Co-existence of Zigbee and WLAN, A Performance Study

K. Shuaib, M. Boulmalf, F. Sallabi and A. Lakas
College of Information Technology, UAE University,
P.O Box 17555, Al-Ain, UAE
E-mail: k.shuaib@uaeu.ac.ae

Abstract

Wireless Local Area Networking standard (Wi-Fi) and the WPAN standard (Bluetooth and Zigbee) products utilize the same unlicensed 2.4 GHz ISM band. Co-existence between such wireless technologies within the same frequency spectrum is crucial to ensure that each wireless technology maintains and provide its desired performance requirements. In this paper, we investigate the co-existence of WLAN (IEEE 802.11g) with Zigbee (IEEE 802.15.4) standard. The paper focuses on quantifying potential interferences between Zigbee and IEEE 802.11g by examining the impact on the throughput performance of IEEE 802.11g and Zigbee devices when co-existing within a particular environment. In addition, the effect of Zigbee on IEEE 802.11g was compared with the effect of Bluetooth under the same operating conditions.

1. Introduction

Next generation wireless systems will provide the users with a broad range of services assuming that the different types of wireless technologies will work transparently and without any major interoperability issues. Wireless Local Area Network (WLAN) technologies [1] have been leading the indoor Internet distribution in education, business and home environments. They are usually deployed as wireless extension of a broadband access to the network. These technologies are based on CSMA/CA media access with a positive MAC layer acknowledgement and a retransmission mechanism that aids noisy channel propagation condition and eventual undetected collisions. Today WLAN standard defines high rate data throughputs; such as the IEEE 802.11b with a maximum throughput of 11Mbps and the IEEE 802.11g with maximum throughput of 54Mbps. Both IEEE 802.11b and g operates at the 2.4 GHz band. Typically, WLAN devices operate within 100 meters of distance range depending on the surrounding environment. While, the IEEE 802.11b utilizes direct sequence spread spectrum (DSSS) using complementary code keying (CCK) modulation, IEEE 802.11g is based on the orthogonal frequency division multiplexing (OFDM) modulation technique and the CCK modulation for backward compatibility with 802.11b.

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The Bluetooth standard [2, 9] is a specification for Wireless Personal Area Networks (WPAN). Although products based on the Bluetooth standard are often capable of operating at greater distances, the targeted operational area is the area around an individual, e.g. within 10 meters of the user. Bluetooth utilizes a short range radio link that operates in the 2.4 GHz industrial scientific and medical (ISM) band similar to WLAN. However, the radio link in Bluetooth is based on frequency hop spread spectrum. Although at any point in time, the Bluetooth signal occupies only 1MHz, the signal changes center frequency (or hops) deterministically at a rate of 1600Hz. Bluetooth hops over 79 center frequencies, so over time the Bluetooth signal actually occupies 79MHz.

The new short range, low power, low rate wireless networking Zigbee [3, 11] complements the high data rate technologies such as WLAN and open the door for many new applications. This standard operates at two bands, the 2.4 GHz band with a maximum rate of 250 kbps and the 868-928 MHz band with data rates between 20 and 40 kbps. Zigbee is based on DSSS and it uses binary phase shift keying (BPSK) in the 868/928 MHz bands and offset quadrature phase shift keying (O-QPSK) at the 2.4 GHz band. While Bluetooth devices are more suited for fairly high rate sensor applications and voice applications, Zigbee is better suited for low rate sensors and devices used for control applications that do not require high data rate but must have long battery life, low user interventions and mobile topology.

Recently, there have been investigation studies related to the co-existence of WLAN with WPAN and other technologies [4, 5]. For example, the authors in [4] discussed interferences between Zigbee and the signals of particular medical equipments. In [5], a study was done on the interference between Bluetooth and IEEE 802.11b. On the other hand, the performance of different scheduling algorithms for Bluetooth intra-piconet and inter-piconets, was evaluated in [6], without examining the effect of a co-existing WLAN. In [7] the authors present a brief technical introduction of the IEEE 802.15.4 standard and analyze the coexistence impact of an IEEE 802.15.4 network on the IEEE 802.11b devices.

The rest of the paper is organized as follow: section two presents technical details on Zigbee and its radio spectrum sharing with WLAN. Section 3 describes the testbed environment used and section four presents the obtained results. The paper is then concluded in section five along with intended future work.

2. Zigbee Spectrum Sharing with WLAN

At the physical layer Zigbee operates in the ISM band within three different frequency ranges. There is a single channel between 868 and 868.6MHz, Ch 0, 10 channels between 902.0 and 928.0 MHz, Ch1-10, and 16 channels between 2.4 and 2.4835GHz, Ch11-26. The Zigbee standards specify a receiver sensitivity of -92 dbm in the 868/915 MHz band and -85 dbm in the 2.4 GHz band. The physical layer of both frequency bands uses the same common frame structure as shown in Figure 1. Having several channels in different frequency bands makes it possible to relocate within the available spectrum.

Preamble	Start of Packet	Length Field	Physical layer payload
4 bytes	1 bytes	1 bytes	(2-127 bytes)

Figure 1. The frame structure for the IEEE 802.15.4 physical layer

The Zigbee standards define two types of devices, a full-function device (FFD) and a reduced function device (RFD). The FFD can operate in three different modes, a personal area network (PAN) coordinator, a coordinator or a device. The RFD is intended for very simple applications that does not require the transfer of large amount of data and needs minimal resources. A WPAN is formed when at least two devices are communicating one being an FFD assuming the role of a coordinator. Depending on the application requirements, Zigbee devices might operate either in a star topology or a peer-to-peer topology. Figure 2 shows both topologies. As seen in Figure 2, in a star topology the flow of communication is established between devices and an FFD acting as the PAN coordinator. The PAN coordinator is a device that is responsible for initiating, terminating and routing information around the network. The star topology is mostly used in small areas such as home automation, personal health care management and hospital rooms while the peer-to-peer topology is used in larger scale and more complex networks.

There are three types of data transfer mechanisms exist between Zigbee devices: from a coordinator to a device, from a device to a coordinator and between two peer devices. The data transfer mechanism used depends on whether the network supports the transmission of beacons or not. For example, in a non-beacon-enabled network, a device simply transmits its data frames using the un-slotted CSMA-CA, to the coordinator. However, in a beacon-enabled network, the device first listens for the network beacon and at the right time, it transmits its data frames, using slotted CSMA-CA, to the coordinator. In a peer-to-peer network, every device can communicate with any other device within its transmission radius using one of two options: by constantly listening to the channel and transmitting its data using un-slotted CSMA-CA or by synchronizing with other nodes so that they can save power.

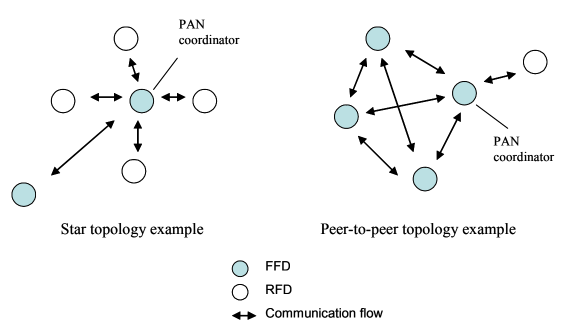

Figure 2. Zigbee star and peer-to-peer example topology

Spectrum Sharing: With the increased use of devices operating at the 2.4 GHz band the WLAN and Zigbee devices are likely to be in close proximity to one another with possible interference. To understand the aspects of this problem the RF spectrum at 2.4 GHz and available channels for WiFi (IEEE 802.11 b, g) and Zigbee is shown in Figure 3. As seen in Figure 3, the RF channels in ZigBee and WiFi overlap and that generates a concern when such devices are within close proximity.

3. Test Scenarios

In this work a test-bed was created to investigate the potential interference effect of Zigbee on IEEE 802.11g and vice versa. Tests conducted are intended to obtain empirical throughput data corresponding with certain realistic scenarios in which IEEE 802.11g and Zigbee connections may coexist. It is important to realize that many other different coexistence scenarios are probable in realistic usage, each with its own unique set-up characterized by different relative distances, applications, and performance measures.

Test-bed Description: Several tests were conducted to see the effect of Zigbee on the performance of IEEE 802.11g and vice versa. These tests were performed in an open indoor cubical office environment area, with no interferences from any other radio frequency devices except for the ones used in the test-bed. We used a Linksys IEEE 802.11g access point (AP), two Dell Latidude D600 laptops with USP Zigbee or Bluetooth interface cards and one similar laptop with an IEEE 802.11g interface card. As seen from Figure 4, the AP and a PC server was connected to the Fast Ethernet switch, while the laptop with an IEEE 802.11g interface card was placed on an 80 cm high desk a distance 10.5 meters from the base of the AP which was placed on a 2.5 meters wood post. TCP traffic was generated from a single source on the IEEE 802.11g client and received at the PC Server. The traffic was generated using the "LanTrafficV2" software with packet payload size of 1460 bytes and a fixed inter-packet delay of 1 ms. For all tests, 60,000 packets where transferred between the IEEE 802.11g client and the PC server.

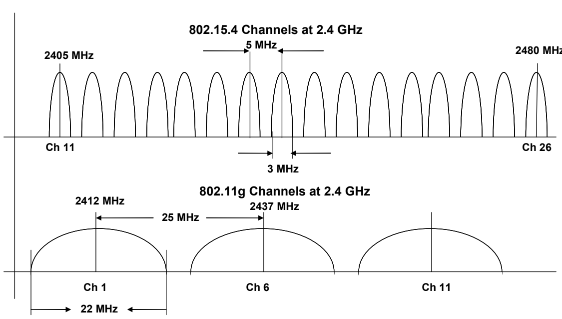

Figure 3. RF Spectrum for Zigbee and WiFi

For all testing scenarios, the RTS/CTS protection mode was on at the IEEE 802.11g Linksys AP. In this mode, when a device wants to communicate it sends a Request To Send (RTS) to the destination node, and waits for a Clear To Send (CTS) message before it transmits any data. This is done to avoid collisions, but it brings the maximum data throughput performance down [8]. The RTS/CTS handshaking provides positive control over the use of the shared medium. The primary reason for implementing RTS/CTS is to minimize collisions among hidden stations. This occurs when users and access points are spread out throughout the facility and a relatively high number of retransmissions occurring on the wireless LAN

After a baseline testing of the throughput performance of IEEE 802.11g, the Zigbee devices were introduced at different positions with respect to each other, the WLAN AP and the IEEE 802.11g client. Figure 5 shows the general layout of the testing area. Figure 6 shows the baseline throughput performance of the IEEE 802.11g client operating when placed in the reference cubical with respect to the AP using Ch6 and then Ch11, with no interference from any other devices. In this case, the average received throughput for the IEEE 802.11g client was 9.8 Mbps for both channels. The reported throughput for all test cases as measured by the "LanTrafficV2" was for the transport layer payload after the removal of all underlying headers.

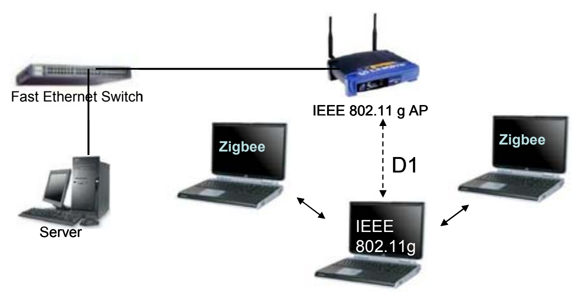

Figure 4. Basic test-bed for IEEE 802.11g throughput

4. Performance Results and Analysis

To look at the effect of Zigbee devices on the performance of WLAN, two laptops were equipped with USP Zigbee interface cards were introduced into the test-bed area and placed at different positions with respect to both the IEEE 802.11g AP and laptop. All tests ran to investigate the effect of Zigbee were run on the WLAN while data was being transferred between the two laptops with Zigbee interface cards. The Zigbee interface cards were Maxstream XBee-PRO USB RF modems [10] using an omni-directional 15 cm antenna. The two Zigbee modems were used in a unicast peer-to-peer communication where data was sent bi-directionally at the rate of 115 Kbps with an inter packet delay of 200 ms. The channels on the Zigbee modems and IEEE 802.11g AP were chosen depending on the test to be run. Several tests were conducted not just to examine the effect of Zigbee on IEEE 802.11g and vice versa, but also to compare Zigbee with Bluetooth as per its interference effect on the performance of the IEEE 802.11g.

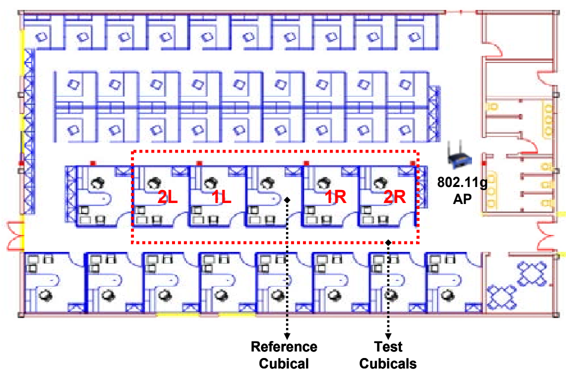

Figure 5. Test-bed layout setup area

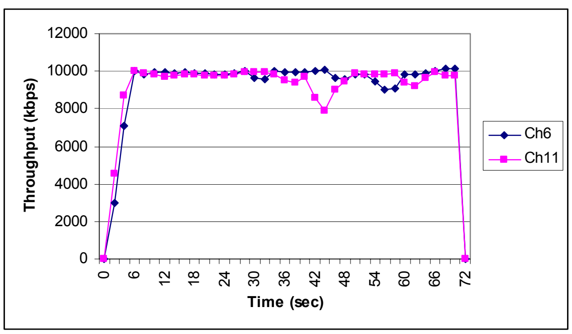

Figure 6. Baseline throughput results of IEEE 802.11g when operating at Ch6 and Ch11

Experiment 1, IEEE 802.11g using Channel 11 and Zigbee using Channel 12: In this experiment, the maximum frequency separation between the central carrier frequencies of the interfering devices was chosen where the IEEE 802.11g channel was set to be Ch11 operating at a central carrier frequency of 2462 MHz, while the channel on the Zigbee modems was set to be Ch 11 operating at a central carrier frequency of 2405 MHz. The IEEE 802.11g client and the two Zigbee devices were placed within the reference cubical as seen in Figure 5. The distance between the IEEE 802.11g AP and the IEEE 802.11g client placed in the reference cubical was 10.5 meters, with the two Zigbee devices being 1 meter a part near the IEEE 802.11g client. For this test case, no interference effect was reported neither on the performance of the IEEE 802.11g client nor on the throughput of the Zigbee devices.

Using the same testbed and under the same conditions, but replacing Zigbee with Bluetooth, there was a great effect on the throughput performance of the IEEE 802.11g client operating at Ch11. The average throughput of the IEEE 802.11g client dropped by 19% and was measured to be 7.9 Mbps.

Experiment 2, IEEE 802.11g using Channel 6 and Zigbee using Channel 17: In this experiment, the channels on the interfering devices were chosen so that their spectrum co-inside with each other. Ch6 operating at a central carrier frequency of 2437 MHz was chosen on the IEEE 802.11g AP, and Ch17 operating at a central carrier frequency of 2435 MHz was chosen on the Zigbee devices. Three test cases were conducted: the first test case was run with the IEEE 802.11g and Zigbee devices within the same reference cubical as in Experiment 1. The second test case was run with the Zigbee devices placed one in cubical R1 and the other in cubical L1 (approximately 6 meters apart) while the IEEE 802.11g client was in the reference cubical. The third test case was as the second one, with the Zigbee devices placed in R2 and L2 being approximately 12 meters apart. The results for these experiments are summarized in Table 1. The same three experiments were conducted with Bluetooth replacing Zigbee and the results are summarized in Table 2.

As can be seen by looking at the results in Table 1, there was no significant effect on the performance of the IEEE 802.11g due to interference from Zigbee for all conducted test cases. However, that was not true for the Zigbee devices since the throughput was affected in all test cases with case three being the worst. Table 2 shows how Bluetooth, as expected, greatly affected the performance of the IEEE 802.11g client and vice versa the performance of Bluetooth was also greatly affected by the presence of an IEEE 802.11g network in close proximity.

Experiment 3, Effect on the uplink from the IEEE 802.11g AP to the IEEE 802.11g client: The first set of experiments was done to study the interference effect when Zigbee or Bluetooth devices are placed within a close proximity from an IEEE 802.11g client. These tests basically looked at the impact on the IEEE 802.11g down link channel from the IEEE 802.11g AP to the IEEE 802.11g client. In this experiment we looked at how such devices might affect the performance of IEEE 802.11g when placed near the AP rather than the WLAN client, i.e. affecting the uplink between the WLAN AP and its client. With the IEEE 802.11g client residing in the reference cubical, the Zigbee or Bluetooth devices were placed D2 meters a part at several positions on the same horizontal line as the IEEE 802.11g AP but on a 50 cm high table. Table 3 summarizes the results for these test cases.

Table 1. Results for the three test cases in Experiment 2

Test Case	*Percentage drop in IEEE 802.11g throughput*	*Percentage drop in Zigbee throughput*
1	Insignificant	10% (from 100% to 90%)
2	Insignificant	10% (from 100% to 90%)
3	Insignificant	22% (from 83% to 65%)

Table 2. Results for the three test cases in Experiment 2, with Bluetooth replacing Zigbee.

Test Case	*Percentage drop in IEEE 802.11g throughput due to Bluetooth*	*Percentage drop in Bluetooth throughput due to IEEE 802.11g*
1	12% (from 9.8 Mbps to 8.6 Mbps)	21% (from 554 kbps to 440 kbps)
2	6% (from 9.8 Mbps to 9.2 Mbps)	36% (from 512 kbps to 328 kbps)
3	4.6% (from 9.8 Mbps to 9.35 Mbps)	17% (from 365 kbps to 303 kbps)

Table 3. Results for Experiment 3

D2 (meters)	*Percentage drop in 802.11g throughput due to Zigbee*	*Percentage drop in IEEE 802.11g throughput due to Bluetooth*
4	11% (from 9.8 to 8.7 Mbps)	19% (from 9.8 to 7.9 Mbps)
6	6% (from 8.8 to 9.2)	17% (from 9.8 to 8.1 Mbps)
8	Insignificant	20% (from 9.8 to 7.8 Mbps)

Experiment 4, IEEE 802.11g weak signal: To see the effect of Zigbee and Bluetooth on WLAN, in an environment where the IEEE 802.11g signal strength is weak, we emulated positioning the IEEE 802.11g client at a distance considered far from the AP. This was done by placing the AP behind an obstacle that brought down the signal strength indicator on the IEEE 802.11g card software fluctuating around -80 dbm. At this signal strength level, a test was performed with all interfering devices were placed within the reference cubical with the AP operating on Ch6 and the Zigbee devices operating on Ch17. The baseline performance of the IEEE 802.11g client without any source of interference and at this signal strength level was measured at 6.7 Mbps. Table 4 summarizes the obtained results for this test case. As seen in Table 4, there was a slight effect on the performance of the 802.11g client for this test case due to interference from Zigbee; however, the effect of Bluetooth was drastic with a 53% drop in the throughput compared to 22% drop when the IEEE 802.11g signal strength was at full strength around -40 dbm as was shown in Table 2.

5. Conclusions

In this paper an extensive campaign of experiments and measurements was done to quantify the interference effect of Zigbee devices on the throughput performance of the IEEE 802.11g and vice versa. The results show that the Zigbee interference has more effect on the IEEE 802.11g uplink rather than the downlink. Furthermore, the results show how IEEE 802.11g is greatly more affected by Bluetooth than Zigbee and how IEEE 802.11g affects the performance of Zigebee when the spectrum of the chosen channels of operation co-inside. Our intended future work will be to expand on the obtained results and conduct more test scenarios under different conditions to further characterize the interference effect of Zigbee/Bluetooth/WLAN on each other and to provide a performance model for an environment where all three technologies can co-exist.

Table 4. Results for Experiment 4

Percentage drop in IEEE 802.11g throughput when using Zigbee	*Percentage drop in IEEE 802.11g throughput when using Bluetooth*
6% (from 6.7 to 6.3 Mbps)	52% (from 6.7 to 3.2 Mbps)

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