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Behaviors of Antenna Polarization for RSSI Location Identification

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Abstract— Real-time position localization of moving objects in an indoor environment is an encouraging technology for realizing the vision of creating numerous novel location-aware services and applications in various market segments. An off the shelf development platform that uses Radio Signal Strength Indication (RSSI) based location tracking technique is studied. In this paper we investigate the affects of polarization on the accuracy of an indoor location tracking system. We present an approach to increase system accuracy based on this investigation. We established a model for determining range from RSSI and showed that the model fits our own experimental data. The model includes parameters used to account of environmental effects and we use the least squares method of determining the parameter values. Antenna polarization angle will affect RSSI and thus range accuracy. We empirically show that the model is still valid for polarization mismatch but with different environmental parameter values. A method based on semi-automated trail and error is proposed as a better method for selecting the environmental parameters. Using experimental data we show that if we adjust the model parameters to account for polarization angle then we can increase location accuracy. A practical solution for determining the polarization angle is with an accelerometer. The addition of an accelerometer could also be used to increase the battery life of the node.

Keywords—Location, RSSI, RFID, Sensor Networking, Zigbee

I. INTRODUCTION

Determining the location of a node in a wireless network has real commercial uses. An example is determining the location of mobile assets like equipment and people in a building. Such systems have found there way into a number of hospitals to track the location of medical equipment, staff and patients [10]. These systems have also been used to prevent loss of equipment or restrict access to areas.

This type of location tracking system requires reliable low cost, low maintenance solutions. It is not acceptable to be changing or charging batteries at regular intervals like you would have to with a GPS based system.

A. Location Identification

Determination of location can be done in a number of ways including: triangulation, trilateration and

multilateration.

Triangulation requires knowing the angle between nodes. However this is generally not an option for this type of wireless network as isotropic antennas tend to be used for both practical and cost reasons. For the 2D case the location of an unknown node can be determined by trilateration. This requires 3 nodes of known location. The 4th node of unknown location can be determined if the distance to the reference nodes is known. However we can only determine the distance within a certain degree of certainty. This affects our ability to accurately determine correct location. By using more reference nodes we can partially average out this uncertainty.

B. Range measurement

Two methods of determining distance (referred to as pseudorange in GPS systems) are based on: propagation time and Radio Signal Strength (RSS).

RSSI based distance calculations add no extra cost to the device. But do require additional power but much lower than that of GPS. However RSSI measurements give lower accuracy range results due to variable Attenuation (path loss) and fading effects with high variance.

In the case where there is a direct path between a Transmitter and receiver. The receiver signal power, P_r is related to distance, d , by the inverse square law.

$$P_r \propto d^{-2} \quad (1)$$

However this is an ideal case for a point source. In the real world the signal power often decays at a faster or slower rate, and we can express this as:

$$P_r \propto d^{-n} \quad (2)$$

Where n is the loss exponent. An expected form of the relation between distance and receive power simplified for the case of a one meter reference distance is [7]:

$$Pr(d) \text{ (dBm)} = A - 10n \cdot \log_{10}(d) \quad (3)$$

Where A = Received power in dBm at one meter, and n is the loss parameter (or loss exponent), d is the distance between the transmitter and receiver. In real life the values of n and A can only be determined empirically [7].

For the linear polarized case, the EM field remains in the

same plane as the axis of the antenna. When the antenna produces an electric field that remains in a plane parallel with respect to earth the polarization is said to be horizontal. Likewise when the electric field remains in a plane normal to earth the polarization is vertical. To receive maximum power the receiving antenna polarization must be in the same as the transmitting antenna. The loss due to misaligned antenna polarization is:

$$\text{Polarization Mismatch Loss (dB)} = 20 \log(\cos \theta) \quad (4)$$

where θ is the polarization angle between the antennas [3].

II. DEFINITIONS

The following is a list terms used in this paper:

Node: An RF transceiver in the network.

1-hop: Direct communication between source and destination nodes in the network (i.e. the data not routed through other nodes.)

Blind Node: A node that calculates its own position.

Reference Node: A node at a known fixed location (sometimes referred to as a beacon)

Dongle: A node that is connected to a computer and configures and monitors the Blind and Reference nodes.

RSSI: Received Signal Strength Indicator, an approximation of RF signal power as measured by the RF transceiver.

CC2431: Texas instruments RF transceiver. [2][16][17]

The CC2431 is an inexpensive 2.4 GHz IEEE 802.15.4 compliant RF transceiver from Texas Instruments. It combines a 8051 microcontroller and a RF transceiver with DSSS (Direct Sequence Spread Spectrum) modem into one package. The CC2431 also includes a hardware 'Location Engine' that can calculate the nodes position given the RSSI and position data of reference nodes. The main inputs to the location engine are the; (x,y) location and RSSI of reference nodes, and the parameters A and N used internally to convert RSSI values into ranges. The output of the 'location engine' is the calculated (x,y) position. The 'location engine' uses an unspecified technique optimized for minimum resource use and speed. The precision for the (x,y) location coordinates is 0.25meters. The precision of A is 0.5dBm, while n uses an index into a lookup table that limits its precision. The range of valid RSSI to the location engine is 40 to 81 (in -dBm), so RSSI values higher than -40dBm must be set to -40dBm.

The CC2431 has a built in RSSI register. The RSSI value is always averaged over 8 symbol periods (128uS). The RSSI value can be used to determine the RF signal Power with reasonable accuracy.

One problem with the RSSI is that a narrow band interferer inside the channel bandwidth can affect the RSSI value [15]. Thus it is important to only use the RSSI value on valid error free packets as bad packets have a higher

probability of being subject to due to this type of interference.

III. RANGE MEASUREMENTS

Determining distances between nodes is key part of location determination by multilateration. The 'location engine' uses the following model for the relation between distance and RSSI:

$$\text{RSSI} = -(10n \log_{10}(d) + A) \quad (5)$$

Where RSSI is in dBm, n is the path loss exponent, d is the distance in meters and A is the RSSI in -dBm at one meter.

By measuring the RSSI at different distances the values of n and A can be determined. This can most easily be done and understood by letting $D_{\log}=10\log(d)$. Then we can rewrite this as a more simple and more obviously linear equation:

If we plot the least squares line, A is the value at zero crossing ($10 \cdot \text{LOG}(1\text{meter}) = 0$), and n is the slope of the line.

Unfortunately effects like multipath fading often result in the average RSSI value at a particular distance not converging on the least squares line of best fit as the number of samples increases. Meaning that at a particular location the average RSSI will also fluctuate with time. The values of A and n are both affected by environmental factors and vary significantly between different locations as shown in Fig 1.

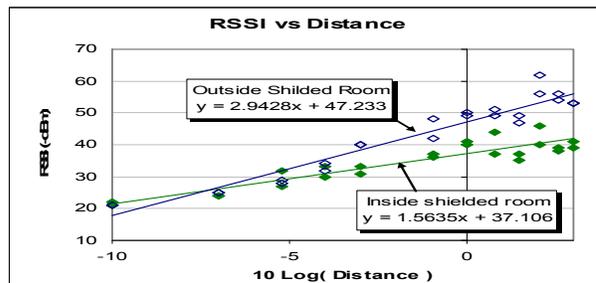


Fig 1. Environmental effects are not just caused by obstacles. Greater reflections in the shielded room cause higher multipath effects. In this case the small size of the room means the primary multipath signals arrive with net constructive superposition.

A. Polarization

Antenna polarization does affect the RSSI value and thus can affect the outcome of location identification. A measured example of how polarization affects average RSSI over a range of distances is shown in Fig 2. The polarization of the system is identified in an abbreviated form where the first letter identifies the polarization of the transmit antenna and the second letter (or number) is the polarization of the receive antenna. The abbreviations used are V (vertical), H (horizontal), 45 (45 degrees).

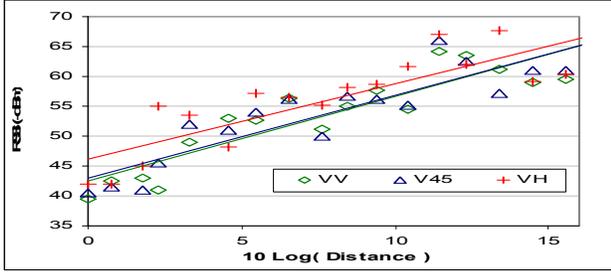


Fig 2. RSSI vs. distance (range). Measurements were taken in a long hallway of varying width. The transmitter is fixed at a location and the antenna is always vertically polarized. The RSSI is recorded for receive antenna polarization of vertical, horizontal and 45 degrees (i.e. Parallel (0°), orthogonal (90°) and 45 degrees)

For our experimentation on location accuracy we study only a single room. The RSSI vs distance measurements were observed along a diagonal of the room and the results are shown in Fig 3.

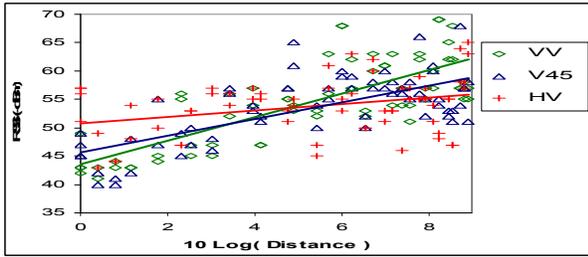


Fig 3. Measured RSSI vs Distance with 3 polarization setups. Note that in all cases there is a high variance between the least squares line of best fit and the 32 sample averaged data.

IV. LOCATION IDENTIFICATION

The testing of polarization effects on location identification were performed with the CC2431DK Development Kit from Texas Instruments. Location engine results were observed using the PC application ‘Z-location Engine’ downloaded from the Texas Instruments website.

The important thing to note about the reference system is that during RSSI measurements, the blind node is the transmitter and the reference nodes are the receivers. The blind node calculates its own position, reducing the network traffic that needs to be sent to the Dongle.

A. Test setup

For testing a room (measuring 5.5×8 meters) was cleared and eight reference nodes were arranged around the perimeter of the room. For ease all nodes were placed at ground level. A 2-dimensional Cartesian coordinate system with a negative y axis is used to define the position of the nodes in positive space.

Assuming that the nodes are normally located on walls, then it is best to use Vertical polarization. This is because real isotropic antennas produce little power in the direction of the antenna axis. The test follows these assumptions and

keeps the reference nodes fixed for vertical polarization and the blind nodes are changed between vertical and horizontal polarization.

B. Range measurement test

As an example of range measurement accuracy, the blind node was placed at the centre location and the RSSI data was collected by monitoring the Zigbee network packets. The result of this test is shown in Fig 4. The nodes were all running the Zigbee Z-location reference firmware v1.4.2 provided by Texas Instruments as part of the Z-Location software for the CC2431DK.

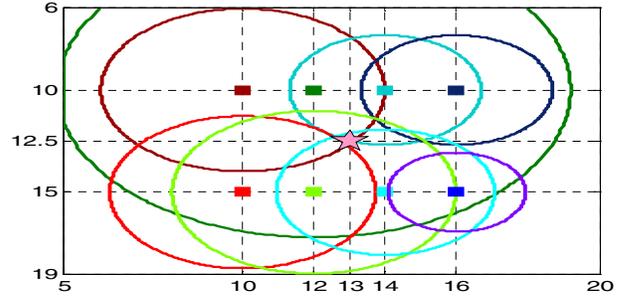


Fig 4. Graphical representation of location identification problem with real data. The small filled squares represent the location of the reference nodes. In this case the blind node is in the center of all the reference nodes at (13,12.5) and is marked by a star. The circles represent the distance based on averaged RSSI measurements using (5), with parameters $A=44$, $n=3.5$. Ideally all circles should intersect at the point (13, 12.5).

It was found that the A and n parameters calculated in the previous section gave very poor location accuracy. Increasing the value of n tended to give much better results. This can be explained by the high variance of the RSSI measurements and the logarithmic relationship between RSSI and distance. Fig 5 shows the relation between n and range (distance) error that helps makes this concept clearer.

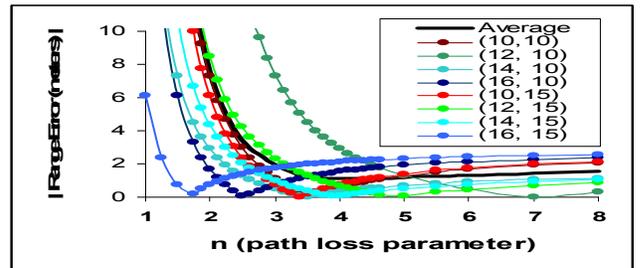


Fig 5. RSSI based range error vs. path loss parameter (n), based on the same measured RSSI data set as Fig and keeping $A=44$. The error is calculated as the difference between calculated range and actual range. It is seen that a positive change in n from the point of minimum error gives a lower range error than the same change in the opposite direction.

1) Location accuracy

The accuracy of the location system is defined here as the displacement error in meters between the actual (x_a, y_a) position and the measured (x_m, y_m) position of the blind node,

and is calculated using the equation:

$$\text{Displacement Error} = \sqrt{(x_m - x_a)^2 + (y_m - y_a)^2} \quad (6)$$

The location accuracy was observed for parallel and perpendicular polarization at a number of different actual locations. As predicted in the previous section the best average result for perpendicular polarization occurs for higher values of A and lower values of N ($A=48$, $N=12$) compared to that of Parallel ($A=44$, $N=20$). If the parallel optimized values ($A=44$, $N=20$) were used to calculate the perpendicular case, then the average error would increase from approximately 1.5 meters to 1.7 meters, that equates to a 0.2 meter improvement. Selecting the best compromise ($A=46$, $N=18$), the advantage of adjusting the parameters based on polarization is reduced to 0.1 meter accuracy gain.

We will be doing further testing to prove that this is the case.

C. System Calibration

To mathematically determine the best parameters (A and n) to use we would need to have a model that accurately predicted the average RSSI variation in a particular area of interest (and know the routine used in the ‘location engine’).

In short, the method is to calculate the location over a sweep range of the A and n parameters at different polarizations, then pick the best result(s).

There is only a limited set of discrete parameter values usable in the ‘location engine’ (20 values of A and 31 values of N) it is possible to try them all then process the results and pick the best set.

D. Antenna Polarization Determination

The antenna polarization can be determined easily by the addition of a 2-axis accelerometer. An accelerometer is a device that converts the mechanical energy of acceleration into an electric signal. Gravity is a fixed acceleration towards the center of earth. When the device is aligned so that its sensing axes are normally parallel to earth, the angle can be calculated as $\text{ARCSIN}(A_x / 1g)$, where A_x is the value from the accelerometer.

The addition of a 3-axis accelerometer would also allow for other benefits. It could be used to reduce the power consumption by only performing location measurements while moving and powering down the node when stationary.

By mathematical integration of the acceleration data the velocity and displacement can also be calculated.

V. CONCLUSION

In order to obtain optimal design for a RSSI based location system, we have shown experimentally that location accuracy of our system is mostly influenced by the accuracy of the range measurements. The RSSI measurement is affected by many factors such as multipath

fading, obstructions and antenna pattern and polarization. Our model has two major parameters that are used to account for all these issues. However we can extract a little more accuracy from the location system by accounting for antenna polarization. To do this we can either take parameter values that are a compromise or we actively track the polarization mismatch and adjust the parameters to suit. Due to the high variance and low increase in accuracy it is probably only worth considering storing two sets of parameters. One set for perpendicular (90°) mismatch and the other for parallel (0°) mismatch. A suitable method for actively determining antenna polarization is with an accelerometer. The most useful of which, is to suspend location tracking activities when the node is stationary in order to conserve battery power.

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