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Mitigating Interference in a Heterogeneous Wireless Network using Channel Selection

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ABSTRACT

With the extensive development of heterogeneous wireless communication technology, combined with the advances of data acquisition, emerges a new trend of networked acquisition systems. Among this range of wireless technology, Wireless Sensor Networks (WSNs) has attracted much interest and visibility due to its huge application space. One challenge using the WSN is the short range of the sensor nodes that increases the complexity of transporting the data to a central server. The integration with Wireless Mesh Networks (WMNs) expands the communication range and allows mobility of the device. Thus, WSN can be used for forming the underlying sensing and WMN supports the network infrastructure in pervasive computing environments. However, interference is a problem as these networks share the same 2.4GHz industrial, scientific and medical (ISM) unlicensed band. The impact of the interference on the IEEE 802.11g (WMN) using OFDM modulation and on IEEE 802.15.4 (WSN) using DSSS is investigated in this research. Results from a series of experiments on the AIT wireless mesh campus network under realistic load conditions are presented. Packet retransmission and packets drop rate were measured and based on this knowledge, a channel interference classification (CIC) method is presented to identify the interfering operating channel. The method introduced is based on a technique proposed by Chowdhury et. al. for channel selection based on reference power values. This work modifies the technique to account for differences on channel spectrum characteristic found in tests on the Mesh Campus Network. A channel selection algorithm was then developed for WSN to decide on the operating transmission channel that is not under interference, hence reducing packet losses in the network. This paper will be of interest to network operators and organisations where critical information retrieval over wide area networks is required.

INTRODUCTION

Many challenges exist if integrated wireless networks are to provide efficient network performance. The shortage of empirical results for integrated heterogeneous wireless networks utilising OFDM modulation, for example in IEEE 802.11g under adverse interference conditions as outlined in [1], are well known.

Wireless Sensor Networks are becoming ubiquitous with the number of applications based on the open IEEE 802.15.4 global standard enabling reliable, cost-effective, low-power, wirelessly networked, monitoring and control products is increasing [2]. The IEEE 802.15.4 standard provides three frequency bands, under which the 2.4GHz (ISM) band is the most popular. The IEEE 802.15.2-2003 standard [3] provides information on the coexistence of IEEE 802.15.4 with other wireless standards; IEEE 802.11b (WiFi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.3 (Wireless USB). Figures for IEEE802.15.11g-OFDM are not given but as IEEE 802.11g matures, existing interference work of OFDM appears to be limited.

As there is significant energy cost associated with packet retransmission and reliability issues in packet drops, the co-existence of the IEEE 802.15.4 (Zigbee) with the IEEE 802.11g using OFDM (WLAN) is of critical importance. While the WLAN devices are not constrained in energy, the sensor nodes are battery powered and must proactively avoid concurrent transmissions.

In this paper, a detailed frequency spectrum measurement of IEEE 802.11g is obtained. It will be followed by power measured of a WiFi interferer in the Zigbee channels. Then, we introduced channel interference

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classification and channel selection as a proposal to mitigate the interference issue. The rest of the paper is organised as follows: Section II describes our experiments with WSN under various IEEE 802.11g WLAN modulation schemes. Section III presents the proposed interference classification technique. Channel selection algorithms were developed and shown in Section IV. Finally Section V provides the Conclusion and a brief summary of our future work.

Coexistence Issues:

A. IEEE 802.15.4 – Zigbee:

The IEEE802.15.4 standard is establishing its place on the market as an enabler for the emerging wireless sensor networks. The objective of IEEE 802.15.4 is to address applications where existing WSN wired solutions are too expensive and the data rate of a technology such as Bluetooth- 802.15.1 is not required. IEEE 802.15.4 complements other WSN technologies by providing very low power consumption capabilities at very low cost, thus enabling applications that were previously impractical.Table 1 illustrates a basic comparison between IEEE 802.15.4 and other IEEE 802 wireless networking standards.

Wireless sensor networks are a form of wireless ad-hoc network which connect embedded sensors, actuators, processors and in which each node consists of a wireless communication device.An example of a commercially available sensor is the MicaZ mote (used in this research) utilising ISM band 2.400MHz – 2.385MHz with 16 channels available [4]. Sensors like this one can be used to build large sensor networks for a variety of applications in different areas including indoor and outdoor environmental surveillance, habitat monitoring, seismic and structural monitoring, intelligent transportation, object tracking, precision agriculture and factory process automations, among others [5].

Table 1: Comparision Between 802.15.4 With Other Ieee 802 Wireless Networking Standard[6]

	802.15.4 – WSN	802.15.1- Bluetooth	802.11b – WLAN	802.11g - WLAN
Range	~ 10 – 30m	~ 10 – 100m	~ 10 – 100m	~ 10 – 100m
Max Data Rate	0.25Mbps	1 Mbps	11Mbps	54Mpbs
Power Consumption	Ultra Low	Low	Medium	Medium

WSN’s require application specific configuration for each deployment if network performance is to be optimized. Critical factors that influence WSN performance include scalability, communicationprotocols at different layers (cross layer communication), failures, and network management. Amongthe design constraints of wireless sensor networks is the small transmission power and consequently the radiated power (on the order of 0 dBm) with the hope to save energy by leveraging multihop communication[7]. The choice of a small transmit power implies a small range of coverage.

One option is to use a Wireless Mesh Network (WMN) as the backhaul for transporting the data to a central server.The range covered by WLANs is clearly shown in Table 1. The integration of WSN with WMN expands the communication range and allows mobility of the devices. WSN’s can be used for forming the underlying sensing and WMN provides the backhaul network infrastructure in pervasive computing environments. A similar approach was introduced by Torsten[8] whereby WSN and WMN were integrated to connect to the Internet.

Apart from extending the communication range, supporting complimentary applications, such as home automation,health monitoring and intelligent building applications deployed in residential areas, hospitals and office blocks which may already be under the coverage of commercial WLANs, prove excellent reasons to collocate WSN and WLAN.

However, interference issues arise whenintegrating and deploying IEEE802.15.4 with IEEE 802.11g as they areoperating in the same ISM band at 2.4GHz (Fig. 1). The overlapping frequency proves to be of concern, resulting in a problem that is asymmetric in nature, nonetheless the output power of IEEE 802.15.4 devices is typically low at 0 dBm or less, whereas the output power of 802.11g devices is 20 dBmor above.Experiments from[9]&[10]revealed nearly 92% packet losses for specific cases of a WSN under the interference of a WLAN.

B. IEEE 802.11g Wireless Mesh Campus Network:

The 802.11 technology has become a ubiquitous solution for wireless LAN’s in the home and offices. Using the two-tier mesh network technology the WLANs have been considered as a cost effective solution to wide area coverage. A two-tier mesh network has an access tier that integrates the clients, and a backhaul tier which forwards the clients packages in a multihop architecture to a wired gateway. A two-tier mesh network when compared with cellular networks or WiMax has a lower deployment cost, is easily scalable, has better coverage and is robust to general individual node failure[11].

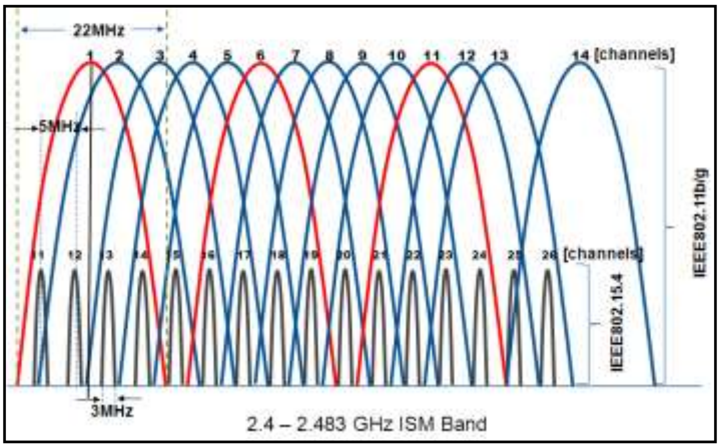

Fig. 1: WSN vs WLAN Overlapping Channel Allocations

The WMN was deployed on the AIT campus (Fig. 2) using industry grade equipment from Motorola and deployed based on the simulated RF performance using the Motorola Mesh Planner software.

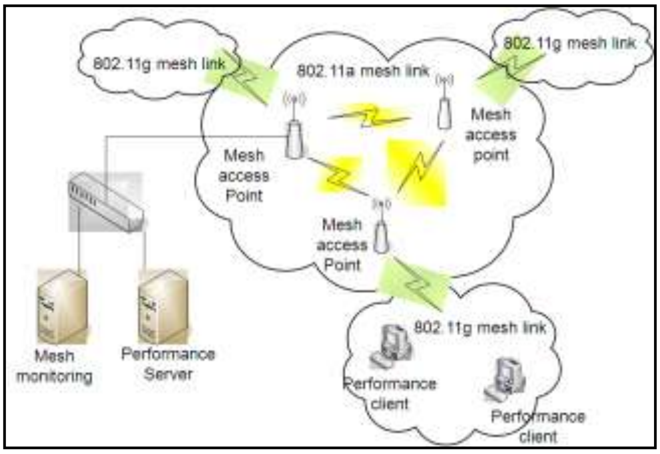

Fig. 2: AIT WMN Architecture

C. *IEEE 802.11g Spectral Analysis:*

Vanheel[1] conducted a similar study of spectral interference betweenWiFiand wireless sensor networks. The work concluded that reducing power will have a positive effect on the frequency spectrum. It is also reported that 10 out of 16 Zigbee channels received more than -30dBm when disturbed by 802.11g. This higher power values of WiFi creates interference towards these Zigbee channels. Our work will expand further by measuring the packet drop and packet retransmission of WSN coexisting with WMN in a network with a realistic network load.

The IEEE 802.11g frequency spectrum experiment was carried out using Motorola WMN at the AIT campus (Fig. 2). Wi-Spy 2.4x spectrum analyser was used to obtain the spectral measurement. IEEE 802.11g 6Mbps and 54Mbps were measured to compare the effect of data rate in OFDM modulation. Within OFDM the number of parallel sub-carriers is the same (52), but the modulation for 6Mbps uses BPSK, while modulation for 54Mbps uses 64QAM. The WMN was fixed to transmit on channel 6 (2437MHz) with transmission power of 20dBm (100mW). The WiFi receiver was placed 3 metre's from the Motorola AP-7131 [12]. Fig. 3 and Fig 4.shows the IEEE 802.11g 6Mbps and 54Mbps spectrum measurement accordingly.

From the graph, the 6Mbps stream has a wider modulated spectrum compared to the 54Mbps stream. The main lobe power measurement of 54Mbps concentrate in channel 16 to channel 19 with power values in the average of -50dBm, and reduce significantly at the shoulder compared to 6Mbps, whereby the shoulder spectrum gradually decreasing. The Zigbee channel 13 to 15 and channel 20 to 22 receives higher power readings at the shoulder of the 6Mbps spectrum in contrast to the 54Mbps spectrum. At this stage we can deduce that at equal power, QAM gives a more efficient frequency spectrum than BPSK. These findings relates to our next experiment when we collocate WSN and WMN.

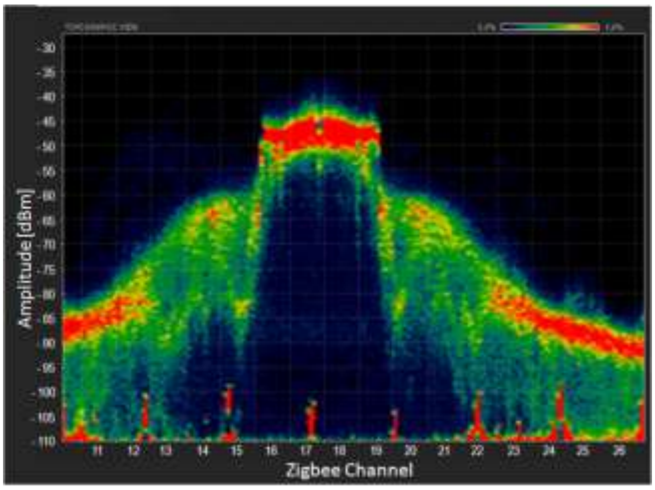

Fig. 3: IEEE 802.11g – 6Mbps BPSK

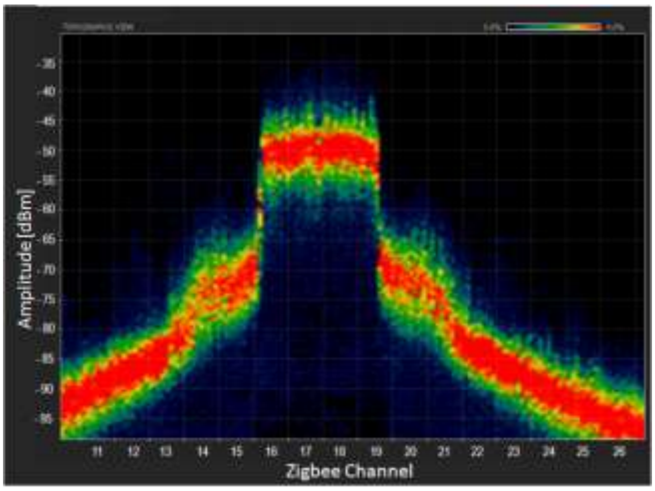

Fig. 4: IEEE 802.11g – 54Mbps 64QAM

Interference Experiment:

The experiments were conducted where the number of packet drops and packet retransmission were monitored and experimentally analyzed. IxChariot (Ver 5.40) [13]is used to generate TCP traffic simulating real load on the WMN.The testbed in Fig. 5 was adopted, whichconsists of an IEEE 802.15.4 WSN and IEEE 802.11g WMN operating in close proximity.The WMN was fixed to transmit on channel 6 (2437MHz) with transmission power of 20dBm (100mW). The WSN was set to variably change channel from 11 – 26 with transmission power at 0dBm (1mW) to measure the impact of WMN on each channel.

The radius (r) between the motes and the gateway is 30cm to ensure a direct link between them with a strong signal. The distance between the WSN gateway to the AP is 3 metres. This distance is selected within the minimum interference region as recommended by vanheel [1] for an offset of 13MHz and PER of 0.1. Crossbow MPR2400-MicaZ wasdeployed as WSN motes and was downloaded with Xmesh[14]application withpacket size of 36 bytes and payload size of 29 bytes. XMTS310CA sensorboardswere used and all the sensors available were activated, hence providing high data transmission from the motes to the gateway.

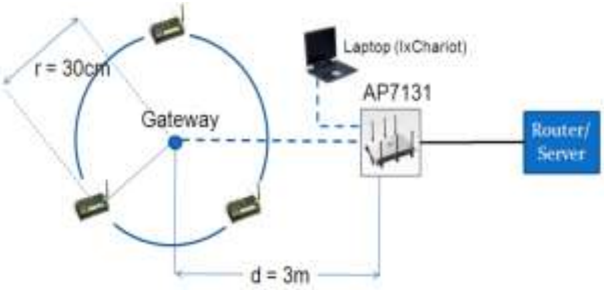

Fig. 5: Adopted WSN and WMN testbed

Fig. 6 shows the result for percentage of packet drops for the WSN. The overlapped WSN channel 16 – 19 has significant implication to the number of packets dropped; within the range of 7.33% -56.01%. Despite the 8 retries before the packet is considered dropped, these figures provide information on the severity of the interference. 54Mbps- OFDM modulation shows better performance than the 6Mbps-OFDM.Interestingly channel 15 and channel 20 shows some noticeable readings to emphasise that these channels are also affected.

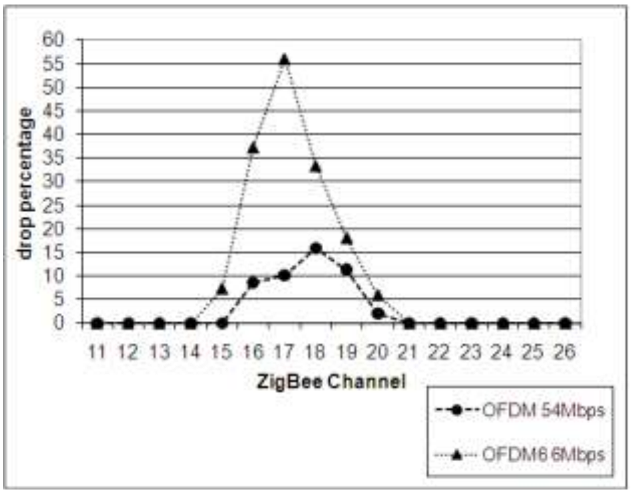

Fig. 6: Percentage of WSN dropped packets

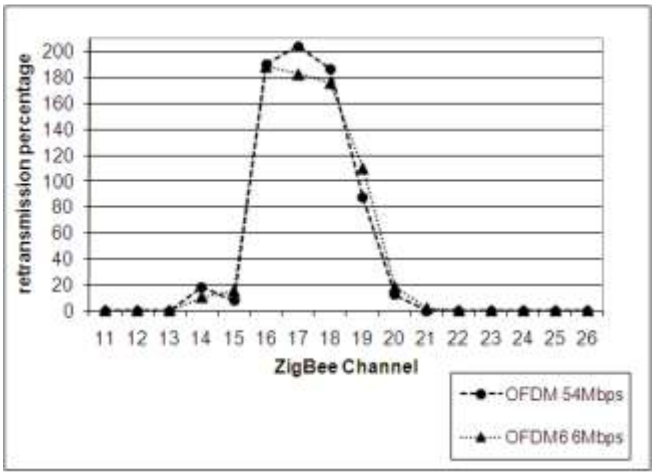

Fig. 7: Percentage of WSN number of retransmission

In the analysis of percentage number of retransmission for the packets in WSN (Fig. 7), it is observed that the percentage number of retries is increasing in the overlapped channel in the range of 87.45% - 204.47%. This means that in a severe case, a packet is resent three times before it is acknowledged by the receiver. Adjacent channels close to the operating channel 6 in the WLAN are also implicated, including the "known to be clear" non-overlapping channels 15 and 20. The impact of coexistence between IEEE 802.15.4 and IEEE 802.11g at this stage are clear, in-line with Vanheel[1] albeit over a wider range of network operating conditions on a realistic network load test.

The result provides concrete evidence that more than 4 channels were affected from WLAN IEEE 802.11g signal. It is suggested that wider frequency off-set is taken into account. As the interference is more pronounced in channels closer to the WLAN central frequency, addingan additionaltwo WSN channels on both sides of the lobes hypothetically is a better resolution. These two channels translate to an additional 10MHz on both sides of a WLAN signal lobe, increasing the channel separation. It should be considered to avoid a total of these 8 WSN channels that can be affected by a WLAN signal lobe when developing a channel assignment model for WSN.

The proposed channel assignment model should provide predicted WSN channels that are free from any WLAN interference. With less interference the WSN offershigher network resiliency and reliability. In order to realise the channel assignment model,the WSN channels that havesignificant WLAN interference must first be identified.

Channel Interference Classification:

In classifying WLAN interference, the algorithm used by Chowdhury[15] is adopted. In his work, the channel interferer classification scheme introduced the angle θ_{obs} as the angular difference between the reference power values and those obtained from current unknown measurement. The angle θ_{obs} is the scalar dot product; $\theta_{obs} = \cos^{-1}$ {a.b}. The conical region around the reference vector a by an angle θ, is defined such that any measured vector b within that region ($\theta > \theta_{obs}$) can be considered as a positive match. A threshold of θ is given as 3 degrees. This means that if $\theta_{obs}$is less than 3 degrees, then the current measurement is identical to the reference power unit vector and thus considered as the channels that are affected by IEEE 802.11g interference.

Fig.8shows an illustration visualizing the channels as a set of orthogonal axes. Vector a is the reference value for the interferer. Vector b is measuring the received power of channel i. and vector $i$is the channel with interference.

However our research work differs where the reference power values were obtained from deploying WSN collocating with WLAN on a heavily loaded network. The WLAN was transmitting at 6Mbps (IEEE 802.11g – OFDM) at 20dBm and the network was loaded with TCP traffic using IXChariot instead of a simple ping at 64bytes at the rate of 11Mbp used by Chowdhury*et.al.* and his reference power values are taken from IEEE 802.11b-DSSS whereas our reference power value is taken from IEEE 802.11g-OFDM.

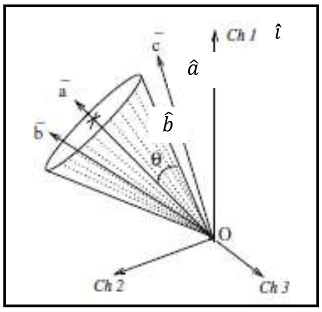

Fig. 8: Conical region for classification of the interferer[15]

Referring to the frequency and channel allocation for IEEE 802.11g and IEEE 802.115.4 (Fig.1), the WLAN channel with 22MHz bandwidth will always interferewith 4 channels of WSN at anytime. This was considered by Chowdhury in obtaining his reference power values. Results shown in our experiments in Section II confirmed that more than 4 channels were influenced by the interferer.

In order to obtain the reference power values, an experimental setup (Fig. 9) was organised whereby WSN and WMN were collocated in close proximity. For this test a pair of MicaZ IEEE 802.15.4-2.4GHz with transmission power set to 0dBm (1mW) were deployed 1 metre away from Motorola AP7131 access point transmitting IEEE 802.11g -6Mbps at 20dBm on channel 6 (2437 MHz). IxChariot was used to load the network with TCP traffic. 6Mbps was chosen for WLAN transmission as this was the worst case condition obtained in our test in Section II.

Given the WSN channels affected by WLAN, i= $(i_1, i_2, i_3 \dots\dots)$, the reference power vector ($\vec{a}$) can then be constructed to represent the sensed power value in all these channels:

$$\vec{a} = a_1\hat{\imath}_1 + a_2\hat{\imath}_2 + a_3\hat{\imath}_3 + a_4\hat{\imath}_4 + \dots\dots$$

Whereby :

a_x= the sensor received power (dBm)

Then, the unit vector along that direction is:

$$\hat{a} = \frac{\vec{a}}{|a|}$$

This unit vector captures the relationship between the power values sensed in the channels through its spatial orientation. This reference power vector is defined as the spectral signature. Results for the experiment are shown in Fig. 10. As suggested in Section II, 8 channels should now be considered as channels under interference. Hence the reference unit vector is obtained as:

$$\hat{a} = -0.412\hat{\imath}_1 - 0.399\,\hat{\imath}_2 - 0.297\hat{\imath}_3 - 0.291\hat{\imath}_4 - 0.285\hat{\imath}_5 - 0.291\hat{\imath}_6 - 0.392\hat{\imath}_7 - 0.424\hat{\imath}_8$$

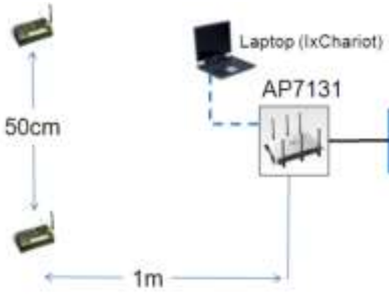

Fig. 9: Experimental setup to measure WLAN interference

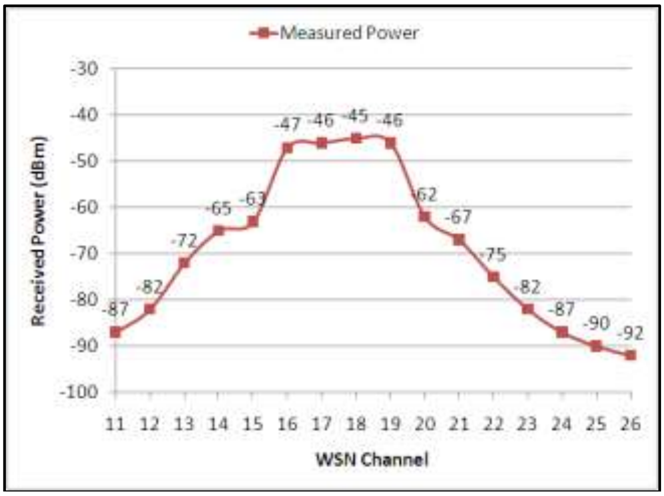

Fig. 10: WLAN Received Signal Strength (RSS)

In order to prove that the referenced unit vector is valid irrespective of the WLAN channel used, two sets of unit vector $\hat{b}$ are measured to identify the angle $\theta_{obs.}$ The first set was chosen from a different 8 channels under interference with the WLAN on channel 8. The second set was purposely taken from another 8 channels that are only partially affected by WLAN channel 11 as a null hypothesis. The outcome should prove that the first set is having $\theta_{obs} < 3$ degrees resulting in an identical match with the reference unit vector. The second set should show that $\theta_{obs} > 3$ degrees; not matched. Table 2 provides the parameters of both sets of unit vector $\hat{b}$ and the resulting θ_{obs} in reference to $\hat{a}$ (reference unit vector).

Table 2: Two Sets Of Vectorb For Validation

Set	WLAN Channel	WLAN Freq.	8 WSN Channels	Power values	$\theta_{obs} = \cos^{-1}\{a.b\}$
1	8	2447	16	-66	1.14 deg
			17	-65	
			18	-46	
			19	-45	
			20	-45	
			21	-45	
			22	-63	
			23	-69	
2	11	2462	**15**	-87	17.46 deg
			16	-80	
			17	-87	
			18	-71	
			19	-69	
			20	-51	
			21	-42	
			22	-40	

*note : the bold channels are channels without interference

The result clearly shows the proposed channel interference classification model is valid.

Channel Selection:

For channel selection, firstly the channels that have the ambient noise floor above the allowed threshold are selected. Then within these channels, if there exists a channel that has WLAN detection by comparing with the spectral signature, then such a channel is avoided. The remaining channels are the best to be chosen as the WSN operational channel with no interference.

Mapping the WSN and WLAN channel so that they can correspond to each other is obtained in equation 1 and 2. Let the channel numbers for the WLAN and the IEEE 802.15.4 based WSN be given by *m*= 1 to 11 and *k*= 11 to 26, respectively. The channel centre frequencies for the WLAN (f_m^{WLAN}) and the WSN (f_k^{WSN}) in the ISM band are then derived as:

$$f_{m=1\to 11}^{WLAN} = 2412 + 5(m-1) \tag{1}$$

$$f_{k=11\to 26}^{WSN} = 2405 + 5(k-11) \tag{2}$$

Knowing the related relationship between the channel number and the frequency, we can then deduce the f_{min} and f_{max} of the WSN channel. Anything in between them will be within the WLAN interference frequency.

Starting with the channel mapping, as an example we take WLAN channel 8 with f_c = 2447MHz, the nearest corresponding WSN channel is 19 with f_c = 2445MHz, incorporating this information together in equation 1 and 2, we can then obtain the following relationship between the channel numbers of the two different standards,

$$m = \left\lceil \frac{\left(f_k^{WSN} + 2\right) - 2412}{5} \right\rceil + 1 \tag{3}$$

The minimum and maximum frequency of the WSN can then be deduced;
WSN Min Frequency;

$$f_{k_{min}}^{WSN} = [(m \times 5) + (2412 + 5)] - 22 \tag{4}$$

WSN Max Frequency;

$$f_{k_{max}}^{WSN} = [(m \times 5) + (2412 + 5)] + 23 \tag{5}$$

Using equation 4 and 5, for example if we take WLAN operating at channel 6 with fc = 2437MHz, then the WSN Min Frequency is 2425MHz (channel 15), and the WSN Max Frequency is 2470MHz (channel 24). Knowing these minimum and maximum channels we can then resolve the WSN interference channels for WLAN on channel 6 to be channel 16,17,18,19,20,21,22 and 23. These are the channels that need to be avoided.

Conclusions And Future Works:

In this research project, we have evaluated the interference level of IEEE802.15.4 WSN and IEEE802.11g in close proximity. The experiments were carried out to gauge the percentage of packets dropped and retransmission by WSN motes from channel 11 to channel 26 under the existence of IEEE802.11g WLAN using OFDM and DSSS modulation techniques. IxChariotwas used to insert TCP based traffic into the WLAN to simulate real network load. The packet delivery rates show that when WSN and WMN channels overlap the WSN packet delivery rate is reduced from 100%. When the channels are separated further in frequency, the packet rate degradation is reduced. As expected, the degradation is more pronounced in areas with a strong presence of WLAN signals. It is deduced that coexistence and interference issues of IEEE802.15.14 WSN and IEE802.11g WLAN can be cautiously addressed through careful channel selection and assignment.

An Interference classification and channel selection was then introduced as a proposal to mitigate this issue. A validationwas also presented to evaluate the accuracy of this model.

For future work, our research will focus on the impact of coexistence under a wider range of operating conditions. We will also expand our research by modelling the interference classification and channel selection using OPNETand analyse the performance of WSN under the influence of this model.

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