

Zigbee RF Signal strength for indoor location sensing – Experiments and results

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Abstract - This paper discusses about the variation of signal strength due to the presence of obstacles in indoor environment. An experimental analysis of impact of various obstacles on ZigBee RF signal strength has been done. The results obtained by the analysis have been used to locate a user inside a smart home. The parameters like Received Signal Strength (RSSI), Link Quality Indication (LQI) and Packet Error Rate (PER) have been measured and analyzed. The location of the user is an important context, based on which various controls and services can be rendered. The objective of finding out the location is to provide various services and controls like location based luminance, personalized Heating Ventilation and Air Conditioning (HVAC) control systems. It was observed that the location accuracy was improved when the number of reference nodes was increased. In future location accuracy will be improved by combining ZigBee RSSI with GSM CellID and also by using better signal processing algorithms.

Keywords - Zigbee, RSSI, Packet Error Rate, Localization, Fingerprinting

I. INTRODUCTION

This paper discusses in detail about how RF signal strength is affected due to various obstacles that are generally found in indoor environments. The usual obstacles are materials like glass, wood, walls in addition to human presence. The analysis has been done to find out, if signal strength alone can be used to locate the user in order to provide various controls and services in indoor environment like smart home and buildings. The experiments have been done using two different radios RF230 and CC2420. The human presence also affects the signal strength to a greater extent.

Received signal strength indicator (RSSI) is a measure of the signal strength at the receiver expressed in dBm. It is usually five, eight or ten bit value depending on the hardware used. This RF signal strength parameter has been widely used for localization and tracking in indoors as it eliminates the requirement of additional hardware which in turn reduces the cost. Other measurements like Time of Arrival (ToA), Angle of Arrival (AoA) are also used. But time based methods have a disadvantage that line of sight is required to give a good level of accuracy which is not possible in indoor environments. According to our measurements round trip time of flight method did not give accurate results when the distance was small. But in RSSI based methods, the challenge is mapping of the signal strength to distance in presence of obstacles such as walls, human activity etc... The relation between the two has to be modeled as

accurately as possible for developing a precise localization system. In a densely populated and dynamic environment where the modeling is not possible fingerprinting algorithms are used. Fingerprinting has a disadvantage that it requires a large measurement database that needs to be frequently calibrated. To overcome the difficulty of large database, compressive sensing techniques are being proposed in the literature. The next section discusses the related work which is followed by other sections that explains the experiments and results obtained.

II. RELATED WORK

Many indoor location tracking systems have been developed based on various measurements of the RF signals. Of these Received signal strength is widely used for location sensing. There are two different types of localization, based on RSSI measurements. They are range based and fingerprinting localization. In range based location sensing a relation between the signal strength and distance is derived. The relationship is used for locating the unknown node by methods like Trilateration and Min-Max. Fingerprinting based methods have two phases namely offline (or training) and online. In this method the nodes are located by using algorithms like k-nearest neighbor, Support vector machines etc. The signal strength has to be analyzed using probability distribution and methods like kalman filters for improving the accuracy of location.

RSSI and Link quality indicator (LQI) are the two parameters well known for link quality estimation. In [2] it has been mentioned that reflection, scattering and other physical properties have an extreme impact on the RSSI measurement. There are three models for describing the distance – path loss. They are free space model, two ray ground model which adds reflection to free space model and log-normal model. The log-normal model has to be derived experimentally. The authors of [2] have done experiments on three different radios and compared the results. They have concluded that RSSI is a bad estimator of link quality.

A survey of wireless indoor positioning techniques has been presented in detail in [3]. Various measuring principles and algorithms have been presented in this paper. It has been mentioned that the time based location methods are not suitable in Non Line Of Sight (NLOS) conditions and RSSI is preferred in NLOS conditions. If fingerprinting based location sensing has to be done, algorithms like k Nearest Neighbors, neural networks, probabilistic methods, Support vector machines have to be used for location estimation. A comparison of localization systems such as UWB, GPS, Bluetooth, WLAN, and GSM has been presented.

Reference [4] proposes a virtual calibration procedure instead of doing a training phase for fingerprinting based location sensing methods. This method is not manual and makes use of measurements between the anchors. In our paper though the experiments are manual the measurements have been done using only the anchors and unknown node.

Paper [5] illustrates a technique to extract an estimate of velocity from signal strength. The characteristic footprints left by the motion of nodes in the network or motion of bodies external to the network have been exploited for movement detection. Experimental results have been presented using Micaz motes. The results are focused how signal strength is affected by motion of the motes. RSSI has been measured at different times and at different velocities. Our paper discusses how RSSI is varying due to obstacles inside a room. Results of [5] focus more on motion detection but our experiments focus on how to improve the location accuracy.

The authors of [6] discuss about the three techniques for automatic location sensing namely triangulation, scene analysis and proximity.

The authors of [7] have discussed about the various measurements, models and algorithms that are commonly used for device free localization. It has been suggested that device free localization is being developed which can be used to improve the existing Real Time Location Systems (RTLs). These methods use the fading characteristics of the RF signal strength for finding out the presence and location of the user. These are termed as sensor less localization as the user need not carry any radio for being localized.

It has been mentioned in [8] that fingerprinting algorithm cannot be used to track more than one user simultaneously. The impact of human presence on RF signal strength due to reflection, diffraction and scattering has been presented. Different models for establishing the relation between distance and signal strength has been described.

In the paper [9] experimental results show how the signal strength is affected by human presence and sensor node height has been presented. The variations in signal strength with and without movement has been discussed in detail. Using the results an approach has been proposed for intrusion detection. A threshold has been defined to detect the motion. It has been concluded that the proposed system can be used along with other surveillance system for better accuracy.

It has been proved in [10] that the location can be estimated in indoor environments up to accuracy of 1m using RSSI and ToA measurements.

III. EXPERIMENTAL ANALYSIS

This section describes the measurement setup that has been used for taking the RSSI measurements. A set of measurements has been taken separately for each obstacle. The obstacles such as wood, glass, wall and human presence have been considered for these measurements.

A. Experimental Setup

Two Crossbow's ZigBee motes (MicaZ and IRIS) have been used. Micaz has an eight bit Received signal strength

indicator (RSSI) and IRIS has a five bit RSSI. The motes have been programmed using TinyOS 2.x and NesC language. One node acts as a transmitter and the base station connected to PC acts as a receiver which forwards the received packets to the serial port of the PC. Further packet processing is done at the PC using JAVA programming language. The transmitter and receiver were both kept at a height of 1m above the ground level. These measurements were taken inside a 15 m x 3 m x 2.6m C-DAC's Ubiquitous Computing Lab.

B. Measurements

One mote was programmed as transmitter that sends a packet every 1 second. The other was programmed in such a way that it receives the packet sent by the transmitter, appends the RSSI value and its Node Id, then forwards it to the serial port. The distance between the transmitter and receiver is known. The received packet is parsed and the RSSI and distance value is stored in the database.

The above procedure was repeated for different distances between the transmitter and receiver. The measurements were taken initially in Line of Sight condition and later repeated by placing glass, wood and wall obstacle between the transmitter and receiver. The parameters that have been measured are Received Signal Strength Indication (RSSI), LQI and Packet Error Rate (PER). The RSSI values are recorded as hex values. Later these hex values recorded were converted to actual dBm values according to the datasheets of RF230 radios. Every packet transmitted is assigned a packet number to check for packet losses at the receiving end.

After the measurements a simple localization system has been tested by fingerprinting method with a single reference node and also with multiple reference nodes.

IV. MEASUREMENT RESULTS

In this section, the results obtained for various obstacles have been discussed. The measurements have been taken for both Line of Sight and Non Line of Sight conditions. The relationship between distance and RSSI has been obtained for each obstacle. The packet error rate has also been monitored along with RSSI in order to ensure that PER does not fall below 2%.

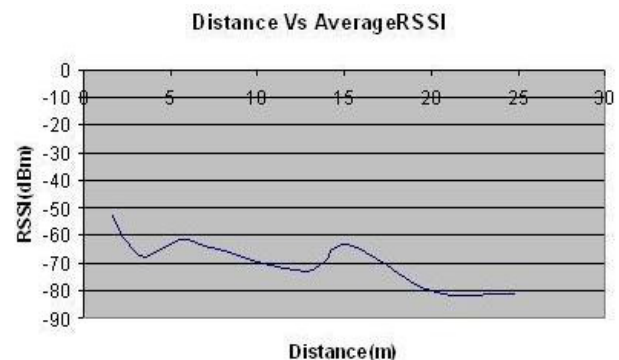


Figure 1. Distance vs Average RSSI (RF230)

A. Line of Sight

These measurements were taken without any obstacle or human activity between the transmitter and receiver. Fig.1 represents a plot of the distance and average RSSI for RF230 radio. At each distance 50 samples of RSSI have been recorded and an average has been taken.

The relationship between the distance and RSSI was obtained by interpolating and fitting a logarithmic curve using the data obtained. Equation (1) gives the relationship between distance and RSSI for RF230 radio.

$$r = -2.503 * \ln(d) - 56.978 \quad (1)$$

Where r is the RSSI value in dBm and d is distance in meters. The packet error rate at different distances between the transmitter and receiver has also been estimated. The maximum allowed packet error rate is 2%.

$$\beta = 1 - \alpha \quad (2)$$

Where α is the packet delivery rate and β is the packet error rate. Fig. 2 shows the packet count versus average RSSI at different distances. As long as the packet error rate is less than 2% the communication between the nodes is acceptable. If it is more than 2% the communication is no longer reliable. The RSSI value of the packets also should not fall below the receiver sensitivity for reliable communication.

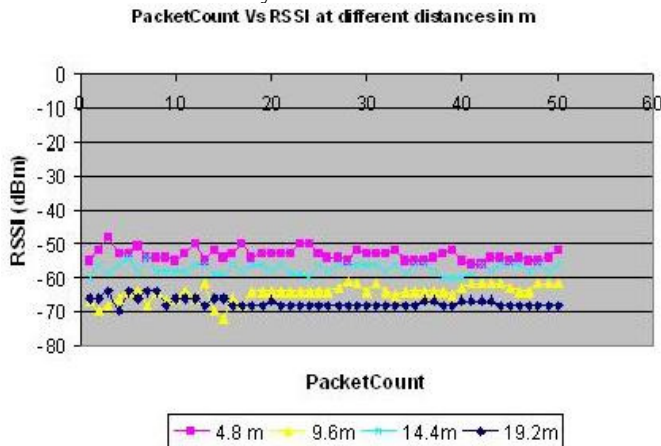


Figure 2. PacketCount vs Average RSSI at different distance between the Tx and Rx.

The results in Fig. 2 were observed when there was no obstacle or movement between the transmitter and receiver. It can be observed that all the packets were received without any loss when there is no obstacle. The PER was 0% upto a range of 40m. The next section discusses results obtained for various obstacles.

B. Non Line of Sight

These measurements were taken by placing a glass, glass-wood and partial wall partitions in between the transmitter and receiver. The transmitter was kept closer to the obstacle and the receiver has been moved to various distances. The properties of the obstacles are shown in table

I. Location estimation has to be done in lab environment with these obstacles. So to model the lab environment the above obstacles have been chosen. Fig 3.a, 3.b, 3.c shows the measurement results obtained when the obstacles were placed in between transmitter and receiver.

TABLE I. TYPES OF OBSTACLES

S.No	Obstacle type	Thickness (mm)
1.	Glass (Glazed Door)	10
2.	Glass + Wood (Compressed Wood)	Wood: 120 Glass: 6.35
3.	Partial Wall (Brick + Gypsum board)	35

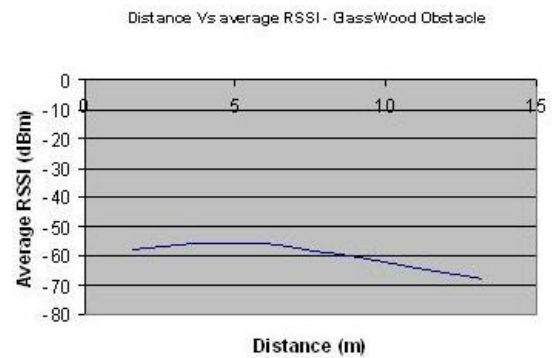


Figure 3.a. Distance vs Average RSSI (glass-wood partition)

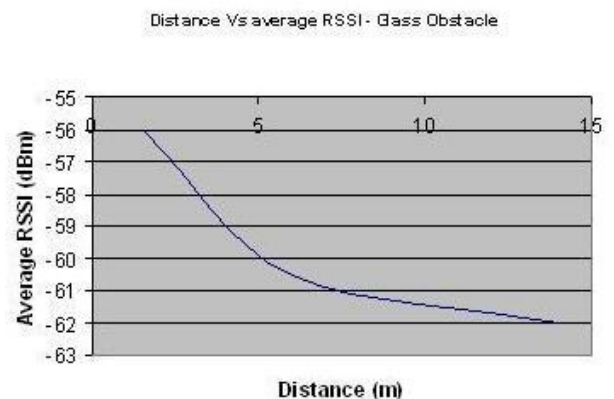


Figure 3.b. Distance vs Average RSSI (glass partition)

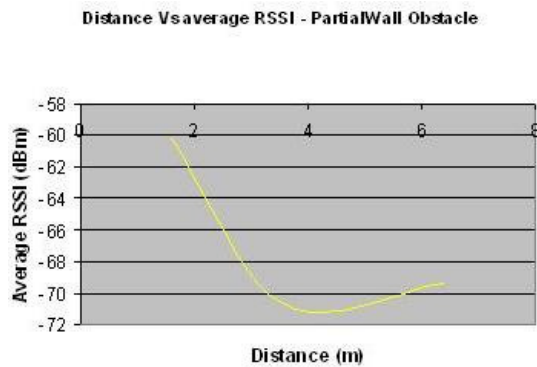


Figure 3.c. Distance vs Average RSSI (partial wall)

When there is an obstacle the packet error rate is also an important parameter to be noted. The obstacles attenuate the signal, so chances for packet loss are more. It is very important to note that the packet error rate should not be above 2%. Fig 4.a, 4.b and 4.c show the PER results observed for different obstacles.

When the measurement was taken through walls the range was reduced to 6.4m. If the distance between the transmitter and receiver was increased beyond 6.4 m, the PER was more than 2 %. So measurements results up to 6.4m are shown in the figure.

But for the glass and glass wood obstacles the PER was less than 2% up to a range of 20m.

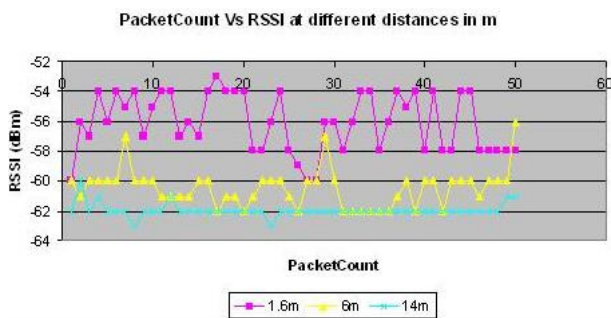


Figure 4.a. Glass wood partition

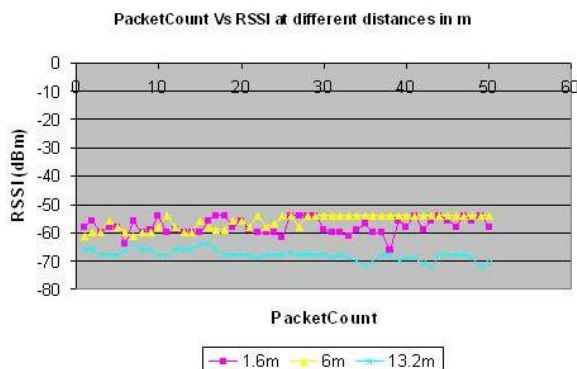


Figure 4.b. Partial wall

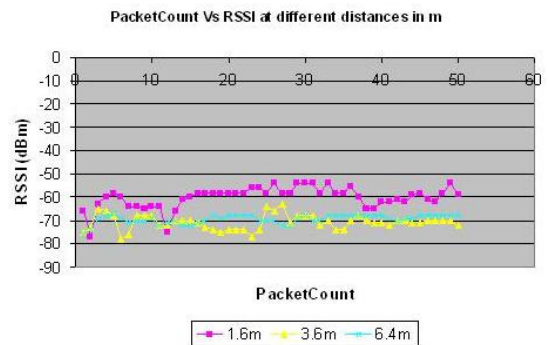


Figure 4.c. Glass door

C. Human Presence

This section discusses about the impact of human presence on the received signal strength values. The measurements have been done for different crowd density by transmitting 1000 packets at the rate of 2 packets per second. The Fig 5.a and 5.b show how the RSSI and LQI values are affected by human presence.

The measurements had been taken by increasing the human count between the transmitter and receiver. It can be noted from Fig 5.a that the RSSI was having the maximum value (-75dBm) when no human was present between the transmitter and receiver.

With increase in human count the RSSI value decreased due to absorption and fading. When the person count was more than 2 the graph (Fig5.a) shows an increase in RSSI value due to reflection and scattering of RF signal. It was observed that the Link Quality remained at 255 through out the experiment up to a distance of 40m.

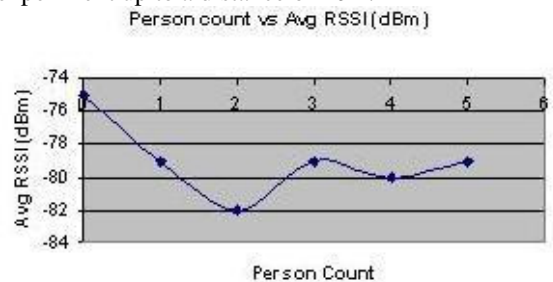


Figure 5.a. Person count vs. Average RSSI

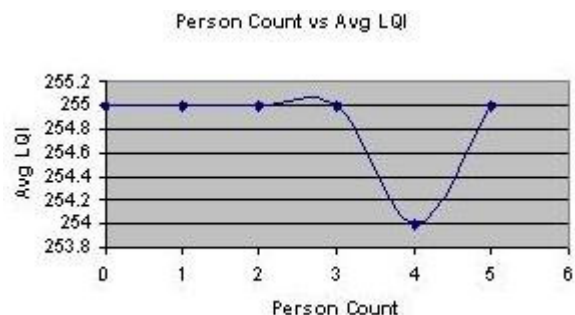


Figure 5.b. Person count vs. Average LQI

V. LOCALIZATION RESULTS

After the measurement and analysis a simple localization algorithm has been implemented and tested inside the UBICOMP Lab of C-DAC Chennai. The location was estimated by fingerprinting method. It was tested with both single and multiple reference nodes.

A. Single Reference Node

The measurement part remains the same as discussed in the previous sections. The accuracy obtained while doing direct fingerprint mapping was 10-15m. A simple sorting and selection of the maximum likely hood RSSI value from the fingerprinting (offline) phase reduced the location estimation error by 1-3m. The same was tried by using three reference nodes.

B. Multiple Reference Nodes

The measurements have been taken by using three anchor or reference nodes to improve the location accuracy. The unknown is programmed in such a way that it broadcasts a beacon every 3 seconds. This beacon consists of its node Id. The anchors which are placed in three different corners of the lab receive the beacon. The anchors append the RSSI and LQI value to the received beacon packet and forwards to the base station. The packets received at the serial port of the PC is parsed and processed for location calculation by fingerprinting.

Fingerprinting

Location estimation by fingerprinting has two phases. The first phase is training phase. The training has been done by using three anchor nodes. The values have been dumped in a database. A row in the database consists of three columns ($\langle \text{anchorId}, \text{RSSI}, \text{Location} \rangle$). While taking these measurements the unknown was kept 0.5m above the ground level. The values are recorded at different known locations inside the lab. At each location the values are recorded for 20 seconds.

During the online phase the unknown broadcasts a beacon every three seconds. The anchors receive the broadcast packet and append the RSSI value and forward it to base station. At the base station the value obtained is compared with the values in the database and the maximum likely hood value is chosen.

Fig 7 shows the anchor node placement and the location tracking setup. Fig 6.a, 6.b, 6.c show the relation between the distance and RSSI values obtained for each anchor node placed at the reference positions as shown in Fig 7.

The signal strength (RSSI) value is parsed from the packet received from anchor1 (A1). The next step is that the algorithm compares the $\langle \text{RSSI}_i, A_i \rangle$ with the offline data $\langle \text{RSSI}_i, A_i, \text{Location} \rangle$. If there is a match the location is returned. In the same way the RSSI values obtained from the three anchors for an unknown beacon message, are compared and finally the location that is likely to be maximum possible is returned.

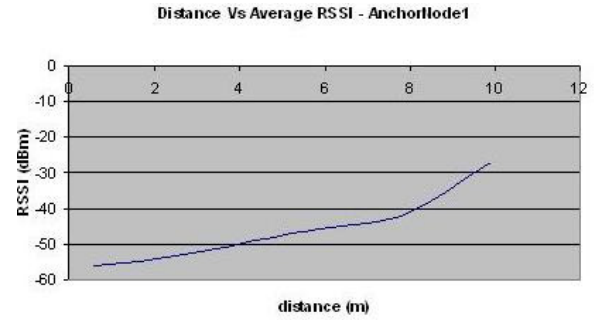


Figure 6.a. Anchor 1

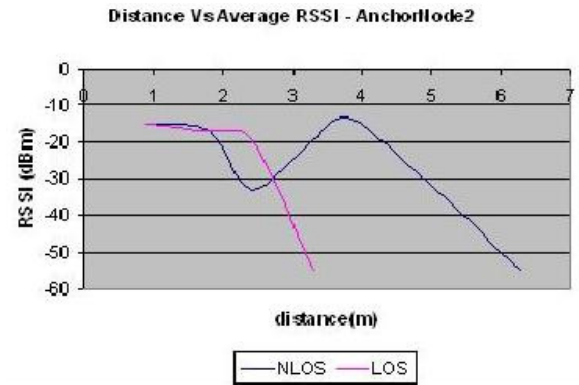


Figure 6.b. Anchor 2 with (NLOS) and without human activity

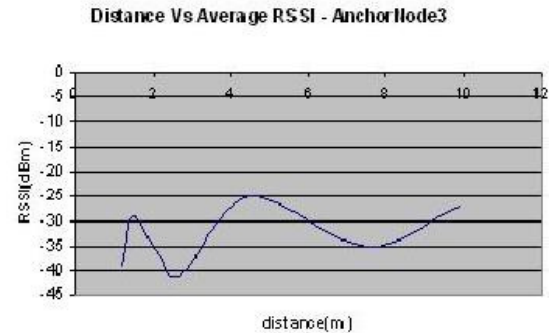


Figure 6.c. Anchor 3

The location error varied from 1m to 8m. The average error was 5 to 6m. The relation obtained between the distance and RSSI, can be used for location estimation instead of fingerprinting method for improving the accuracy. It also minimizes the training phase and the need to calibrate the database very often. By obtaining the three coordinates (anchor location) and distances using the equations three circle equations are solved to obtain the location of the user. If the environment cannot be modeled then this method cannot be used.

VI. CONCLUSION & FUTURE WORK

It can be concluded from the above results that the RSSI alone cannot be used for precise location sensing with

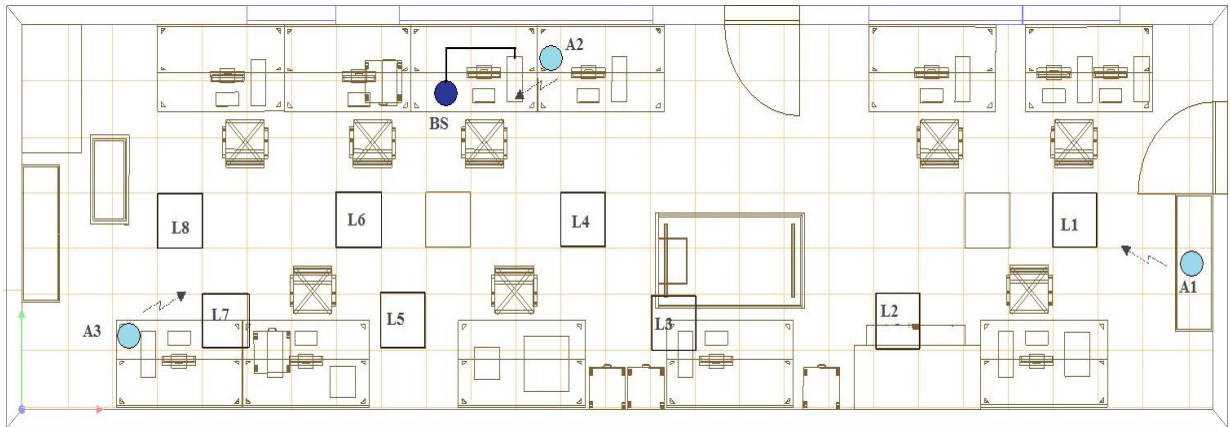


Figure 7. UBICOMP LAB

L1, L2....L8 – Training points, A1, A2 & A3 – anchor nodes
Distance between A1- A3 is 13.2 m, A1-A2 is 6.4m and A2-A3 is 8.6m

obstacles in an indoor environment. Work is in progress to improve the location accuracy by increasing the number of reference nodes and also by using better signal processing algorithms for modeling the environment, instead of directly mapping the RSSI values. Other parameters such as humidity in the atmosphere, heights at which the nodes are placed and interference from other RF sources also affect the signal strength. Location from other technologies like GSM Cell ID has to be combined and the resulting accuracy has to be verified. The location obtained has to be integrated with activity based lighting control which helps in providing various levels of luminance based on the location of the user. In future UWB based localization system will be developed for precise location tracking.

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