2.4GHZ ISM BAND CONGESTION: WLAN AND WPAN PERFORMANCE ANALYSIS

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ABSTRACT
The 2.40 GHz frequency band is also known as the ISM (Industrial Scientific and Medical) band, is a license free band allocated for a variety of consumer applications: environmental monitoring, agriculture, medical care, smart buildings, factory monitoring and automation, and numerous military applications. A wireless sensor network (WSN) consist of small nodes with sensing, computation, and wireless communications capabilities, is an exciting new technology and can also be considered as the underlying infrastructure that will be an integral part of future ubiquitous and embedded computing applications. Due to the independent design and development in WSN, together with the unexpected dynamics during deployment of co-existing networks and devices, within the same frequency spectrum, IT is crucial to ensure that each wireless technology maintains and provide its desired performance requirements. This paper proposes to study multi-frequency functionality among overlapping but cooperative WSNs and potential interferences with Wireless Local Area Network (WLAN) are examined according to the impact on the throughput performance of WLAN and WPAN devices when co-existing within a certain environment.

INTRODUCTION

Interference mitigation has always been and remains a big part of any communication system design cycle. Since wireless system engineers have always had to contend with interference signals from both natural phenomenon which are not within our capability to eliminate and those manmade signals that, by large, can be attenuated or controlled. The classical communication design cycle has consisted of predicting channel impairments and choosing adequate modulation and error correction schemes.

The impulsive of the wireless medium affect all Wireless Sensor Networks (WSNs). These unexpected changes can cause intermittent network connectivity, packet loss and ultimately result in lower network throughput and increased energy expenditures (Musˇaloiu-E., R. and Terzis, A. 2008).

A sensor network is spread both spatially and temporally. The channel condition in the network need not be uniform across all parts of the network over a given period of time. In today's networks single network wide frequency scheme that simplifies development implemented, at the same time suffers from a number of problems (Nilesh Mishra et al, 2007).

Since, 802.15.4 shares the 2.4 GHz ISM band it can suffer from heavy interference by devices using other protocols. 802.11 (operate in the 2.4 GHz band along with various proprietary protocols) have moved from niche applications into commodity products and one comes across them more often. 802.11 devices can specially affect the operation of 802.15.4 devices as they have order of magnitude higher transmit power (26 dBm) as compared to 802.15.4 devices (0 dBm) (Petrova et al. , 2007) .

Co-location of such networks is also becoming more common as both the protocols provide different benefits. On one hand where 802.15.4 gives low power, low rate, small range operations 802.11 devices can provide high bandwidth, long range communication capabilities (with certain changes in software over COTS hardware).

Another problem suffered by static single frequency usage across the network is that all the links in the network contend for the channel. This effectively reduces the channel throughput as it is possible that different links not sharing a node can do simultaneous transfers. The possibility becomes more attractive when we have multiple sinks (such as in CTP) and hence if we can come up with schemes allowing simultaneous data transmissions we can increase the effective throughput of the network (Nilesh Mishra et al, 2007).

In the coexistence of 802.15.4 and 802.11, the main concern is the performance degradation of 802.15.4 caused by the interference of 802.11. A measurement study reported that over 92 % of the 802.15.4 frames were lost by the interference of 802.11b (Steibeis, 2004).

2. PRIOR WORK

The problem of interference and sharing of limited radio spectrum has been extensively studied in the wireless networking literature as well as the wireless communication literature in general. The traditional solution to this problem has been to license frequency bands to primary network users who are the only ones allowed to transmit in that frequency (Mus˘aloiu-E., R. and Terzis, A. 2008).

This disadvantage of static frequency allocations has led to the use of *shared* or *unlicensed* frequency bands that can be used by multiple networks at the same time. The 2.4 GHz band is a prime example of this paradigm, used by 802.11, 802.15.1 (Bluetooth) and 802.15.4 (Zigbee) data networks and even cordless telephones. The dominant technology used to reduce interference among multiple networks operating in the same frequency range employs a technique generally known as *Spread Spectrum.*

802.11 networks use the Direct Sequence Spread Spectrum (DSSS) mechanism in which the original bit stream is expanded into a larger sequence of chips according to a pseudo-random pattern and is subsequently spread out over a larger frequency range. The received signal is perceived as noise by all receivers other than the one which shares the same pseudo-random code with the transmitter.

(Golmie et al. , 2001) analysis on PHY level simulations show that WiFi can generate up to 15% packet loss to a collocated Bluetooth network. In the context of sensor networks, an early study from Crossbow reported packet loss on Zigbee networks up to 15% caused by interference from an adjacent WiFi network (Crossbow Technology Inc., 2004). The Time Synchronised Mesh Protocol, TSMP (Dust Networks, Inc., 2006) uses frequency hopping to limit the interference from competing RF sources.

Since the frequency hop pattern is a pseudo-random sequence of all available channels a competing sender that is constantly sending at a particular frequency will still generate packet loss. Given that a WiFi channel overlaps with four 802.15.4 channels (see Figure 1), a WiFi source that sends packets constantly would still inflict packets loss equal to 4/16 = 25% to a 802.15.4 WSN using TSMP.

Perhaps closest to this work are recent spectrum sensing proposals presented in the context of Dynamic Spectrum Access (Challapali et al., 2005; Ganesan and Li, 2005; Ghasemi and Sousa, 2005). However, those proposals require specialised hardware (i.e. software radios) while our approach employs off-the-shelf, commercially available radios. Moreover, spectrum sensing techniques are primarily concerned about deploying multiple networks in a way that does not cause interference to the primary owner of the spectrum (e.g. a TV station). On the other hand, if we consider 802.11 as the primary spectrum owner, it is unlikely that low-power WSN radios will interfere with 802.11 APs.

Lastly, Srinivasan and Levis (2006) recently demonstrated that under certain conditions, there is strong correlation between RSSI measurements taken by a Zigbee receiver and the packet reception rate experienced by the same mote. The authors investigate RSSI during Zigbee transmissions and high values indicate good reception rate (Mus˘aloiu-E., R. and Terzis, A. 2008).

Furthermore, in this work we aim to maximise network utilisation and allocate spectrum resources fairly among users and reduce interference among users of different networks.

3. EXPERIMENTAL METHOD

The investigation begins in measuring the RSSI of the transmission data when sensor networks are deployed in environments, which also covered by other wireless networks. The measurement used TelosB motes that are based on CC2420 radio chip, which apart from being more advanced than older radios based on IEEE 802.15.4, an emerging WSN standard. Specifically, the interference was measured between 802.15.4 and WiFi networks.

3.1 RF Transceiver -CC2420

CC2420 operates in 2.4 GHz ISM band with an effective data rate of 256 kbps, a much higher rate than older radios. In the 2.4 GHz band, it has 16 channels (numbered 11 through 26) with each channel occupying a 3 MHz bandwidth with a center frequency separation of 5 MHz for adjacent channels. CC2420 uses an encoding scheme that encodes 32 chips for a symbol of 4 bits. This encoded data is then OQPSK (offset quadrature phase shift keying) modulated.

CC2420 provides two useful measurements: RSSI and LQI. RSSI is the estimate of the signal power and is calculated over 8 symbol periods and stored in the RSSI VAL register. Chipcon specifies the following formula to compute the received signal power :

(P) in dBm: P = RSSI VAL + RSSI OFFSET

Where RSSI OFFSET is about -45. We refer to this power, P (in dBm) as RSSI throughout this article. LQI (Low Quality Indicator) can be viewed as chip error rate and is calculated over 8 bits following the start frame delimiter (SFD). LQI values are usually between 110 and 50, and correspond to maximum and minimum quality frames respectively.

3.2 BACKGROUND

Figure 1 describes the frequencies that the 16 802.15.4 channels occupy as well as the corresponding WiFi channel frequencies. Each 802.15.4 channel is 3 MHz wide, centred around the frequency indicated in the figure. On the other hand, each WiFi channel is 22 MHz wide and in most cases it overlaps with 4 802.15.4 channels as well as with other 4–8WiFi channels. The three non-overlapping WiFi channels (1, 6 and 11) are shown with red dash in Figure 1. Zigbee channels 25 and 26 are special cases since they do not overlap with any WiFi channel.

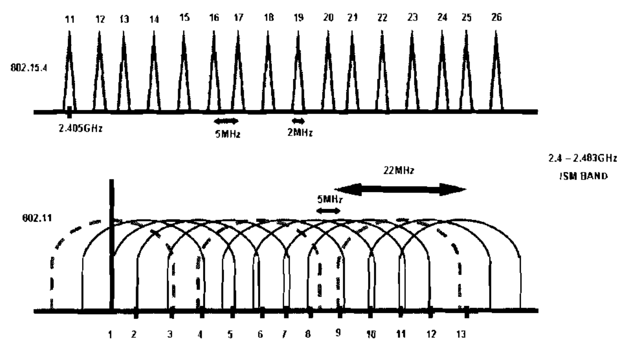

Figure 1 2.4 GHz ISM Band frequency ranges

One could argue that the interference problem would be solved simply by using channels 25 and 26. Unfortunately, WiFi networks in Asia and Europe occupy two more channels on the higher end of the frequency band, overlapping with Zigbee channels 25 and 26. The fact that both Zigbee and WiFi employ DSSS techniques to reduce crosstalk that could lead to the impression that inference is not an issue. This however is not true, since WiFi transmission power can be up to 100 mW (Cisco Systems Inc., 2006), 100 times higher than the maximum allowed 802.15.4 transmission power (Texas Instruments, 2006).

Therefore, WiFi transmitters can create noise levels at an 802.15.4 receiver that overwhelm the interference resistance capabilities of DSSS. Furthermore, a WiFi channel completely covers an overlapping Zigbee channel so spreading the signal over the whole Zigbee channel does not avoid interference from the signal transmitted by the collocated WiFi radio.

3.3 MEASUREMENT SET-UP

The evaluations was carried out on a Crossbow's TelosB Motes. Three TelosB motes was placed at different locations from a total of 4. Each TelosB mote was connected to the Base Node (BN). The motes are programmed to accept commands from the BN to send 1 to 255 packets data delivery ranges from 1 to 60 seconds. Every packet sent was a unicast instead of a broadcast because unicast is the general form of traffic that is observed in a real WSN and the performance of the nodes was observed with this traffic pattern. One drawback, however, with the unicast traffic evaluation was that we were not able to look at spatial correlation of PRR, RSSI and LQI among near-by nodes.

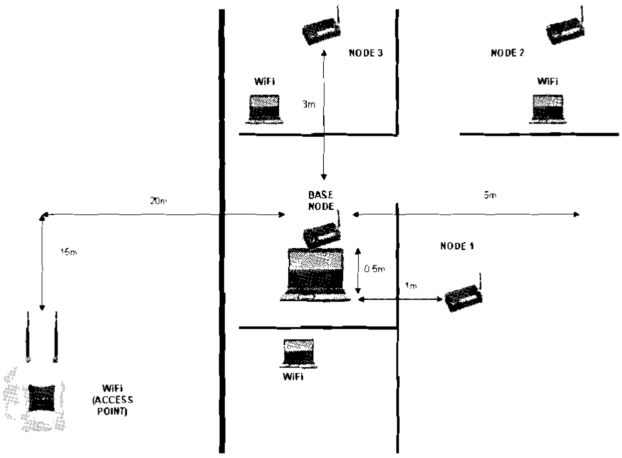

Figure 2 Measurement environments.

Every mote sent 10 packets to every other node, one node at a time. Upon sending 10 packets, the transmitter node informed the BN. The BN then sent a command to the corresponding receiver node to send statistics (sequence number and RSSI) it collected for the packets it received. Once all the nodes finished sending packets to all other nodes and the same experiment was repeated at different channel. The same experiment was carried out at OdBm transmit power. The following section presents evaluation results and observations of the experiment.

4. RESULTS

Figure 3 has plots of RSSI against 802.15.4 channels at transmit power of OdBm.

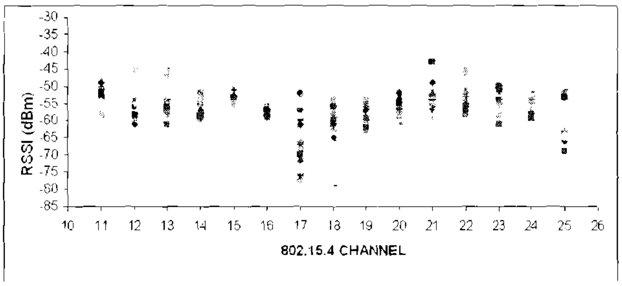

Figure 3 Utilization of channel at power level 0dBm for 802.15.4

From the plots it is clear that channel 21 (802.15.4) depicts the highest RSSI value amongst other channel. According to Figure 1, center frequency for channel 21 is 2.455GHz which overlapped with center frequency of channel 9 and 10 (802.11) and lower frequency of channel 11. Observation from Figure 3 shows during the WSN deployed at channel 21 (802.15.4), channel 9,10 and 11 (802.11) is not utilized (see figure 4).

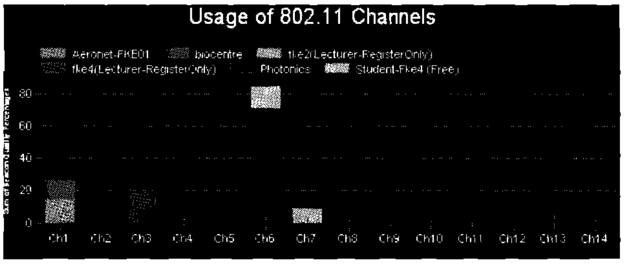

Figure 4 Usage of 802.11 channels during measurement conducted 802.15.4

While for channel 17 (802.15.4) shows the lesser RSSI value. This is due to the highest RSSI value of channel 6 (802.11) which overlapped each other at center frequency 2.435GHz for channel 17 and 2.437GHz for channel 6.

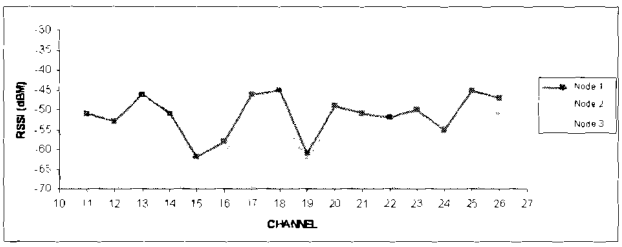

Figure 5 RSSI vs. Frequency channel

Figure 5 shows RSSI vs. Frequency channel for each nodes (node 1,2,3) based on Figure 2 topology. From the plots, it guaranteed that distances of each node influence the RSSI value.

CONCLUSION

In this paper we had identified the problem of interference caused by WiFi networks deployed in the same general geographical area with WSNs that use 802.15.4 radios. Given the big discrepancies between maximum transmission powers across the two radio technologies, interference from competing WiFi networks can cause high data loss rates in low-power, battery-operated WSNs. We verify this expectation through measurements collected from WSNs using 802.15.4 radios, deployed within an office building as well as in the field.

Using RSSI samples it was noticed that to detect 802.15.4 channels overlapping with WiFi channels used by nearby 802.11 networks could be deployed in order to examined the impact on the throughput performance of WLAN and WPAN devices when co-existing within a certain environment.

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