The Effects of Interference On The RSSI Values Of A ZigBee Based Indoor Localization System

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Abstract— **Indoor positioning systems (IPS) have gained a lot of traction within the research community in recent years. Received Signal Strength Indicator (RSSI) of wireless networks are the most commonly used metric for indoor localization. The objective of this paper is to see how Wi-Fi interferers of different data rates affect the packet RSSI values of TX-RX links in a ZigBee based indoor localization system. The factors we examine also include the rate of corrupted packets and the overall packet loss. We also explore whether a Microwave Oven, a common source of interference for the ISM Band in a dwelling, perturb RSSI values in a localization system.**

Keywords— RSSI; mobile robot; wi-fi interference; 802.15.4; ZigBee; indoor localization; packet loss; packet corruption; Microwave interference

I. INTRODUCTION

In recent years, research into localization has become very popular as the proliferation of Wireless Sensor Networks (WSNs) grows. This has seen an increase in the number of proposed applications within sensor and robotics fields. Low power off the shelf radios have been employed for localization based implementations for detecting animal presence [1], outdoor mobile robot localization [2], biobot localization [3] or indoor mobile robot localization [4-7]. When these localization solutions are implemented indoors, they are termed as Indoor Positioning Systems (IPS) [8]. Simultaneous Localization and Mapping (SLAM) algorithms are commonly used to solve the localization problem for a mobile robot. The problem with these approaches is that they usually require expensive sensors, and even low cost approaches require the robot to carry multiple sensors [9]. Wireless network based localization is attractive as by using a single off the shelf robot mounted radio, with an associated sensor network, the implementation cost is reduced as the number of robots increases. Wireless solutions also have the benefit of not requiring visible light, which makes them more appropriate than camera based SLAM for emergency situations where a robot may have to traverse through rubble or a pipe.

A common metric used to implement IPS using wireless sensors is the Received Signal Strength Indicator (RSSI) due to its ready availability in off the shelf 802.15.4 [10] and Wi-Fi [11] equipment. This paper focusses on ZigBee which is more suitable for long term, battery operated, robotic solutions as it offers mesh networking and better power consumption than Wi-Fi [12]. For 802.15.4 ZigBee radios, RSSI is implemented as an 8-bit register. The register value is often scaled/offset to give a measured value in dBm. There are two types of RSSI measurement. The first type of measurement is used to estimate the ambient power within the channel itself (also known as an ED Scan). The second type of measurement is used to estimate the Received Signal Strength (RSS) of a received packet [10]. When this paper refers to RSSI, we are referring to the second type of measurement as this is most commonly used for localization purposes.

This paper presents experimental results on the effects of Wi-Fi and microwave oven interference on the magnitude of RSSI values, packet loss and corrupted packets within an 802.15.4 TX-RX link. Since packet RSSI has become a popular metric to use for localization, especially IPS, it is important to know whether it remains accurate and therefore usable in the presence of common interference sources. The impact of interference on ZigBee packet loss and throughput is well understood and has been extensively investigated in literature [13-17]. However the impact on the accuracy of packet RSSI values has not been investigated very thoroughly. Most studies focus on the impact of interference on ED scan RSSI values. The handful of studies that investigates the impact on packet RSSI are limited to low Wi-Fi data rates [18] that is impractical in today's wireless networks or TX-RX separation that is more in line with body area networks (BAN) [14] and not robotics and other typical application.

II. BACKGROUND

An IPS using RSSI can be implemented through either Device-free Passive (DFP) [19] or Active localization [20, 21]. DFP works by creating a dense network of "linked pairs" as

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each radio surrounding the area of interest can transmit and receive wireless signals. DFP systems analyze which links are currently experiencing change due to the robot passing through them, and thus a moving robots location can be detected as the intersection of multiple affected links [22]. Active tracking utilizes the same information (RSSI), but instead uses it as a form of wireless ranging where the tracked robot is in contact with several other nodes at any given time to contribute to the localization.

RSSI based localization will often use either a variation of one of the following methods, or a combination of multiple techniques.

A. Range-free Algorithims

Range-free algorithms use the concept of relative signal strength loss to locate a target node. They are often based on the assumption that RSSI decreases with distance, but do not use absolute point-to-point distances or angles to estimate a location [23].

B. Path-Loss Algorithms

Path-Loss based localization (also known as Range-based localization) create and employ a statistical model to estimate the distance (range) between a beacon and robot based on the TX-RX link power between them. This approach is then used by multiple known beacon nodes to infer location coordinates, often via a lateration approach [24].

The problem is that all these systems rely on either the RSSI values themselves, or the fluctuations between RSSI values to be accurate. Research into the effect of Wi-Fi on 802.15.4 networks has shown that strong Wi-Fi interference will cause significant packet losses and will increase the received signal strength of the 802.15.4 channels noise floor [25]. Further research into BAN has shown that a Wi-Fi interferer will cause significant packet losses in a ZigBee network but have minimal effect on the ZigBee packet based RSSI values [14]. From a localization perspective, it is common place to have ZigBee TX-RX links with up to 10m separation. Therefore further work needs to be done to ascertain the usability of packet RSSI values in networks with greater TX-RX separation than the 1.5m of a BAN.

Common existing solutions to the interference problem of a ZigBee network are as follows: Use 802.15.4 channel 25 or 26 [16], introduce a channel hopping protocol that changes channel based on the presence of interference [25] or introduce a MAC layer transmission protocol to mitigate interference [14]. Using the upper 802.15.4 channels is not viable as they are not globally free of Wi-Fi interference due to the use of Wi-Fi channels 13-14 in Europe and Asia. Introducing a channel hopping protocol only works if there are 802.15.4 channels available that are not affected by Wi-Fi. As the demand for higher data rates become more common due to advancing technology and services such as 4k content streaming becoming commonplace, Wi-Fi saturation could become more frequent. The problem with MAC layer protocol variants is that they are proprietary and therefore will not likely be compatible with global standards such as ZigBee 3.0. This means that any current solution using them either is incompatible with communicating to other ZigBee devices, or would require a very bespoke implementation. Therefore we assume the worst-case situation, a localization system operating in the presence of a strong Wi-Fi interferer and investigate whether the integrity of the system is affected by heavy Wi-Fi interference, i.e. do the RSSI values of correctly received packets change? This is important as interference induced packet RSSI fluctuations could seriously impair the accuracy of a RSSI based localization system.

We also investigate the effect of Microwave interference on ZigBee TX-RX links. We chose these interference sources as both Wi-Fi and Microwaves are common in indoor environments.

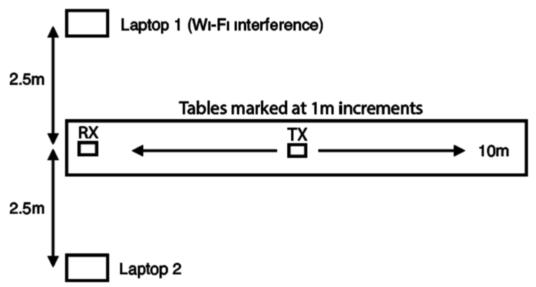


Fig. 1. Wi-Fi Interference Test Setup

III. EXPERIMENTAL SETUP

We chose to use the TI CC2530 [26] which supports a fully compliant ZigBee stack and provides a good analog of a chip that may be used within Home Automation / Lighting Systems / Industrial Control or Health Care applications. The chip provides an affordable off-the-shelf system-on-chip that incorporates both a CC2530F256 RF transceiver and an enhanced 8051 MCU. We used a Rohde & Schwarz Spectrum Rider FPH [27] to analyze the spectrum of the test environment when either Wi-Fi or Microwave interference are present.

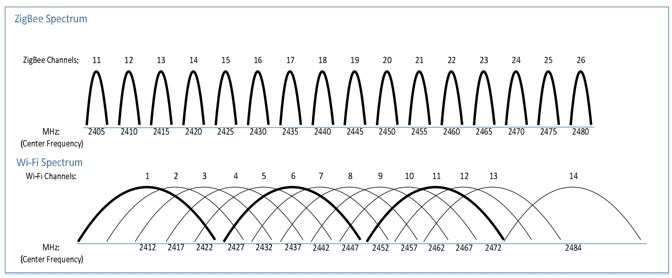


Fig. 2. ZigBee and Wi-Fi spectrum usage

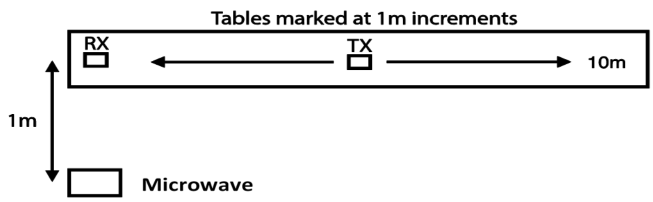


Fig. 3. Microwave interference Test Setup

Two experiments have been conducted to analyze the effect of Wi-Fi interference on 802.15.4. For the first experiment, we maintained a fixed CC2530 TX-RX separation of 5m while varying the Wi-Fi transmission rate from 0-20Mbps. For the second experiment, The RSSI was measured at 1m intervals as the CC2530 RX-TX separation increased from 1m - 10m, in the presence of a constant 10Mbps/20Mbps Wi-Fi interferer. In both experiments the duration of each result was defined by the 802.15.4 receiver having received 5000 packets (correct or corrupted). Both experiments were set up as per Fig. 1 with the laptops, acting as the Wi-Fi interference source, perpendicular to the CC2530 TX-RX pair. All Devices were sitting on tables 0.71m above the ground. The Laptops and CC2530 RX remained completely stationary between both experiments. When the CC2530 TX node was moved, antenna orientation was kept constant to ensure it would not affect the results. The experiments were performed with no humans or moving objects present to minimize any potential impact from varying multipath propagation. Wi-Fi (802.11n) interference was generated by sending constant traffic from Laptop 1 to Laptop 2 using the program iPerf3 [28]. Both experiments were performed inside an empty classroom in the evening at Massey University. Wi-Fi channel 6 was selected for the experiments as it was completely empty of other nearby Wi-Fi channel 6 access points during the time of testing. ZigBee (802.15.4) channel 18 was chosen as it is completely encompassed by Wi-Fi channel 6, as can be seen in Fig. 2, and therefore helps represent a worst case interference example.

We also did an experiment using a 1200w microwave as the interference source. The microwave was placed 1m away from the CC2530 RX node, perpendicular to the CC2530 TX-RX LOS path as seen in Fig. 3. The CC2530 TX-RX pair was operated on channels 11, 18 and 26 to observe whether RSSI was affected differently in different parts of the spectrum. In each trial a bowl of cold water was put into the microwave and it was set on High. This was done to verify whether a commonly present interferer within the 2.4 GHz band, but with a different profile to Wi-Fi would have the same effect on RSSI values as a Wi-Fi interferer.

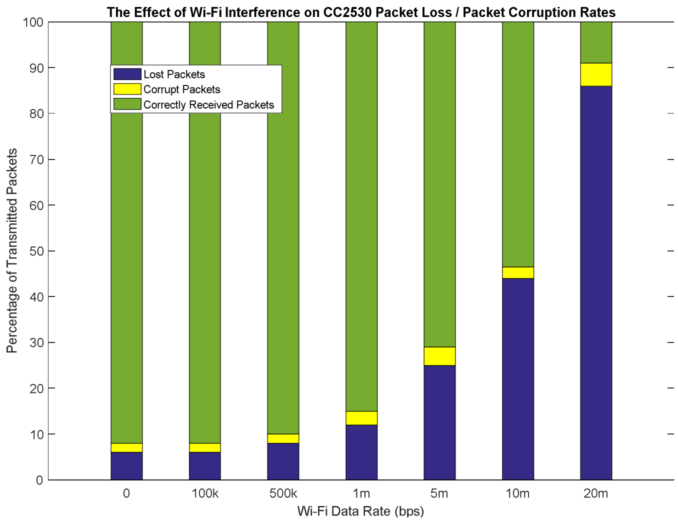


Fig. 4. The effect of Wi-Fi interference on a ZigBee 5m TX-RX links packet loss and corruption

IV. Results

A. Experiment 1

There are several interesting findings from experiment 1 that can be observed in Table 1 and Fig. 4. Firstly, as can be seen in Table 1, the RSSI of correctly received packets is unaffected by Wi-Fi interference, regardless of the Wi-Fi's data rate. Fig. 4 shows that packet loss increases significantly in the presence of a Wi-Fi interferer.

TABLE I.

	The Effect of Wi-Fi Interference on ZigBee RSSI values						
	Wi-Fi Data Rate (bps)						
RSSI (dBm)	No Interference	100k	500k	1m	5m	10m	20m
Correct Packets	-60	-58	-60	-60	-60	-59	-60

B. Experiment 2

Table 2 shows that RSSI values do not change due to the presence of a Wi-Fi interferer, even as the ZigBee TX-RX separation increases.

TABLE II.

	The Effect of Wi-Fi Interference on ZigBee RSSI values									
	ZigBee TX-RX Separation (m)									
RSSI (dBm)	1	2	3	4	5	6	7	8	9	10
No Interference	-33	-38	-47	-50	-60	-63	-74	-65	-64	-67
Wi-Fi 20Mbps	-34	-37	-47	-48	-60	-62	-74	-63	-64	-68

Fig. 5 shows that the packet loss associated with an interference source increases significantly for any TX-RX link that is longer than 2m.

The results also show that a Wi-Fi interferer has a more significant impact on lost packets than CC2530 TX-RX link separation for distances up to 10m. Experiments 1 and 2 show that the percentage of corrupt packets remains relatively stable and does not show a strong correlation to either Wi-Fi separation or CC2530 TX-RX separation for the distances tested.

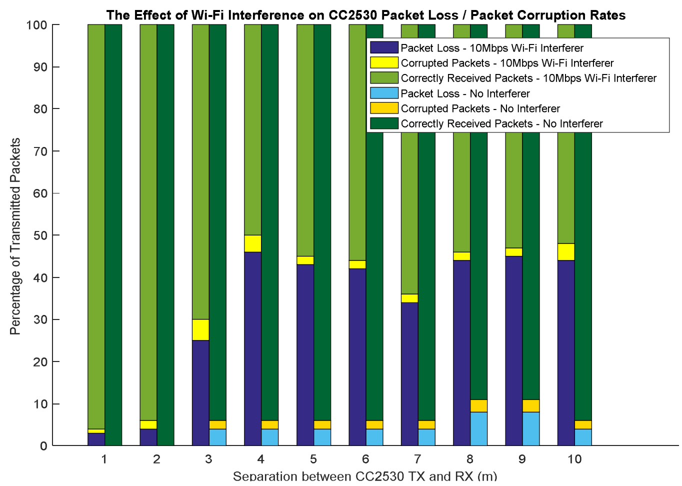


Fig. 5. The effect of a 10Mbps Wi-Fi Interferer on ZigBee packet loss and corruption

TABLE III.

	The Effect of Microwave Oven Interference on ZigBee RSSI values		
	ZigBee Channel		
RSSI (dBm)	11	18	26
No Interference	-55	-62	-63
Microwave Oven Interference	-55	-61	-63

C. Experiment 3

Experiment 3 with a Microwave Oven also showed that there was no influence of interference on the RSSI values of correctly received packets as seen in Table 3.

We also noticed that there was no increase in the number of corrupt packets or the number of lost packets. This is interesting as both the Wi-Fi source (Fig. 6(b)) and the Microwave source (Fig. 6(c)) had noticeable effects on the channel, when compared to the static environment (Fig. 6(a)), as measured from the ZigBee RX node. This is also contrary to results reported by [17] that suggest placing radios at least 2m away from microwaves to ensure reliable communication. We believe that this is caused by different microwaves having different radiation patterns, which in turn affect co-channel signals differently.

There is a significant relationship present between the Wi-Fi data rate and the number of lost packets as seen in Fig. 4, with an increase in Wi-Fi data rate resulting in an increase in lost packets. As the Wi-Fi data rate increases, so does the probability of a collision as there is more data travelling through the shared 2.4 GHz ISM band. When collisions do occur, the ZigBee receiver is often unable to decode the appropriate packet, thus turning a Wi-Fi – ZigBee collision into a ZigBee packet loss.

V. Discussion

The experiments undertaken have clearly shown the effect a Wi-Fi interferer has on ZigBee communication. The findings can be concluded as follows:

1) Interference (both from Wi-Fi and Microwave Ovens) has no measurable impact on the RSSI values of correctly received packets within a ZigBee TX-RX link.

2) Wi-Fi interference causes a significant increase in lost ZigBee packets as its datarate increases.

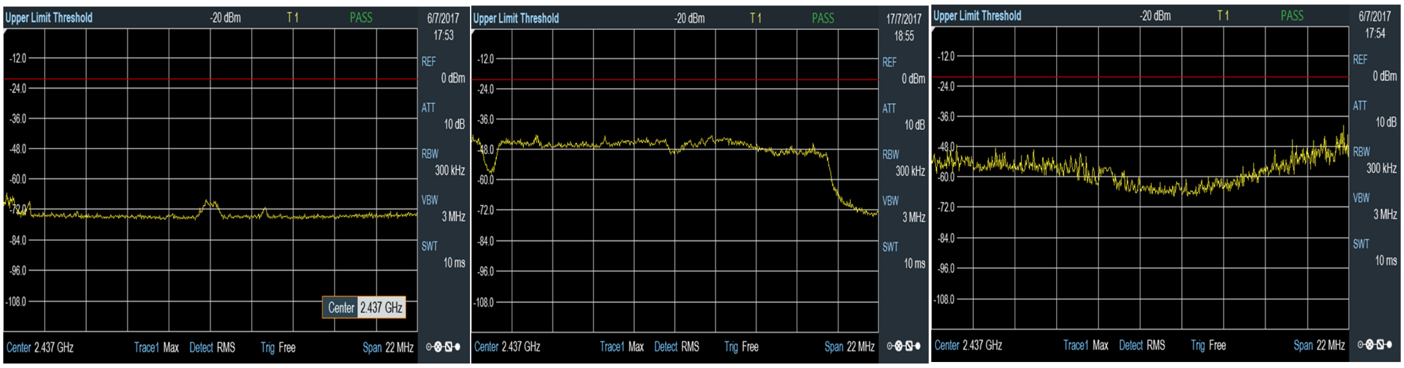
3) An increasing Wi-Fi datarate has a stronger effect on ZigBee packet loss than increased ZigBee TX-RX link separation in an indoor network.

Since interference has no effect on the RSSI of correctly received packets, this suggests that the data integrity of a ZigBee RSSI based localization system would not be affected. This is important as it means the localization accuracy should not be affected due to the presence of a strong interferer. However if an algorithm that employs some form of time averaging [29], is implemented using ZigBee devices, latency could be made worse in the presence of interference due to the increased packet loss. This could occur for both Active Tracking solutions (such as tracking an autonomous/mobile robot) and DFP solutions. This means that and IPS containing mobile robots with low mobility should be largely unaffected but an IPS that requires high mobility and accuracy will need to take interference into account.

The results showed that a Wi-Fi interferer has a stronger effect on the systems packet loss than ZigBee node separation. With relation to a localization system this means that while the location of beacon nodes within the localization region is important, their separation distance will have less of an effect on tracking performance than an external interference source will.

VI. Conclusion

Through testing we have shown that interference from common sources like Wi-Fi and Microwave Ovens will not influence the RSSI values of correctly received links in a coexisting ZigBee network. We have also shown that a Wi-Fi interferer will greatly increase the rate of packet loss with a ZigBee network. Future work includes analyzing what level of Wi-Fi interference will noticeable affect the latency of common RSSI localization systems. Following this, we wish to investigate whether the RSSI of corrupt packets can be a secondary source of RSSI values when strong interferers are present.



(a) (b) (c)

Fig. 6. Spectrum Images of Wi-Fi Channel 6. (a) No introduced interference. (b) Introduced Wi-Fi interference. (c) Introduced Microwave Oven interference

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