ESTIMATION OF THE POSITION OF A NODE FOR INDOOR WIRELESS SENSOR NETWORKS BY IMPLEMENTING RSSI BASED LOCALIZATION ALGORITHM BASED ON MAXIMUM LIKELIHOOD THEORY

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Abstract: - *This RSSI based localization algorithm based on Maximum Likelihood Theory, is based on finding the location of a node in wireless networks. In environments where the GPS does not work, the estimation of position of a node can be done using this technology. Although some other systems have been proposed so far, using ultrasonic signals, Infrared, etc. But those require additional hardware to be used for location finding. This project describes an algorithm, which computes the location of a node for indoor wireless sensor networks. The objective of this algorithm is to estimate the position of the nodes, using RSSI (i.e, the power of the incoming signals). Due to the high variability of this parameter, which depends heavily, not only on the distance among nodes, but on many other circumstances as well, such as presence of obstacles, walls, etc. We are using Maximum Likelihood Theory in order to remove the errors in identifying location of a node. This work is an attempt to implement the RSSI based localization algorithm using Maximum Likelihood Theory. The methodology adopted for developing this algorithm is water fall model. The validation has been done for some benchmark problems availed from the literature. The system yielded encouraging results in terms of optimized decision variable values. Though the package has given satisfactory results at academic level, the package needs to be field tested for its adaptability and usefulness.*

Key Words: **RSSI, GPS, Node, Maximum Likelihood Theory, Water Fall Model**

1. INTRODUCTION

In the last decades, the numbers of mobile devices and applications (from PDA embedded cellular phones to wireless sensor networks) have boomed. The main reason for this is the availability of cheap wireless electronic devices which, when used with low cost micro-controllers, enables the appearance of low power communication nodes. In many wireless applications, apart from connectivity, some other characteristics, such as node location measurement, are desirable to provide a complete service.

In wireless sensor networks, the system must not only provide the measurement of a certain magnitude, but its location as well. Let us suppose that this kind of network is used to measure the temperature in a building. The fact that sensor A measures a temperature of T degrees, is meaningless if we do not know where this node is.

- In many medical facilities, the rapid location of doctors is needed to give a better service to patients. Wireless devices (PDAs or cellular phones) may be used to decide who should attend each emergency in this scenario.
- In big offices, where wireless LAN enabled laptops are heavily used to enable workers to move around, it is also useful to locate each laptop, to accelerate the search process of an employee.
- At airports or ports, there are huge stocks, where thousands of containers are kept. If these containers were provided with a wireless device, the port authority could track its position, and the space management in these facilities could be eased.

In Ad Hoc networks, the geographical topology may be used to route datagrams more efficiently and to save battery power in every node.

Numerous location-tracking technologies are available today. They range from Global Positioning Systems (GPS) to the cell-of origin in cellular communications to wireless LAN access points to base station triangulation. Combined with the massive adoption of pervasive computing devices, they enable an important class of mobile commerce applications, such as location-sensitive billing and queries, targeted advertisement, and retail store navigation.

Methods using ultrasound or lasers achieve high accuracy, but each device adds to the size, cost, and energy requirements. For these reasons, such methods are not suitable for sensor networks. An inexpensive RF-based approach with low configuration requirements has been studied. But received signal strength indicator (RSSI) has a larger variation because it is subject to the deleterious effects of fading or shadowing.

An RSSI-based approach therefore needs more data than other methods to achieve higher accuracy. However, collecting a large amount of data causes an increase in traffic and in the energy consumption of sensors and decreases the lifetime of sensor networks.

Furthermore, increasing the data collection time has a negative influence on realtime operation of the location information collection method. Considering this background, we are studying a localization system that estimates the position of targets by using RSSI in sensor networks.

In wireless sensor networks, it is important to keep energy consumption low, so IEEE 802.11 for wireless LANs, which was designed for high-power devices such as PCs, is not suitable for wireless sensor networks.

1.1 Purpose

The purpose is to implement the localization algorithm, which can estimate the position of the nodes or tags for an indoor environment using RFID technology and Received signal strength as raw data.

1.2 Problem Description

Let us assume, there are N wireless nodes distributed in a geographical area, whose exact locations in the scenario are known. These nodes will be referred to as RFID readers. These readers have a relatively simple radio interface to communicate among them, which allow not only data exchange but the measurement of the power of the incoming signal as well (RSSI). Another wireless node has also been deployed in the scenario, but we do not know its location. We shall refer to this node as the unknown node. The aim of this system is to estimate the exact location of the unknown node using only the RSSI measurements and the known positions of the readers.

1.3 Proposed System

Location estimation of a node (signal emitter) can be done based on the strength of signal the emitter emits. This class of algorithms is based on the RSSI-maps generated by each static wireless node. In particular, this map takes into account the location of the static nodes as well as the topology and morphology of the environment including wall and static objects. The most popular tracking systems in this class are the RADAR and MoteTrack tracking systems.

The RSSI-map is obtained either through an analytical model of propagation of the radio signal or by a series of measurements. The analytical RSSI-map can be provided by standard tools like ray-tracing, but it does not take into account small objects like tables and shelves, or dynamics in the environment, thus possibly leading to poor performance. The empirical RSSI-map, instead, better represents the real situation, but requires an extensive set of experiments.

These algorithms are based on the fact that a radio signal attenuates as it goes further from the emitter. If the emitted power is known, measuring the incoming power at the receiver, the distance between the two of them can be estimated. Nevertheless, the medium exerts a substantial influence on the arriving signal's power: obstacles attenuate the signal and produce reflections, other signals or even the reflections of the signal of interest may interfere with the emitted signal, which alters the signal's power, etc. In order to overcome these problems, several strategies have been developed.

In some cases, a signal strength map of the geographic area to cover may be empirically measured. Thus, a database is built and when a target node reads the power of the beacons' signals, it can find its own location in the database.

In other cases, the detection range of the beacons may be treated as an area in which the target node may be. The detection of the target node by a beacon means that the target node is within the detection range of the beacon, in an area of known dimensions (the contrary may not be true, due to the effect of obstacles). If several beacons have detected the target node, the area where it might be can be reduced.

For indoor environments, a simple yet effective method has also been developed, to locate the target in a certain room of a building. In this system, the target node has an IR emitter, which sends IR frames in all directions. In every room there are one or more beacons, which detect these IR rays. If a beacon has received the IR signal, the target is in the same room as the beacon (IR cannot cross walls and suffers from poor wall reflections).

Features:

1. It is an effective algorithm which can locate target object or tag or node when something in the environment changes or when the location system moves from one location to another.
2. The algorithm described provides location estimation even when the distance measurements are not reliable, due to the errors produced by reflection, attenuation or interference with other signals.
3. It does not need any extra mechanical system that moves the antenna or an antenna array.
4. It is of low cost.

In our system, we propose a trilateration approach to determine the position (two dimensional location: X and Y Coordinate) of a wireless device using received signal strength indicator (RSSI), received from a fixed set of access points with known locations.

The proposed algorithm assumes that the distances estimated in first phase are prone to errors. In the second phase, it draws circles centred at the RF access points. The RF access points have known locations. The radius of each circle denotes the estimated distance from the measured signal strength. While estimating the location of mobile user, the algorithm awards higher weightage to the point of intersection of circles obtained from stronger received signal strengths. The proposed algorithm differs from the previous works in that,

(1) It considers all received RF signals.
(2) It awards higher weightage to stronger signals in location estimation.
(3) Two levels of trilateration have been proposed. The first level is applied to all possible pairs of circle and

the second level is applied to points obtained in the first level.

(4) It tries to find the most probable location of the mobile device at all levels.

(5) It employs Maximum Likelihood Theory in order to reduce estimation errors.

1.4 Working Overview

We consider a system in which sensors estimate the position of a target in an observation area. The target node is a wireless device that sends a packet to three or more sensor nodes, which measure the received power. If there are multiple targets, each packet includes the target's ID. After receiving a packet, sensors measure RSSI and send the results (sensing data) to the sink node, which calculates the target position from the sensing data. An outline of this localization system is shown in Fig. 1.

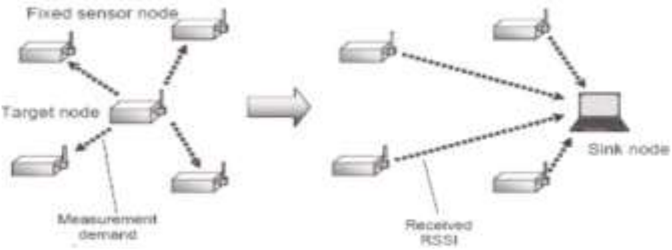

Fig 1: Working Overview

1.4.1 Sensor node placement

We assume that all sensor nodes have already been deployed and that they do not move. Sensor nodes are assumed to know their own position. There are two ways in which a sensor node can learn its position: 1) A manager registers the sensor node's position in the sink node's database. 2) A manager places a few beacon nodes that know their own positions, and a sensor node estimates its position by using information from some of the beacon nodes. A System based on such beacons can handle a lot of randomly placed sensors.

The proposed algorithm comprises two phases. In the **first phase**, the distance between the wireless device and each access point is estimated based on the received signal strength. In the **second phase**, the location of mobile device is estimated based on its estimated distances from various access points and position of the access points.

1.4.2 Distance Estimation Phase

In this phase the distance between mobile device and access point (AP) IS estimated based on the signal strength received by the device. The power of the transmitted signal from the AP is different from that received at the mobile device, due to attenuation and other factors. The received signal strength indicator (RSSI) of an AP at a location is an indicator of how strong the signal from that access point is at that location. The received signal strength is measured in dBm.

We are using Trainable algorithm that entail the measurement of certain fixed locations in advance and from those measurements try to determine the location on which the received signal strength's look the most like the measured values of the training session.

1.4.3 Data collection

Sensors receive packets from targets, measure the power of the packet, and transform the RSSI into distance for use in theoretical or empirical models. The packet includes a target ID and a packet number. By reading the packet, a sensor gets the target ID, packet number, and the distance between the sensor and the target. It then sends the following data to the sink: sensor ID, target ID, packet number, and sensor-to-target distance.

In the given table below the RSSI values are measured in terms of db and also average of all the RSSI values at different angles had been calculated. Also the distance has been estimated on the basis of average RSSI values.

Angle (in degree) → / Distance (in meters)	0	45	90	135	180	225	270	315	360	Average
	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value	RSSI Value
1 mts	61.0	62.5	62.0	61.0	72.5	72.5	61.0	56.0	60.0	63.16
2 mts	63.5	78.5	62.5	61.5	67.5	67.5	60.0	60.5	70.0	65.55
3 mts	63.5	73.0	78.5	67.5	67.5	78.5	73.0	63.0	68.5	70.30
4 mts	70.5	76.0	74.5	71.0	73.0	72.5	69.5	71.0	68.5	72.05
5 mts	70.5	74.5	74.5	74.5	72.0	73.0	72.0	70.0	71.0	72.44
6 mts	72.5	74.0	93.5	72.5	69.0	72.0	78.5	68.5	72.5	74.88

Figure -2: Data Collection

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1.4.4 Location Estimation Phase

In this phase the location of the mobile device is estimated based on the estimated distances from fixed access points. Suppose there are N access points in indoor environment, whose locations (X and Y Coordinates) are known.

Let us assume that (Xl, YI), (X2, Y2), (X3, Y3), (XN, YN) are the coordinates of N access points. The estimated distances of mobile device from those access points are dl, d2 .., dN respectively. The circle centered at the access point is denoted by (X, Y, d), where (X, Y) is the position of access point in two dimensional coordinate system and d is the estimated distance between access point and mobile device.

The procedure of location estimation of mobile device is as follows:

STEP 1: Any two access points, let us say ith and jth , are chosen. The two circles (Xi, Yi, di) and (Xj, Yj, dj) intersect each other at two points A and B as shown in figure 1. It should be noted that the points A and B can be two different points or same point also. The two circles not intersecting each other at real point(s) is not taken into consideration in this step.

Assuming the estimated distances from these two access points are correct, the mobile device could be located at either point A or at point B. Let us assume the third circle (Xw, Yw, dw) cuts the arcs AA1B and BB1A at two points D and C respectively.

Ideally, the third circle should cut the two circles at either point A or at point B. But in reality, it may not be the case since the estimated distances might not be equal to the actua distances. If these two points D and C are nearer to the point B than to the point A, it can be assumed the location of mobile device to be lying within area BDC. But such an assumption will not be valid if the fourth circle (Xz, Yz, dz) cuts the arcs AA1B and BB1A at two other points E and F which might be nearer to the point A than to the point B.

Let us assume the circle (Xk, Yk, dk) where k ≤ N and k ≠ i, j cuts both arcs AA1B and BB1A at two points Pk1 and Pk2 respectively. It may also be possible that the circle cuts both arcs at the same point. The circle which does not cut both arcs is not taken into consideration for this step. Now I consider the two polygons, the first being formed by point A and all other intersection points on arcs AA1B and BB1A other than the point B, and the second being formed by point B and all other intersection points on arcs AA1B and BB1A other than the point A.

We explain this with the help of figure 1. For simplicity of understanding, we have considered four circles only. The two polygons formed are AEDCFA and BDEFCB. The weighted centroids of these two polygons are calculated as explained in the next step.

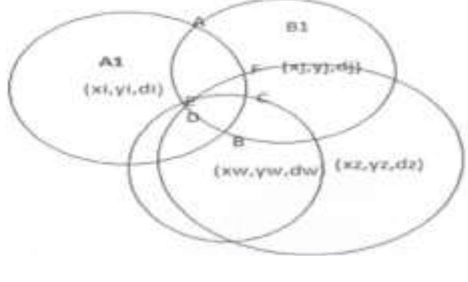


Figure 3: Intersection of Circles

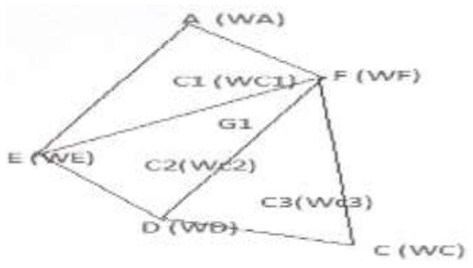


Figure 4: Polygon

STEP 2: In this step the weighted centroids of two polygons are calculated. In a polygon, the weight assigned to a vertex is the sum of RSSI values of access points whose corresponding circles intersect at that point, as received by the mobile device. The procedure of calculating weighted centroid of a polygon is explained with the help of Figure 3. The same approach is applied to calculate weighted centroid of a polygon formed by any number of intersection points.

Figure 4 represents the enlarged view of polygon AEDCFA. The weights assigned to vertices A, E, D, C, and F are W_A, W_E, W_D, Wc, and W_F respectively. First of all the polygon AEDCFA is triangulated. The triangles formed are +AEF, +EDF and +DCF with weighted centroids C_1, C_2 and C_3 respectively. The weighted centroid of a triangle is calculated as follows:

X_{C1} (X Coordinate of C1) = $(X_A*W_A+X_E*W_E+X_F*W_F)/(W_A+W_E+W_F)$

Y_{C1} (Y Coordinate of C1) = $(Y_A*W_A+Y_E*W_E+Y_F*W_F)/(W_A+W_E+W_F)$

Where X_A and Y_A are X and Y coordinates of vertex A and so on. Weighted centroids C_2 and C_3 are calculated similarly. The weighted centroid "G" of a polygon having 'n' number of triangles after triangulation is calculated as follows:

$$X_G \text{ (X coordinate of G)} = \frac{\sum_{i=1}^{N} X_{Ci} W_{Ci}}{\sum_{i=1}^{N} W_{Ci}}$$

and

$$Y_G \text{ (Y coordinate of G)} = \frac{\sum_{i=1}^{N} Y_{Ci} W_{Ci}}{\sum_{i=1}^{N} W_{Ci}}$$

where X_{Ci} and Y_{Ci} are X and Y coordinates of centroid of i^{th} triangle and W_{Ci} is the weight assigned to the centroid of that triangle. The weight assigned to the centroid of a triangle is equal to the product of area of that triangle and sum of weights assigned to its vertices. Thus the weighted centroid "G1" of polygon AEDCFA is given by:

X_{G1} (X Coordinate of G1) = $(X_{C1}*W_{C1}+X_{C2}*W_{C2}+X_{C3}*W_{C3})/(W_{C1}+W_{C2}+W_{C3})$

Y_{G1} (Y Coordinate of G1) = $(Y_{C1}*W_{C1}+Y_{C2}*W_{C2}+Y_{C3}*W_{C3})/(W_{C1}+W_{C2}+W_{C3})$

where W_{C1}, W_{C2} and W_{C3} are weights assigned to centroid C_1, C_2, and C_3 respectively. Similarly the weighted centroid "G2" of polygon BDEFCB is calculated. If |AG1| is less than |BG2|, G1 is taken as the probable location of the mobile device in this step. Otherwise, G2 is taken as the probable location.

STEP 3: Steps 1 and 2 are repeated for all combinations of two circles. Since there are N access points, a maximum of N(N-l)/2 such combinations are possible. Those combinations are not considered where the two chosen circles do not intersect each other. In this way we will get up to N(N-l)/2 such probable locations of the mobile device. Finally the weighted centroid of all such probable locations, let us say L, is calculated as described in the previous step. This gives the most probable location or, in other words, finally estimated position of the mobile device.

2. IMPLEMENTATION OF LOCALIZATION SYSTEM

Figure 1 depicts the system design for this real time location tracking system. The system consists of a set of static reference nodes at preset coordinates, and a blind node carried by the mobile target. Blind node broadcasts signal to the reference nodes nearby and reference nodes reply by sending their RSSI values at that distance back to the blind node. Blind node then selects the best eight highest RSSI signals (from 40dBm to -95dBm) to be dispatched to the base station, which is connected to a laptop, using RF transmission from CC2420 radio chip. Refining algorithm and estimation of blind node's position are implemented in the base station after the reference node’s RSSI data (RSSli) and position information (Xi, Yi) are received. Estimated position is continuously updated and visually represented on a monitoring application. The position information can be accessed remotely from other personal computer (PC) via

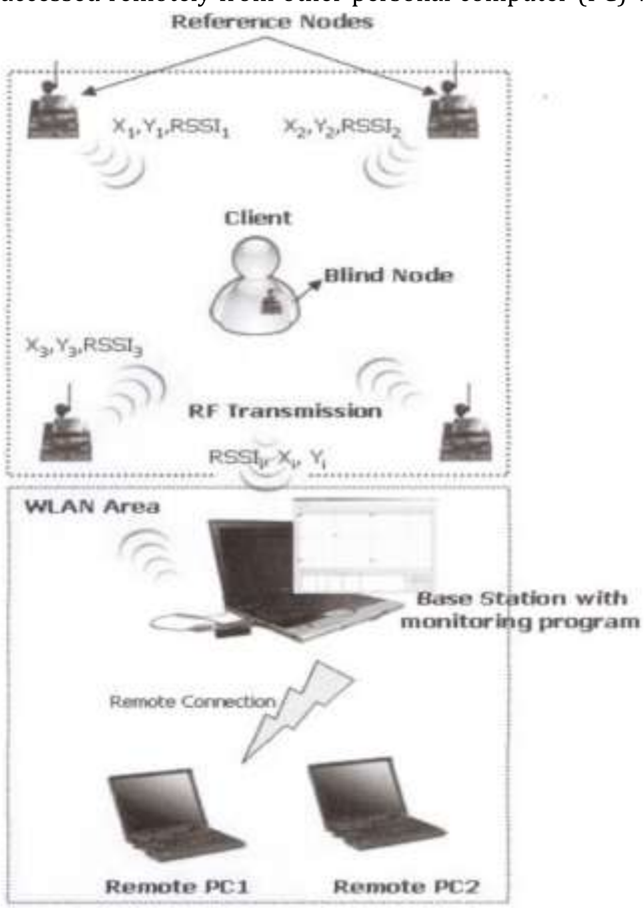


Figure 5

Table 1 Specifications of Ubiquitous(RFID) Device.

Radio frequency band	2.4 GHz
Transmission speed	250 kbps
Modulation	O-QPSK
Spread spectrum	DS-SS
Antenna	1/4λ monopole
Transmission power	1 mW

Figure 6: Ubiquitous RFID device equipped with the optional serial port

3. SYSTEM ANALYSIS

In any tracking system, the area to be tracked has same importance as the objects to be traced. Observation area has direct impact on budget of the installing the system. If the observation area is large, then the number of RFID readers required to read the data from tag will also increase. So we need to make a optimum usage of hardware.

Number of RFID tags depends on the number of objects to be tracked. Reader’s placement also has impact on the success of system. If the readers are placed in the corners or too close to walls, then the readers cannot be used at optimum level. So readers are to be placed in such a way that it should be able to receive signals from all the directions from the RFID tags.

RFID tags will be attached to the objects to be tracked. Since these objects may travel through the area, the tags are to be attached firmly to the objects.

Finally since all the readers will transmit the data they get from tag to the central computing system, an computer system with efficient data storage must be present. Proposed system should be implemented in this system. It should have capable to get the data from multiple readers and to store them continuously in the database.

In order to give the user a real time experience, an effective User Interface must be provided to monitor the movement of objects. This User Interface must also provide some functionality like adding information about readers and tags etc.

3.1 Requirements

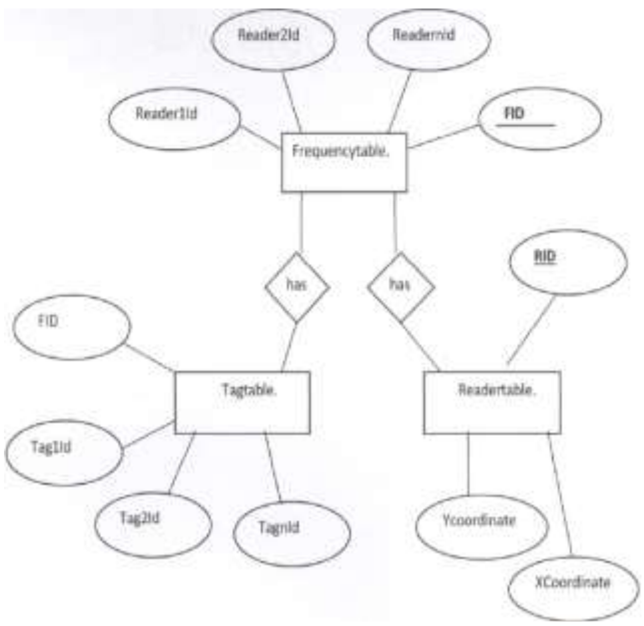
By studying the prevalent system in the Organization, the requirement for the software has become crystal clear. The main requirement are the identifying the objects to be traced and the number of RIFD tags, RFID readers and to perform the data collection to store the distance with respect to RSSI and to create a database that should be manageable even if the database size grows into a huge one since the data from readers are taken for every 3 seconds.

4. SYSTEM DESIGN

4.1 ER-Diagram

There is no much scope for database in our system. Our system needs only strong mathematical model that can furnish the raw data into the final required output.

Behalf of this some handful of data are to be stored into the database. Much importantly the "Received Signal Strength" which will be calculated by readers and which is sends to the central computer system where all these raw data are stored.



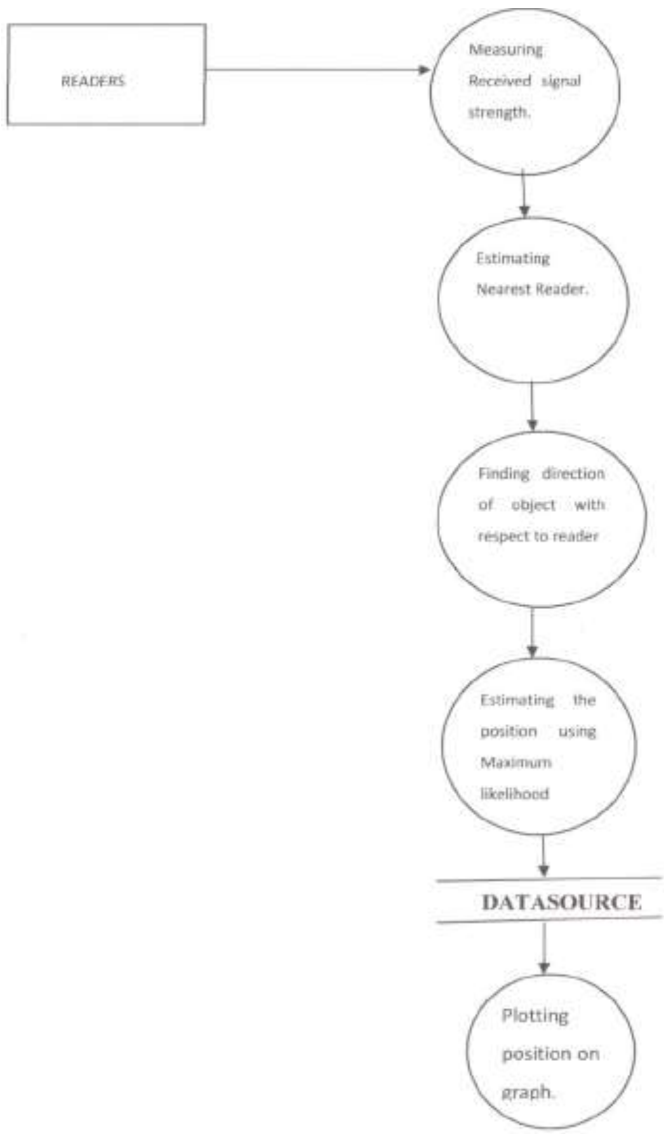
There are mainly 3 tables in our system.

1) **Reader Table**: This is used to measure the incoming signal strength of the RFID tags which can be differentiated by giving each reader a unique Identification number.
Each reader has given a fixed position coordinates where the readers are placed. Position of a reader can be expressed in terms of coordinates in a observation area. So each reader position can be expressed in terms of coordinates, which consists of two values xcoordinate, ycoordinate.
So for each reader two data to be stored that is always unique.
Each table entry in this table consists,
Readerld: A unique Identification number of type varchar
xcoordinate: xcoordinate of reader of type float.
Ycoordinate: ycoordinate of reader of type float.

2) **Tag Table**: RFID tags that are attached to the object being in observation can be differentiated by giving each tag a unique identification number. So each reader can identify the signal coming from a particular tag properly.
The estimated position of a particular tag is also an important data that is to be stored for further process.
So each tag consists of two data namely:
Tagld: unique identification number of type varchar.
xcoordinate: estimated xcoordinate of the object of type float(inversely the xcoodinate of tag attached to it).
ycoordinate: estimated ycoordinate of the object(inversely the ycoodinate of tag attached to it).

3) **ftable**: Signal strength observed by readers are the crucial input for our system.
These signal strength data of multiple tags observed by each reader is to be stored somewhere. Based on these data, further calculations have to be done.
These signal strength data is stored in this table namely ftable.
Fid: This table consists of a primary key called 'fid' – frequency ID, which has auto incrementing Property. Remaining fields store the rssi values observed by each reader.
This 'fid' field is used as foreign key in other tables.

4.2 Data Flow Diagram



Data flow happens in the following way:

1) Firstly source of data is readers which send RSSI to our system. This data is stored in table according to each reader's field in ftable.

2) RSSI observed in the previous step will be converted into distance. RSSI and distance is inversely proportional. If RSSI is strong (greater) then the distance is less. If RSSI is weak, then the distance is larger. There are many methods to convert the signal strength into distance. Since we are using trainable method, we will decide the distance of tag from the previously observed distances from doing survey of observation area.
3) After converting the raw RSSI into distances, nearest readers from the tag (i.e tag which receives strong signal when compared to other readers.) will be selected one by one. Intersecting points of all these virtual circles drawn by each reader is calculated.

4) After getting these n points "trilateration" method is used to find the center point where tag is can be present.

5) Since RSSI value can vary for many obstacles, we have do take a precautionary measures to rule out the errors in the data. Here we are using Maximum Likelihood theory to rule out the errors.

6) Finally the estimated position of the tag will stored in the database for further use, also it will be plotted on the graph.

4.3 Cost/Benefit Analysis

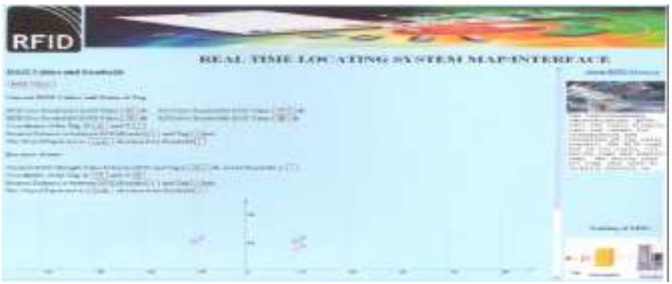
Cost/Benefit analysis is performed to ascertain whether the cost in the system match with the benefits it will provide. The various kinds of costs incurred in the development and implementation of the system include:
• **Hardware Costs**: Cost incurred in purchase of hardware, i.e., RFID readers, RFID tags, computer and its peripherals.

More number of readers lead to more input of data i.e RSSI, then clarity in estimating position of tag will be increased. Cost of installing monitoring system will be reduced since we are using the algorithm to estimate the position. This algorithm requires minimum number of readers to estimate the position of tag. So inversely it leads to reduction in investment on readers.

5. INPUT AND OUTPUT DESIGN

Screen shot 1

This Snap shot shows the user interface of our system.
The observation area is divided into coordinates and will be represented in the form of graph.
This helps the user to monitor the movement of tag in the observation area.



Screen shot 2

Above snapshot shows the readers showing RSSI and the estimated position of the tag.
As the tag moves the corresponding RSSI will get changed in each reader and estimated position will be updated to current location.

6. CONCLUSIONS

In this system we have implemented a RSSI based localization algorithm based on Maximum Likelihood Theory that uses only received RF signals from various access points and the location of access points.

This algorithm takes into consideration all visible access points locations and received signal strength from those access points with more weightage being awarded to the one with stronger and less attenuated signal. It is a kind of non-trainable algorithm that does not require any storage of location map. The implemented algorithm is basically a two phase algorithm. In the first phase, the distance between mobile device and access point is calculated based on the received signal strength. This phase is most error prone where it is quite difficult to get real distance from any mathematical modeling of indoor environment. In the second phase, the algorithm tries to remove the errors occurred in first phase by using weighted triangulation approach.

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