less power in axial direction of the antenna as shown in Fig. 1. Due to this, omnidirectional antenna or half wave dipole antenna radiation pattern gives less received power at nodes which are placed at the bottom of the antenna. In practical scenario because of the antenna radiation pattern effect localization error could increase. This motivated us to propose new radiation pattern based 3D localization algorithm, which considers radiation effect to give less error in localization.

A. Related works

In [12] authors proposed a novel centroid algorithm for 3D. Authors of [13] proposed new 3D DV-Hop Localization algorithm which is extended version traditional range-free DV-Hop algorithm in to 3D. In [14] authors described a range-free 3D azimuthally defined area localization algorithm. Authors of [15] proposed unitary matrix pencil algorithm for range-based 3D localization. It depends on time-of-arrival (TOA) estimation of ultra wideband signal using unitary matrix pencil algorithm. Paper [16] proposed a 3D positioning algorithm based on RSSI, which uses maximum likelihood estimator to estimate 3D location. Authors of [17] and [18] proposed

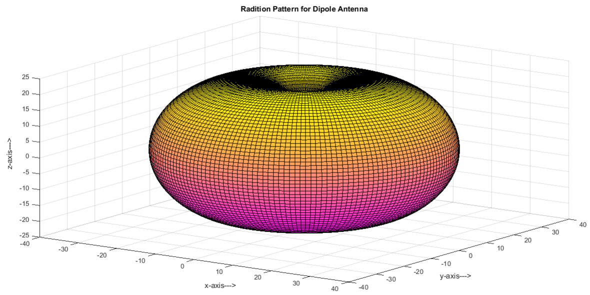

Fig. 1: 3D radiation pattern of half wave dipole antenna.

directional antenna based 2D localization techniques. These techniques depend on radiation pattern of the antenna.

In this paper we propose antenna radiation pattern based 3D localization technique by using node's omnidirectional antenna radiation pattern.

The rest of the paper is organized as follows. Section II describes proposed 3D localization algorithm. Section III describes the algorithm implementation and simulation setup for 3D localization. Section IV describes simulation results analysis. Finally, section V concludes the paper with future scope of work.

II. Proposed 3D localization algorithm

This section describes the proposed radiation pattern based 3D localization technique. We assumed that target node (the sensor node which location has to be estimated) is equipped with half wave dipole antenna, which has omnidirectional radiation pattern. In all directions, omnidirectional antenna radiation pattern is not same. It radiates less power in the axial direction of antenna. 3D radiation pattern of half wave dipole antenna is shown in Fig. 1.

A. Estimating 2D location of target node

We considered that target node is placed above the XY-plane with antenna in Z-axis direction. Omnidirectional antenna radiates power concentrically in horizontal direction with circular patterns as shown in Fig. 2. Received power from transmitting antenna at equidistant beacon locations is almost same on 2D plane (ground plane). The 2D location of the target node can be estimated by locating center of the circular patterns. To find out center of the circular patterns on 2D plane where beacon nodes are placed, the plane is divided in to circular patterns which are having arbitrary center point. These circular patterns form rings on 2D plane. Variance of received powers is computed over each ring. The mean of variances of received power where it goes to minimum, that center point of circles is regarded as 2D location of the target node.

To estimate target node 2D location (X_e, Y_e), we considered n beacon nodes in 2D plane. Location of beacon nodes are (x_i, y_i) where $i = 1, \ldots, n$ (a sensor node which is placed on mobile robot can be used as beacon node to get n beacon node locations [11]). Received power of i^{th} beacon node is Pr_i. Rn_{kl} represents l^{th} ring centered at an arbitrary point

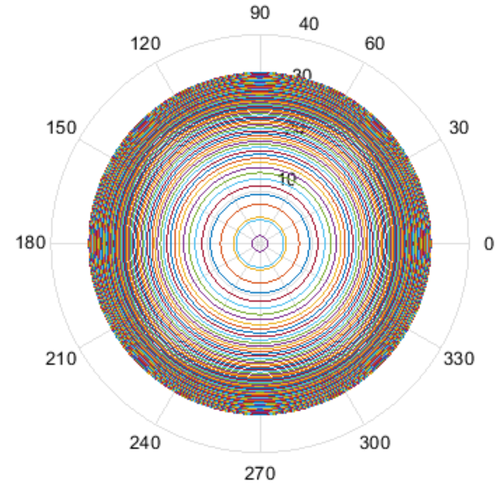

Fig. 2: Power distribution of the omnidirectional antenna in horizontal plane.

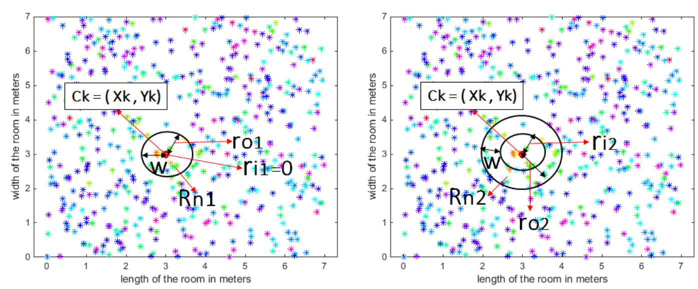

Fig. 3: The defined area is divided in circular rings.

$C_k = (x_k, y_k)$, where the radius of inner circle is ri_l, outer circle is ro_l and the width of each ring is w. Consider D_{ki} is the Euclidean distance between each points on 2D plane (x_i, y_i) and an arbitrary point $C_k = (x_k, y_k)$ which is calculated from equation (1). d_{1l} is the minimum distance between l^{th} ring's inner circle circumference and the points lying inside the ring. d_{2l} is minimum distance between l^{th} ring's outer circle circumference and points lying outside the ring i.e. points which distance $D_{ki} > ro_l$. Pt_i is the set of points of beacon node locations. Algorithm starts at an arbitrary point C_k with $ri_l = 0$ and $ro_l = w$. In next step if $d_{1l} < d_{2l}$ then $ri_l = d_{1l}$, $ro_l = ri_l + w$ else $ro_l = d_{2l}$, $ri_l = ro_l - w$. Fig. 3 shows plot of two iterations. In iterative process d_{2l}, d_{1l}, ri_l, ro_l will be update until $A_{kl} = \{\emptyset\}$.

$$D_{ki} = \sqrt{(x_i - x_k)^2 + (y_i - y_k)^2} \quad (1)$$

Here the set of points located in the ring Rn_{kl} are represented by $A_{kl} = \{Pt_i \mid Pt_i \in Rn_{kl}\}$. E_{kl} represents the mean of received power at different beacon nodes in the ring Rn_{kl} and calculated by equation (2).

$$E_{kl} = \frac{\sum_{Pt_i \in A_{kl}} Pr_i}{n_{kl}} \quad (2)$$

n_{kl} is the number of point of the set A_{kl}. Variance of received power values of each ring V_{kl} calculated using equation (3).

$$V_{kl} = \frac{\sum_{Pt_i \in A_{kl}} (Pr_i - E_{kl})^2}{n_{kl}} \tag{3}$$

$$EV_k = \frac{\sum_l (V_{kl})}{M_k} \tag{4}$$

Equation (4) is used to find the mean of the variances of the rings centered at C_k. Here M_k is the total number of rings for C_k. Finally the estimated position (X_e, Y_e) is determined using the following equation (5).

$$(X_e, Y_e) = C_k \text{ which minimizes } EV_k \tag{5}$$

B. Estimating height of the target node

The gain of omnidirectional antenna in vertical direction is lower than horizontal direction [19] as shown in Fig. 1. Thus, received power measured at the beacon nodes under the target node will be low. The average value of received power at beacon nodes from target node will decrease as target node height increases. This fact helped us to propose a new relative height estimation method for 3D localization.

To calculate average received power of beacon nodes under target node, a circle with radius r from estimated 2D location of the target node (X_e, Y_e) is considered. Set of Beacon positions M, which distance from (X_e, Y_e) is less than r is considered, i.e. $M = \{Pt_i \mid D_{ki} < r\}$. N_M is the number of beacon node in the set M. Average received power of beacon nodes P_{avg} is calculated using equation (6).

$$P_{avg} = \frac{\sum_{Pt_i \in M} Pr_i}{N_M} \tag{6}$$

Specifically, the proposed algorithm estimates the relative height Z_{ej} of target nodes N_j. Here we assumed that all target nodes heights are uniformly distributed along Z-axis with different 2D locations. First we find the average received power of all target nodes (inside the circle with radius r under target nodes). The minimum P_{avg} value is denoted by $P_{avg_{min}}$, the corresponding height of $P_{avg_{min}}$ is H_{max}. To estimate relative height of other target nodes, received average powers of all target nodes are divided in to groups. K-means clustering algorithm is used for grouping the received average powers of different target nodes with different heights. K-means algorithm will give group numbers according to received average powers. All the target nodes are classified into M groups from G_1 to G_M depending on its P_{avg}. The height of a target node in group G_h (where group number $h = 1, 2, ..., M$) is estimated by following equation (7).

$$Z_{ej} = \frac{H_{max}}{M} * h \tag{7}$$

III. Algorithm implementation and simulation setup for 3D localization

The proposed algorithm is implemented using Matlab software. Radiation pattern of the half wave dipole antenna is generated with reference of [21], [22] using Matlab. To implement the algorithm we considered beacon nodes are randomly deployed on 2D plane. Target node is considered above 2D plane (which is placed in 3D location). Received power Pr_i at randomly deployed beacon nodes (x_i, y_i) depend on gain of the antenna at respective positions. Antenna Transmit gain $G_t(\theta, \phi)$ and antenna receive gain $G_r(\theta, \phi)$ are function of azimuth angle ϕ and elevation angle θ. Transmit and receive antenna gain of beacon nodes will be different for different azimuth angle ϕ and elevation angle θ with respect to target node. Depending on these azimuth and elevation angles, antenna gains are mapped to different beacon node's location. To find received power at beacon node's location Revised Hata Okumara path loss model [20] is used (8).

$$\begin{aligned} logD_i = \frac{1}{10\eta}[P_t - Pr_i + G_t(\theta, \phi) + G_r(\theta, \phi) \\ -X_\alpha + 20log\lambda - 20log(4\pi)] \end{aligned} \tag{8}$$

Where $D_i \rightarrow$ distance between the target node to all beacon nodes (X_t, Y_t, Z_t) and i^{th} Beacon node (x_i, y_i).
$G_t(\theta, \phi)(dBi) \rightarrow$ Transmit antenna gain
$G_r(\theta, \phi)(dBi) \rightarrow$ Receiver antenna gain
$P_t(dBm) \rightarrow$Target node transmit power
$Pr_i(dBm) \rightarrow$ Measured received power at i^{th} beacon position
$\eta \rightarrow$ Measure of influence of obstacle like partitions and obstacles in indoor environment ranges from 4 to 5 and for free space it is equal to 2.
$X_\alpha \rightarrow$ Normal random variable with standard deviation of α and varies from 3dB to 20dB.

TABLE I: Path loss model parameter values used for simulation

Parameter	Value
P_t	-3 (dBm)
X_α	3 (dB)
λ	0.125 (meters)
η	2.5

A. Simulation setup

For simulation purpose we considered area of 7m*7m, number of beacon nodes are 1000 which are placed at random locations. All beacon nodes are placed on 2D plane with

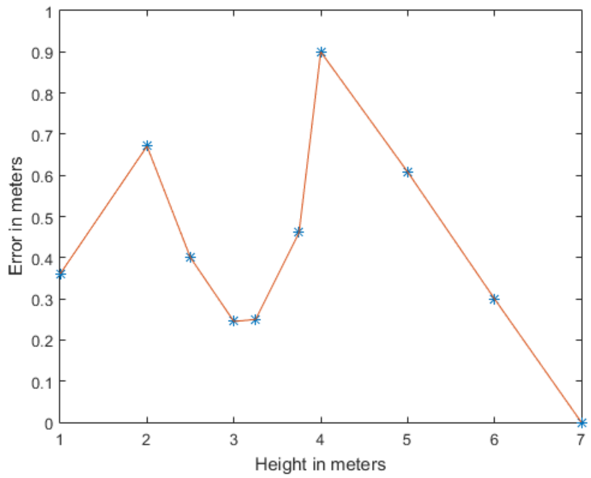

Fig. 4: Predicted location error vs height of the target nodes

random azimuth angle. We considered all target nodes and beacon nodes are equipped with half wave dipole antenna. Along with this setup 10 target nodes are considered which are placed at different 3D locations. Considered number of groups are $M = 10$ and considered maximum height is $Hmax = 7m$ which is maximum height of the considered target nodes. To calculate average received power of beacon nodes under the target node, a circle with radius $r = 0.5m$ which centered at estimated 2D location is considered. TABLE I shows path loss model parameters considered for simulation.

IV. Simulation Results analysis

Estimated location error with different heights is plotted in Fig. 4. Actual, estimated locations are tabulated in TABLE II.

TABLE II: Estimated and actual location of the sensor node at different heights

Actual locations (m)			Estimated locations (m)		
Xt	Yt	Zt	Xe	Ye	Ze
0	0	1	0.2	0	0.7
1	2	2	1	1.7	1.4
2	3	2.5	2	3	2.1
4	1	3	4.1	0.9	2.8
3	3	3.25	3	3	3.5
5	2	3.75	5.1	2	4.2
6	6	4	6	6	4.9
3.5	1.5	5	3.5	1.6	5.6
4	2	6	4	2	6.3
2	4	7	2	4	7

The error of the estimated 3D location of the target node to actual location of the target node is calculated by using equation (9).

$$E_{rr} = \sqrt{(X_t - X_e)^2 + (Y_t - Y_e)^2 + (Z_t - Z_e)^2} \quad (9)$$

Where $(X_t, Y_t, Z_t) \rightarrow$target node real location.

$(X_e, Y_e, Z_e) \rightarrow$ target node estimated location.

Estimated average error for 10 different locations with 10 different heights given in TABLE II is $0.4196m$. This result is more accurate compared to existing algorithms [11].

V. Conclusion

In this paper we proposed an antenna radiation pattern based 3D localization algorithm for estimating the 3D location of sensor node in a sensor network. The simulation results shows that the proposed algorithm gives less average error ($< 0.5m$) in estimating 3D location of target node compared to it's actual location. Our future plan is to implement proposed algorithm in real environment and test with different experimental setups.

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