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CHARACTERIZATION OF RF SIGNAL BEHAVIOR FOR THE USE IN INDOOR HUMAN PRESENCE DETECTION

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ABSTRACT

This paper presents a method or technique that identifies physical intrusion detection in an indoor environment that is based on received signal strength indicator (RSSI) on radio frequency identification. The objective of this paper is two folds. Firstly, is to characterize the signal behavior in an indoor environment using statistical measures. Secondly, is to identify the existence of a human presence inside a contained environment (e.g., room). The objective is to use simple means like the recorded readings of the received signal strength indicator (RSSI). The characterization was observed during three distinctive time intervals, namely; empty room, with human presence, and transitional period during link crossings. The experiment was repeatedly conducted for 5 minutes to validate the averaged results. In order to emulate real-life environment, experiments were conducted using Zigbee-compliant iris mote XM2110 and MIB510 programming boards with transmitter and receiver antennas, and interfaced using TinyOS software on Linux. Our results show that there are distinctive statistical features that can utilized as flags to classify the three cases stated above, empty room, occupied and link being crossed. These results motivate the design of alarm system to detect human presence using RSSI statistics only.

Keywords: radio frequency, iris motes, human presence, indoor, RSSI.

1. INTRODUCTION

Wireless sensor network have become an important tool to human and it has the potential to increase human ability to develop user-centric application to monitor and prevent harmful events. The existence of low cost low-power sensors, radios and embedded systems can enable the development of distributed sensor networks to provide information to users in different environment and it will offer them control over unwilling situations [1]. The use of wireless sensor technology can be used for various aspects such as medical, to environment and military. There is one possible usage which is indoor perimeter security. In addition, a wireless sensor network (WSN) could be useful in detecting the presence of an intruder. Therefore, the use of the Received Signal Strength Indicator (RSSI) can determine the movement or the mobility of an intruder [2].

These applications needed for day to day usage is what motivates the work done in this paper. Although by no means exhaustive, but the experiments conducted shed some light on the possibility of using simple statistical measures to learn about our surrounding environment. Researchers have done a lot of experiments and researches on the radio frequency characterization for indoor environment for different purposes. However, the objective of this paper is to characterize statistically the RF signal behavior in a contained indoor environment to determine if a human presence is detected. RSSI feed is used solely for the analysis although several statistics can be combined to make an informed decision on the outcome.

This paper is organized as follows. Section 2 reviews the major ideas of radio frequency identification and received signal strength indicator (RSSI). In section 3, we present the proposed model and its procedure. Section 4 and five shows the experiment setting; experiment results and their analysis were reported.

2. RELATED WORK

The possible use of received signal strength indicator (RSSI) and link quality indicator (LQI) value for intrusion detection has been discussed in [2]. The RSSI can be used on its own to determine more accurately the presence of an intruder compared to LQI. Later on, it is found that if the transmitter receiver separation is increased, the RSSI level will decrease and the effect of the intruder on the signal falls below the one standard deviation limit making it harder to detect and increasing the number of generated false alarms.

The detection of human presence based on principal components analysis (PCA) of the signal strength by means of several radio links has been introduced [3]. PCA is a useful statistical technique used in many forms of statistical analysis. It compresses raw RSSI inputs that were obtained from each radio link. The appearance of a human subject brings about RSSI variation in the environment. They discover that the advantage of using raw RSSI values instead of compressed is that the

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accuracy of the detection happens to increase in contrary standard deviation of the RSSI.

Based on [4], the detection of a slight motion such as "typing" affect the reading of RSSI value and are detectable with few wireless sensor network (WSN) nodes. The tests were carried out with the selected activities such as walking, standing, sitting, sitting and typing, lie, lying and waving as well as being outside of the room. It proves that RSSI is a very sensitive to the subject being experimented on and with that sensitivity, a lot of things can be detected.

In tracking human body motion, a different technique has been discussed [5]. Luttwak A. was the first to combine inertial sensors (INS) data and RSSI to track human bod motion. By successfully combining INS and RSSI based sensors, a good accuracy robust to environment changes and drift can be achieved. An anchor node has been used that consist of a single mobile node and N static nodes. The RSSI values were being calculated by the anchor nodes, whereas the mobile node is equipped with inertial sensors which record the node's inertial data. The position of a moving hand along the surface has been tracked by the tracking filter. It was found that the gyroscope signal suffers greatly before the hand starts moving. The filter parameter initialization was found to work well after running number of tests in the presence of stimulated disturbances. For different trajectories and time-varying disturbances, different sets of filter parameters would be better.

The work in [6] discusses a new infrastructure to Vehicles (I2V) communication and control systems for intelligent speed control, which is based upon Radio Frequency Identification (RFID) technology for identification of traffic signals on the road. The RFID was used to detect warning signals that were placed in the dangerous portions of the road. A simple setup was run to demonstrate the validity of RFID-based automatic vehicle speed control. Each signal was configured to pass on different speeds to the driver. Perez J, et.al. found that RSSI value decrease with the increasing distance to the signal, and the tags behind the body of the signal are detected only at lower ranges and with lower signal strength.

M. Quwaider and S Biswas in [7] discussed networked proximity sensing and Hidden Markov Model (HMM) based mechanism that can be applied for stochastic identification of body posture using a wearable sensor network. It helps the optimal maintenance of a chronic condition from continuous monitoring by wearing the Wireless Body Area Network (WBAN). WBAN contains a number of tiny body-mounted sensors that are placed on patient's body forming a small wireless network to monitor the posture of human subject. The body postures are set for SIT, STAND, WALK and RUN. They found out that the average value of RSSI can be high for SIT and low for STAND.

A technique to differentiate the transmission of different 802.11 NICs based on physical layer information was discussed [8]. Traffic from only authorized NICs is only permitted into the network based on their MAC address. This findings lead to variety possible security applications that lies in enterprise security where PARADIS can provide wireless intrusion detection functions.

Wei-chuan. L, W. K.G. Seah and W. Li in their paper [9] has been focused on the radio-based detection and counting methods. The human movement can be detected by observing consistent patterns of RSSI. An algorithm has been designed to compute the different fluctuations between RSSI of received packets at a receiver.

Improving the localization accuracy has been discussed in [10], with results of several motions and location sensing algorithm gathered from existing WLAN infrastructure. With four proposed algorithms, which exploit the frequency domain characteristics reporting a precision and recall over 90%.

The detection of human presence has been successful exploited in [11]. It is basically prototyped with existing Wi Fi infrastructure. RSSI works best in current device-free detecting schemes yielding a limited resistance to noise made by the environment, thus undermine the accuracy of cell coverage models and offers little flexibility for omnidirectional detection. Working around antenna radiation pattern to obtain omnidirectional coverage, while maintaining a link-centric architecture for the communication, has achieved a low false alarm rate in 4 directions.

In addition to the value of RSSI extracted, the use of alpha-trimmed mean filter helps to reduce the effect of sudden fluctuations caused by the interference of people in different motions. In fact, the sensors that were set with four readings per second were sensitive enough to detect a slight movement as per discussed in [4]. The work in [12] discusses the implementation of alpha-trimmed mean filter to reduce the impact of multipath fading that occurs in the indoor environment. According to N. Pirzada, M. Y. Nayan and M. F. Hassan, the alpha-trimmed filter is appropriate for cleaning the data of received signal strength indicator (RSSI) and performs better in reducing the noise. The filter takes average of data by removing some sample of data rather than taking all the data perceived in a time window. This may be good to localization in indoor environment but it certainly reduces the level of sensitivity to human presence.

3. PROCEDURE AND METHODOLOGY

The experiment is conducted inside a small class room. The first step was to set up the required equipment before starting the experiment. The needed equipment is: Laptop Computer, Iris motes fitted with Zigbee-compliant modems which are receiver (Rx) and transmitter (Tx) antenna as well the MIB520 programming board. After

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setting up the proposed method, four scenarios are taken into consideration. 1) Empty room, 2) occupied room, 3) link crossing with sensor antenna orientation are placed on horizontal/horizontal, 4) link crossing with sensor antenna orientation are placed on vertical/vertical. Thus, we deploy 2 nodes in the experiment room in the height of 120 cm. First, we recorded the received the reading of received signal strength indicator (RSSI) for an empty room. Then, we recorded the reading of RSSI when a person was sitting inside the room. Finally, the RSSI was recorded when the person crosses the link at point of entry, stands for a few seconds then leaves the room. This has been repeated for a period of five (5) minutes. The room is a typical class room with chairs tables and chairs. Figure-1 below is the layout of the testing room. The room dimensions were 550x360 cm. **T** represents the node of the transmitter sensor and **R** represents the receiver. The receiver is simply the connection between the MIB510 programming board with Iris XM2110 mote which is the Zigbee modem and connected to a laptop to receive the reading the transmitted antenna. The link is kept at 2 meters to have strong fluctuations during repeated link crossings.

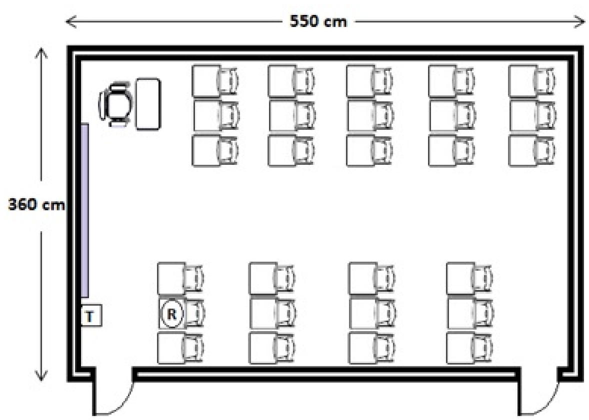

Figure-1. Layout of the testing room.

4. EXPERIMENT SETTING

In this experiment, actual Zigbee motes were used instead of signal generators and spectrum analyzers in order to demonstrate the feasibility of using these motes practically in characterizing the signal behavior. The iris motes operate at a frequency around 2.4 GHz. Any type of Iris mote can function as a base station when it is connected to a programmable board MIB520. The role of MIB520 is to act as a interface for both programming individual motes and for data communication from base station to PC. TinyOS is a free and open source component-based operating system and platform targeting wireless sensor networks (WSNs). It is described as an embedded operating system written in the NesC programming language as a set of cooperating tasks and processes. The experimented were repeated several times and then the RSSI readings were compared to confirm the repeated pattern of behavior of the signal, hence increasing the confidence level in the conclusions drawn from the experiments.

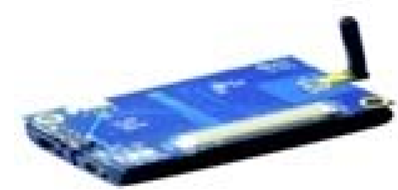

Figure-2. Iris XM2110 mote.

Figure-3. MIB510 programming board.

5. EXPERIMENTAL RESULTS

The packet transmit rate was set to 250 milliseconds so the receiver sampling rate was set to a resolution of 4 packets per second. This allows for any walking speed motion to be captured. An average normal walk is taking to be 1m/sec when crossing the link. Faster speed are possible but require adjusting the packet transmit rate to achieve the CW transmission effect. So a walking peed of 1meter/sec requires at least a transmission rate of two packets /sec on order to capture the signal fluctuations due to link crossings.

Figure-4(a) presents the RSSI fluctuations for an empty room and when a person is sitting still inside. The signal mean can easily capture the difference between an empty room and an occupied one for a small room size. However, larger rooms may not exhibit similar degradation in the mean. –From Table I one can infer a drop in signal mean of 2.67 dB between an empty room and occupied, while the variance has increased from 0.1363 0.1493. The same conclusions can be drawn with regard to other statistics such median, standard deviation, kurtoses and to a lesser degree skewedness. This is only true if raw RSSI is used instead of compressed one with low sampling rate as almost all fluctuations are captured in real time. Compressed RSSI data using averaging, aggregation etc. can be suitable to estimate the distance between transmitter and receiver and is commonly used in propagation models to estimate the path loss. However, raw RSSI is not a common measure due to its random

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fluctuation's temporal and spatial distributions. Figure-4(b) demonstrates the difference in RSSI readings for an empty room and an occupied room but this time the person is placed far away from the link and is sitting still. Contrasting Figures-4(a) and (b) indicates that regardless of the location of the person in the room, the status of the room can still be inferred from raw RSSI readings as indicated by Table-1. For example, the mean has dropped by only 1.1 dB instead of 2.67 dB while the variance has increased further from 0.1363 to 0.2901. This indicates an important conclusion that is sitting closer to the transmission link affects how the signal fluctuates and therefore adds constructively to the signal reflections. However, sitting further away contributes lesser effect on the signal fluctuations as has been reflected in the signal mean statistic. Nevertheless, a distinctive difference is present in all statistics such as variance, standard deviation, kurtoses and skewedness. Figure-4(c) shows signal fluctuations when the person is standing still in the room. Comparing Figures-4(a), (b) and (c) indicates that when a person is standing, signal fluctuates more strongly resulting in higher variance values of almost 9 times the value for an empty room, as shown in table I. Kurtoses is indirectly related to variance and directly related to tendency of concentration of RSSI readings in their bell-shaped histogram graphs. The taller the bell curve, the lower the kurtoses and the more the repetition in the RSSI readings. The higher the kurtoses and more flattened the bell-shaped curve is and the more RSSI levels are recorded. This feature makes the kurtoses a well suited statistical measure, and probably as good as the variance, to infer the environmental status of the room.

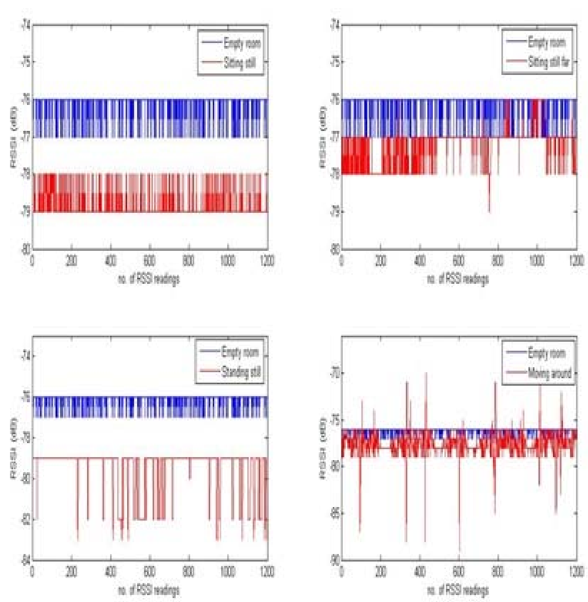

Figure-4. Graph of RSSI for various scenarios in the room shown against empty room (a) Sitting still (b) sitting still far (c) standing still (d) moving around.

Figures-4(d) shows the RSSI fluctuations when the person is made to move around the room. As the person moves closer or crosses the transmission link, signal fluctuations similar to multipath fades were generated due to strong constructive and destructive reflections caused by the person in the room. Similarly and as expected, stronger statistics are present in this case in comparison to previous measurements, as shown in Table-1.

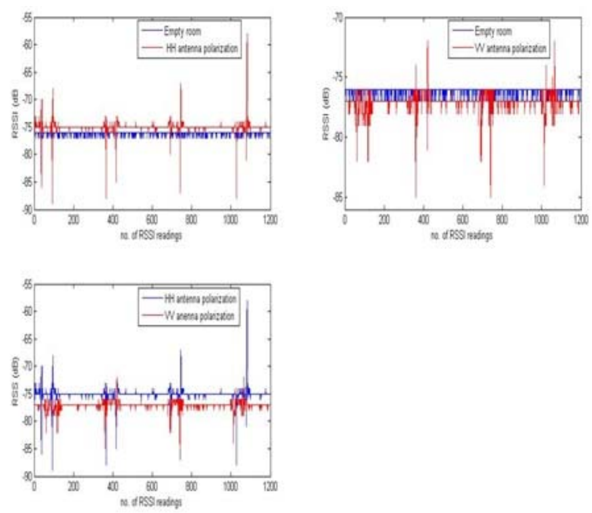

Figure-5. Graph of RSSI for antenna orientation against empty room (a) HH (b) VV (c) HH vs VV.

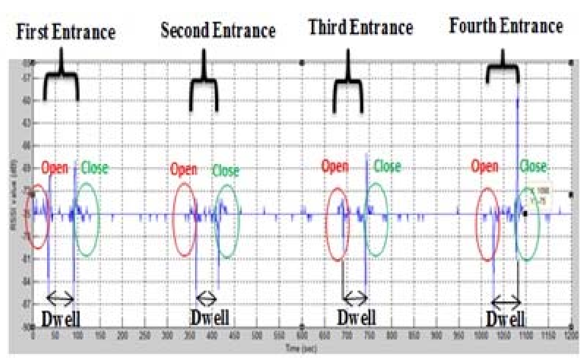

Figure-6. Entry, exit, Dwell time and door open/close inferring.

a) Antenna orientation effect

To test the antenna polarization/orientation effect on the signal behavior during a link crossing, Figures-5 (a), (b), and (c) were generated. The graphs shown about are for: (a) empty room vs. individual enters and leaves the room when the antennas are set on horizontal/horizontal (HH) (b) empty room versus individual enters and leaves the room when the antennas are set on vertical/vertical (VV) and (c) comparison between HH and VV during a

300 sec (1200 RSSI readings). The data statistics of each graph have been recorded which are: minimum, maximum, mean, median, mode, standard deviation, range, variance, skewedness and kurtosis.

Figure-5(a) and (b) show that when an individual coming in and out from the room, he crosses the communication link with a walking speed of 1m/sec. The receiver with a sampling rate four times that perfectly captures the effect of crossing by registering a deep fade into the signal fluctuation. Antenna polarization at the Tx/Rx were changed from vertical/vertical (in Figure-5a) to horizontal/horizontal (in Figure-5b) to highlight the effect of antenna orientation on link performance. When antennas were placed in the horizontal position, the desk surface, where the mote is placed on, acts as a perfect reflector causing strong reflections in the RSSI as compared to vertical polarization. It also shows that there is an extra 1 dB when the sensors are set on vertical/vertical compared to an empty room where as this difference becomes 2 dB when horizontal/horizontal antenna setting is used. This indicates much larger sensitivity to fluctuations, and hence the variance and kurtoses statistics, as shown in Table-1. Similar conclusion can be inferred from the table. That is, horizontal polarization improves the sensitivity of the RSSI readings by generating further fluctuations into the signal. These extreme fluctuations, perfectly captured by the statistics especially the variance, can act as an alarm to indicate physical intrusion when guarding an indoor parameter is important. Although the detection of the individual entering and leaving the room have been recorded for 5 min, it can be seen from the graphs that, repeatedly, whenever an individual interfering with the line of sight connection, strong fluctuations were produced indicating an intrusion detection.

Table-1. Data statistics for all the reading.

Statistic	Empty Room	Sitting Still	Sitting Still Far	Standing Still	Moving Around	(HH)	(VV)
Min	-77	-79	-79	-83	-89	-89	-85
Max	-76	-78	-76	-79	-70	-58	-72
Mean	-76.1	-78.8	-77.2	-79.49	-77.65	-75	-77.09
Median	-76	-79	-77	-79	-78	-75	-77
Std dev	0.370	0.386	0.538	1.13	1.46	1.426	0.893
Var.	0.136	0.149	0.29	1.2769	2.131	2.033	0.798
Skewedness	-1.81	1.644	-0.2	-1.889	-1.024	-0.019	-2.645
Kurtosis	4.287	3.702	2.799	4.6670	16.19	67.92	24.82

b) Further observations

From the last Figure-6, the analysis of the opening and closing of the door are taken into consideration. This is when the individual enters the room, he opens the door and it closes by itself due to the mechanical spring attached to it at the back allowing for the door to close gracefully. One can deduce the moment of room entry, the dwelling duration, the exit time and a confirmation of the door opening and closing. That is because although people may use different speeds and force to open the door, closing of the door takes the same duration almost always, because it is automated. The duration of the first entrance is 6ms for door opening and 7ms for door closing respectively. The second entrance varies from 8ms for door opening to 14ms for door closing. In addition, the third entrance has duration of 9ms for door opening and 12ms for door closing; the last entrance has duration of 5ms for door opening and 15ms for door closing. It can be seen that the average duration for door opening is about 7ms while for door closing it takes about 12ms. One can observe the speed of opening and closing the door. Further details can be found in [15].

6. CONCLUSIONS

In this paper, the raw readings of received signal strength indicator in a contained indoor environment like a class room were used to characterize radio frequency signal behavior statistically. RSSI readings for several scenarios were recorded, plotted and analyzed in order to better understand how raw RSSI data can be used. Several statistical measures were calculated for the RSSI traces. The presence of humans inside the room can be profiled easily using raw RSSI. Several useful information; such as entry, exit and dwell durations, can be inferred from the data. The use of raw RSSI instead of compressed one allows for ant statistical measure to be used such as mean, median, mode, standard deviation, variance and kurtoses. Skewedness may not be suitable for use on its own but in conjunction of another statistic would re-enforce the learned decision about the environment status. Furthermore, antenna orientation can enhance further the extremity of the signal fluctuations due to its stronger fluctuations, as reflected in the statistics. This motivates the use of these statistics as a threshold for a physical intrusion alarm system to secure an indoor environment perimeter.

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