UDC 004.735, DOI: 10.2298/CSIS0901169M

Co-existence Performance Evaluation of Wireless Computer Networks in a Typical Office Environment

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Abstract. The Wireless Local Area Networks (WLANs) are often used as a wireless extension to the typical office network infrastructure providing mobility to the users. In addition Wireless Personal Area Networks (WPANs) serve interconnection to computer and mobile phone peripherals as headsets, input devices, printers etc. Thus it is common that WLANs and WPANs have to operate in the same area. IEEE 802.11b/g is the most popular WLAN technology operating in the 2.4GHz Industrial Medical and Scientific (ISM) band. On the other hand Bluetooth (BT) is the technology often used to support WPANs. As BT also uses the 2.4GHz ISM band, there an issue of interference between WLANs and PANs. In this work the performance degradation in Wireless Local Area Networks and Wireless Local Area Networks due to co-existence is examined by real measurements. Both 802.11 to 802.11 and 802.11 to Bluetooth coexistence is addressed.

Keywords: Co-existencse; WLAN; WPAN; Bluetooth; 802.11.

1. Introduction

The replacement of the classical wired network infrastructure, with wireless technologies is a fact. The most popular technology used for Wireless Local Area Networks is the IEEE802.11b/g. On the other hand, to provide wireless peripheral connectivity, the Wireless Personal Area Networks (WPAN) based in Bluetooth (BT) technology, are commonly used. Therefore, there is the need for these two technologies to coexist and cooperate in the same location.

802.11 compliant networks are based in Direct Sequence Spread Spectrum (DSSS) transmission technique [1] or Orthogonal Frequency Division Multiplexing (OFDM). Using 13 frequency channels with 22MHz bandwidth and 5MHz spacing 802.11 technology occupies a total bandwidth of 82MHz from 2410MHz to 2483MHz. Taking advantage CCK-OFDM modulation, 802.11 WLANs are capable to achieve a bit-rate of 54MBit/s (802.11g). In Fig. 1 the channel allocation of 802.11b/g technology is presented.

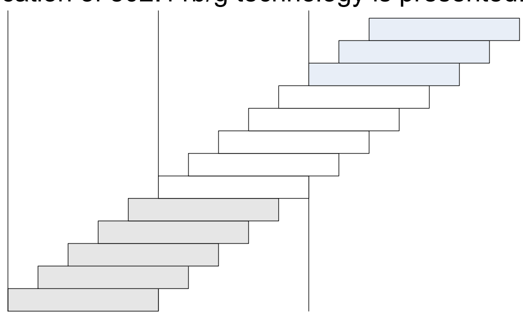

Fig. 1. 802.11b/g channel allocation. As it can be seen there are only 3 independent (adjacent channel interference free) channels available

BT [2] compliant networks take advantage of Frequency hopping Spread Spectrum (FHSS) Technology to provide a gross bit rate of 1Mbit/s. Each hoping channel has a bandwidth of 1MHz whereas 79 hopping channels are used to provide interference immunity. Thus Bluetooth devices occupy a 79MHz bandwidth from 2400MHz to 2479MHz.

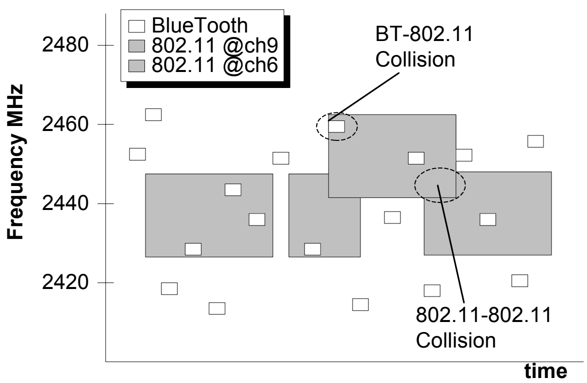

Fig. 2. Graphical Representation of 802.11 and BT packet collision. A collision occurs when different traffic packets

Therefore, both 802.11 and BT technologies operate in the same frequency band of 2.4GHz, known as the Industrial, Scientific and Medical band (ISM). Thus the co-existence [3] [4] of these two technologies introduces performance degradation to each other due to interference. In addition due to the fact that the 802.11 channels are overlapping each other adjacent channel interference often exists which also result to performance degradation.

In Fig.2 a graphical representation in the time-frequency plane of such interference (packet collisions) is presented.

As it can be seen, collisions occur whenever different traffic packets coexist in the same time with overlapping frequencies. This representation is used in this paper to describe several co-existence scenarios.

In this paper a performance evaluation of WLAN and WPANs in an office co-existence environment is presented. The evaluation is based in real measurements in a typical office environment. Both the 802.11 to 802.11 and 802.11 to BT interference is examined. The rest of this paper is organized as follows. In section 2 the measurement site is presented. Section 3 describes the measurement methodology. In section 4 the results are presented for several coexistence scenarios. Finally section 5 contains the conclusions.

2. Measurement Site

To perform measurements a site was chosen in the Technological and Educational Institute (TEI) of Crete. The room of Non-Ionizing Radiation Laboratory (NIRL) was selected which is a big room (9.5m by 7.2m) where several working station exist. Due to the fact that this area is in a semi-basement in a new unpopulated building, the measurement area is unaffected by external sources of electromagnetic radiation. Spectrum measurements were carried out in the laboratory area to ensure the control of the interference during the experiments. In Fig. 3 the layout of the measurement environment is shown.

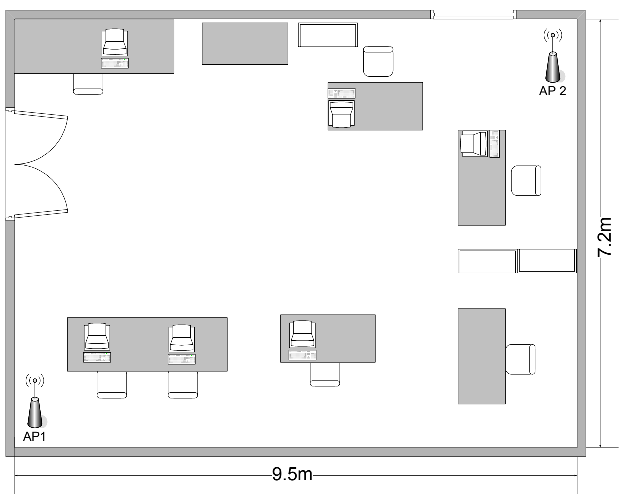

Fig. 3. Measurement site layout (Non-Ionizing Radiation Laboratory room).

Two 802.11b/g Access Points (APs) are placed in the room to provide wireless connectivity shown as AP1 and AP2 in Fig. 3. This way we can also examine the 802.11 to 802.11 interference. In the area several Desktop and laptop computer exist. Some of the computers are having wireless access to the network. In addition some computers are equipped with BT dongles which allows them to have communication sessions using BT technology.

3. Measurement Methodology

Today's wireless nodes are using either TCP or UDP packets to communicate trough the network depending on the provided service. Usually real time network traffic (such as video streaming, Voice over IP e.t.c) are using User Datagram Packets (UDP) whereas file transfer require Transmission Control Protocol (TCP) packets to ensure errorless delivery as TCP traffic is connection oriented [5].

To perform a measurement, first the required network topology is created. After network setup, network traffic has to be created and captured to measure performance. To do this iperf was used in a Windows XP platform. Iperf is special purpose software that creates and captures TCP and UDP traffic and is commonly used for measurements [7]. After traffic creation and capturing, packet analysis is performed using tcptrace utility in linux.

To provide a reference for the measurements, the performance of each wireless network (802.11 and BT) in no coexistence environment is measured. Then several coexistence scenarios, as described in section 4 are examined.

Four different measurement parameters are used to evaluate network performance: Throughput Round Trip Time (RTT) delay, Packet to Packet (P2P) delay and P2P delay variation (Jitter). Throughput is a metric of the information rate that can be achieved for the user and is applicable both in TCP and UDP traffic.

In wireless networks, Round Trip Time (RTT) delay measurements constitute the basic feedback information that the end hosts can use to infer the state of the network connection between them [6]. RTT is defined as the time in between, when the data packet is sent and when the acknowledgment is received, thus RTT delay is applicable only to TCP traffic. The RTT delay measurement is used to infer the rate at which a real time connection between two hosts can be initiated, so that it does not disrupt existing connections.

P2P delay describes the inter-arrival time of subsequent data packets that arrive over a network (usually applicable in UDP traffic). The variation of P2P delay is commonly referred as Jitter. For most types of data traffic large variations between arrival times are acceptable. However for networks that carry real time data (voice, video e.t.c) relatively small differences in arrival times introduce cause perceptible disturbances in the quality of Service (QoS).

4. Results

To examine coexistence effect several coexistence scenarios (cases) have been examined. In this section measurement results form some of these cases are presented.

4.1. Case 1, 802.11 Adjacent Channel Coexistence

In case 1 the interference between 802.11 coexistent networks that operate in adjacent overlapping channels is examined. An 802.11 subnet is exchanging data using channel 1 for 60sec whereas in the first 30 seconds, another 802.11 subnet operating in channel 3 is also transmitting. This scenario is graphically presented in Fig. 4. As it can be seen half of the bandwidth of the 802.11 channels is overlapping each other.

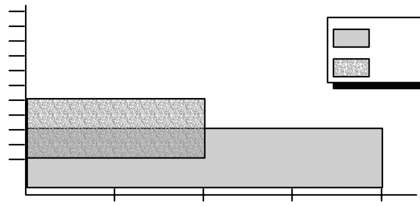

Fig. 4. Case 1: 802.11 to 802.11 overlapping channel interference). Interference occurs for t=0sec to t=30 sec.

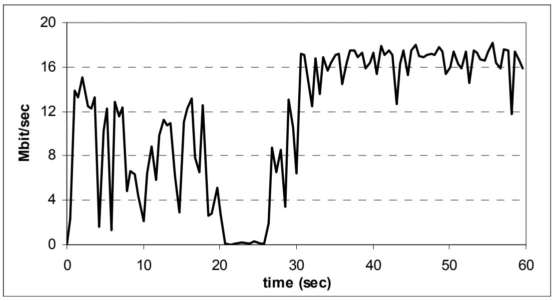

Fig. 5. Case1 TCP throughput. Performance degradation during co-existence period (t=0sec to t=30sec) is noticeable.

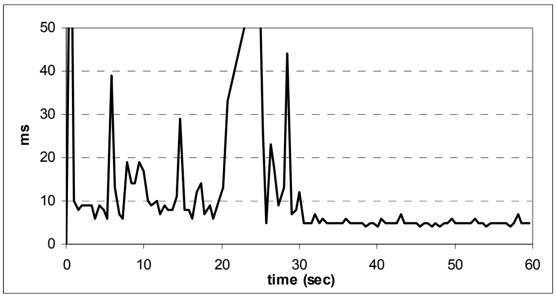

Fig. 6. Case1 RTT delay. Performance degradation during co-existence period (t=0sec to t=30sec) is noticeable.

In Fig. 5 the throughput for TCP traffic for case 1 is presented showing the affect of 802.11 to 802.11coexistence effect. Table 1 presents the average throughput for case 1 with (first 30 seconds) and without interference (next 30 seconds).

Table 1. Average throughput and RTT delay for case1

	0-30sec	30-60sec
Average throughput	7.02Mb/s	16.49Mb/s
Average RTT Delay	21.47ms	5.07ms

As it can be seen, the performance decrease in this case is about 57% regarding throughput whereas the average RRT delay triples.

4.2. Case 2, 802.11 Non-Overlapping Adjacent Channel Coexistence

In this case the interference between 802.11 coexistent networks that operate in adjacent non overlapping channels is examined. The traffic scenario is presented in Fig. 7.

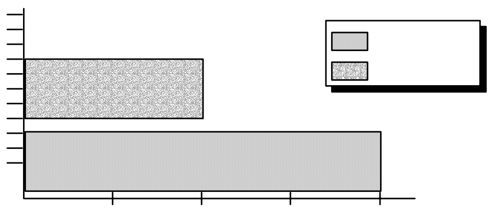

Fig. 7. Case 2:802.11 to 802.11 non-overlapping adjacent channel interference

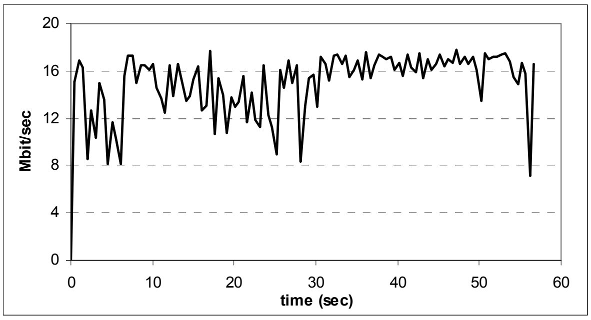

Fig. 8. Case2 TCP throughput.

In Fig. 8 the TCP traffic throughput for case 2 is presented whereas in Fig. 9 the RTT delay for case 2 is shown. It is obvious, although the operating 802.11 channels in this case are non-overlapping, there is a degradation of about 14% in throughput and 20% increase in RTT delay. This is possible due to out of band emission of such systems. Table 2 contains the average throughput and RTT delay for case 2.

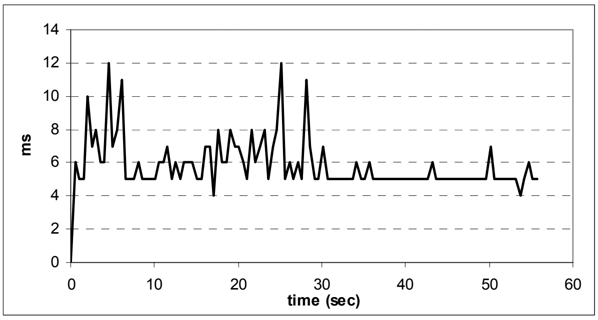

Fig. 9. Case2 RTT delay.

Table 2. Average throughput and RTT delay for case2

	0-30sec	30-60sec
Average throughput	13.87Mb/s	16.12Mb/s
Average RTT Delay	6.43ms	5.35ms

4.3. Case 3 BT To 802.11 Interference

In this case an 802.11 transmission is interfered for 30 sec by a BT transmission. The 802.11 network operate in channel 6 and after 30 sec a coexistent BT session takes place with another 30 sec duration. After 30 sec of coexistence the 802.11 network is measured for another 30 sec. This case is presented graphically in Fig. 10.

In Fig. 11 the throughput in this case is presented. The performance degradation due to the BT interference is noticeable. Fig. 12 presents the RTT delay for this case.

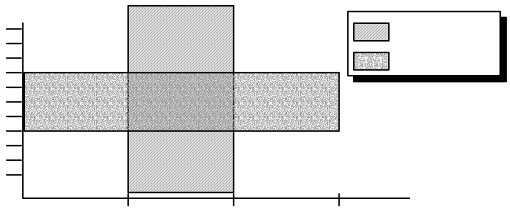

Fig. 10. Case3 (BT to 802.11 Interference). Interference occurs for t=30sec to t=60 sec

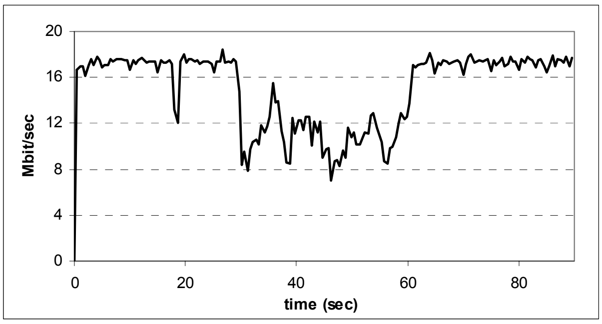

Fig. 11. Case3 TCP throughput. Performance degradation during co-existence period (t=30sec to t=60sec) is noticeable.

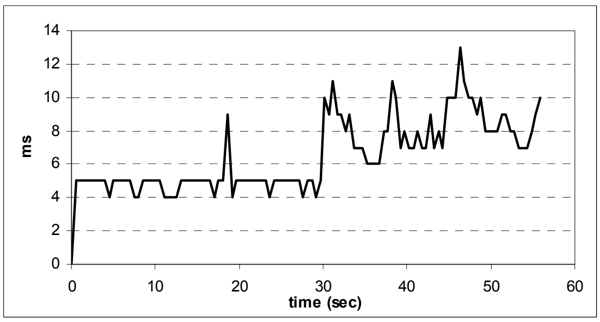

Fig. 12. Case3 RTT delay. Performance degradation during co-existence period (t=30sec to t=60sec) is noticeable

4.4. Case 4 Multiple Coexistence

In case 4 a multiple coexistence scenario is examined. A BT network is transmitting for 150 seconds. 30 seconds after the start of BT transmission, 802.11 subnetwork1 starts a session in channel 1 for 60 second. In addition, 30 second after the start of subnetwok1 session, another 802.11 session initiates, which also lasts for 60 seconds. This scenario is represented by Fig. 13

In Fig. 14 the throughput of the BT transmission for case 4 is presented, where in Fig. 15 the RTT delay. It can be noticed that about 10 seconds after the start of the transmission of subnetwork2 (t=70), BT performance improves. This is due to the fact that the used BT device incorporates an adaptive frequency hopping mechanism to avoid occupied channels, which mechanism require some time to discover the occupied bandwidth. The same effect can be noticed in Fig. 15 where the RTT delay is presented.

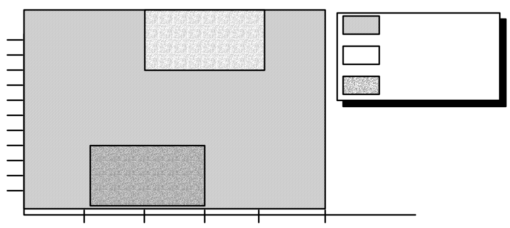

Fig. 13. Case4: Multiple 802.11 to BT interference.

Fig. 16 and Fig. 17 shows results for case 6 regarding P2P delay and P2P delay variation (Jitter) when using UDP traffic. It can be shown that in case of single coexistence (time 30sec to 60sec) the average P2P delay increases by 26% whereas in double coexistence (time 30sec to 60sec) by 49%. This would increase the need for anti-jitter buffers to compensate for, in such a scenario which will increase service ping time.

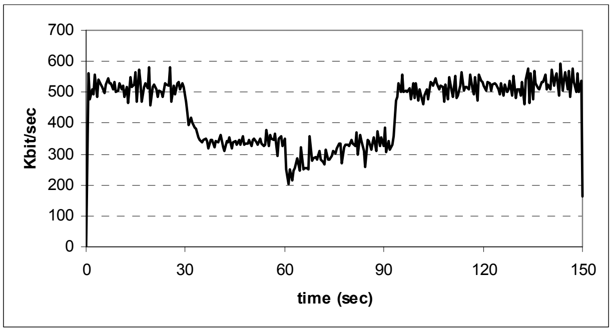

Fig. 14. Case4 TCP throughput For BT

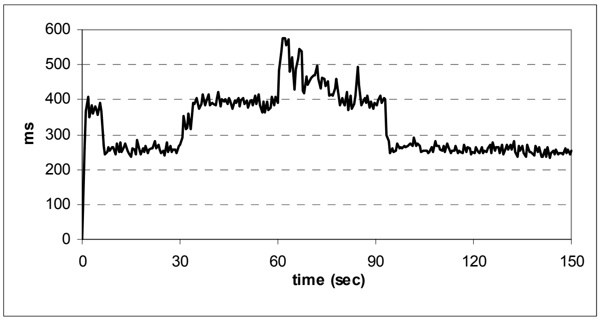

Fig. 15. Case4 RTT delay.

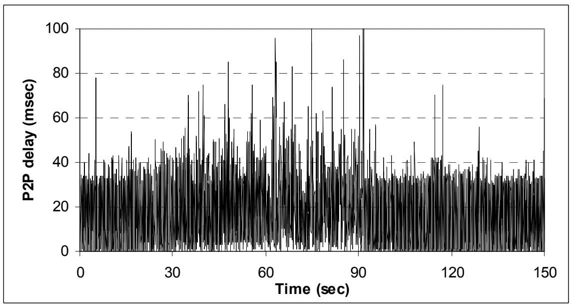

Fig. 16. Case4 P2P delay.

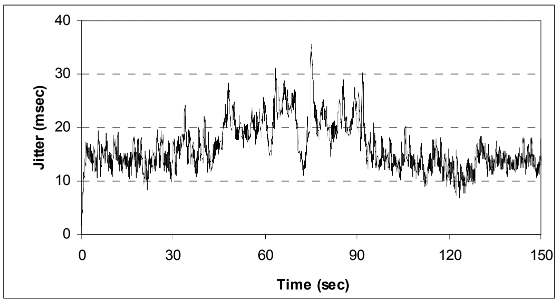

Fig. 17. Case4 P2P delay variation (jitter)

Table 3. Average throughput RTT delay and P2P delay for case2.

	0-30 sec	30-60 sec	60-90 sec	90-120 sec
Average troughput	519.0Kb/s	346.7Kb/s	302.8Kb/s	514.4Kb/s
RTT delay	278.9ms	384.9ms	446.1ms	257.4ms
P2P delay	14.21ms	17.96ms	21.19ms	14.11ms

4.5. Spectrum Measurements

To demonstrate the operation of AFH of the used BT network, spectrum measurements with a Spectrum analyzer have been performed. These measurements were carried out in the scenario described by Fig. 18. In this scenario, an 802.11 WLAN starts transmission using channel 1 at time t=0sec. 10 seconds later (t=10sec) a BT network begin to transmit data an thus interfere with the WLAN. At time t=20sec coexistence stop to occur as the WLAN stop communications.

Fig. 19 through Fig. 22 show spectrum snapshots during this scenario at varies time instances. Fig. 19 depicts the occupied spectrum at t=2sec where the only RF source is the WLAN operating channel 1.

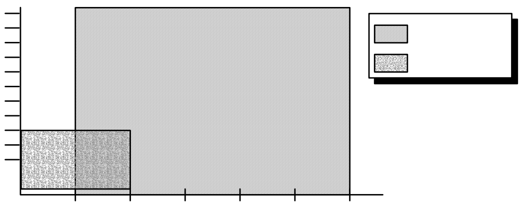

Fig. 18. Case5 Collision description.

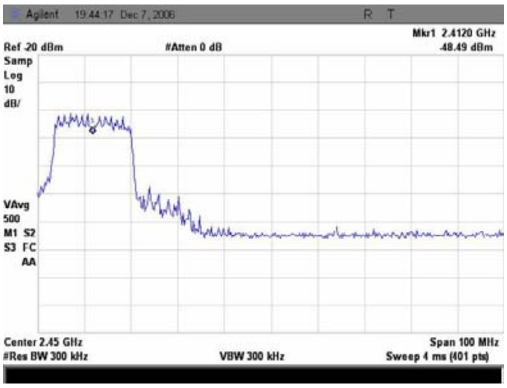

Fig. 19. Spectrum measurement for Case5, t=2sec. Only 802.11 traffic is present occupying 802.11 channel 1.

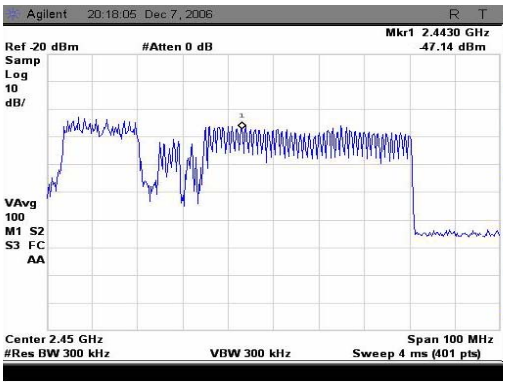

Fig. 20. ISM Spectrum for Case5 (t=14sec). 802.11@channel 1 and BT traffic share the 2,45GHz ISM Band

A snap shot of the spectrum 4 sec after co-existence (t=14drc) is shown in Fig. 20. At this time, the BT network senses the presence of the WLAN and start avoiding the occupied by the 802.11 transmission bandwidth.

Fig. 21 shows the spectrum of the ISM band 10 seconds the coexistence termination. It is obvious that at this time the BT AFH mechanism has not yet sensed the release of the previously occupied bandwidth and continues to avoid frequencies in 802.11 channel 1.

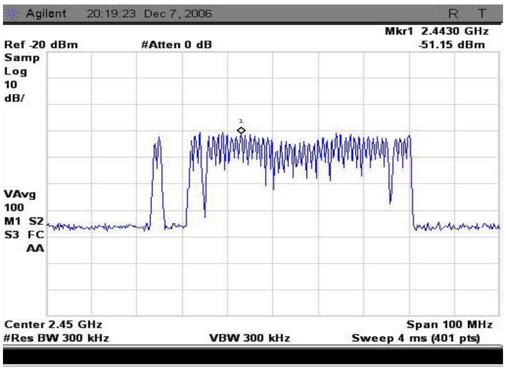

Fig. 21. ISM Spectrum for Case5 (t=30sec). 802.11 Traffic is just stopped. BT AFH mechanism has not noticed yet the availability of the 802.11 channel 1 bandwidth

Finally in Fig. 22 where the spectrum 30 seconds after the coexistence termination is presented, it can be seen that the BT AFH mechanism have sensed the absence of the WLAN interference and thus it start using the released frequencies.

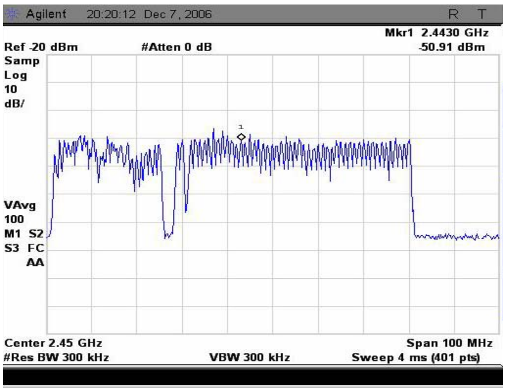

Fig. 22. ISM Spectrum for Case5 (t=60sec). BT AFH mechanism has noticed the availability of the 802.11 channel 1 bandwidth and uses it to serve traffic

5. Conclusions

Wireless local area networks are very commonly used in today's network infrastructure to provide user mobility. Moreover wireless personal networks are used to serve wireless peripheral interconnection. Thus WLAN and WPAN usually have to coexist in the same location as the serve different needs in the same environment. In this work the performance degradation of the wireless local area networks and wireless personal area networks is examined by means of real measurements.

Several coexistence scenarios have been examined regarding both WLAN to WLAN and WLAN to WPAN interference. Measurements were performed to obtain quality metrics such as throughput, RTT delay, P2P delay and jitter for TCP and UDP network traffic.

Results show the degradation to the performance when coexistence occurs which in some cases (802.11 to 802.11 adjacent channel interference) reaches 70% for WLAN throughput, and 50% for RTT delay. Regarding WPAN the degradation proved to be less as the used WPAN incorporates AFH coexistence mechanism.

6. References

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He was a leader or participant in numerous EU, national, bilateral and industrial programmes. He is an author of more than 120 publications in international journals, conference and workshop proceedings.

Received: August 04, 2008; Accepted: November 10, 2008.