Ultra Wideband Signal Impact on IEEE802.11b and Bluetooth Performances

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***Abstract*— This paper presents the results of a co-existence study investigating the impact of ultra wideband (UWB) interference on IEEE802.11b and Bluetooth networks. Results are based on the experimental test measurements made at the University of Oulu, Finland using simple high power UWB transmitter prototypes as interference sources. Preliminary results showed that, under the extreme conditions of this experiment, both IEEE802.11b and Bluetooth networks will slightly suffer from the existence of several high proximity UWB signals. In our study, several high power UWB transmitters that greatly exceed the FCC radiation regulations have been used, and the measurement settings presents the worst case scenario due to the very short distance between the interferers and the victim system. Effectively our study indicates the use of hundreds of FCC compatible UWB devices at a same space.**

Keywords; co-existence, Bluetooth, IEEE802.11b, throughput, ultra wideband, WLAN

I. Introduction

At present, 10’s of millions of IEEE802.11b enabled WLAN devices have been installed worldwide representing a huge investment in a popular wireless technology. Bluetooth enabled devices have also become popular for short range wireless connections. The huge bandwidth of UWB devices overlays both 802.11 and BlueTooth and has, in some cases, lead to concerns for the performance of these unlicensed radio systems.

In this paper, the performance of IEEE802.11b and Bluetooth connections are examined when intentional UWB interference is present. A large number of UWB transmitters are used to disturb the short range network transmission link and the throughput and SNR from the networks were recorded.

Effectively the measurement scenario represents the situation when hundreds of FCC compatible UWB devices are simultaneously active. The UWB transmitters used exceed the current FCC radiation limits [1] and cannot be commercially used but are suitable for modelling the aggregate phenomena of the heavy UWB population.

The paper is organized as follows. Chapter II introduces the hardware used in the study. In Chapter III, the test network has been described. Chapter IV gives the results of the experimental co-existence tests and finally Chapter V gives conclusions.

II. UWB Hardware Description

The WLAN laboratory measurement network is based on off-the-self IEEE802.11b WLAN cards installed on two laptops, and the dataflow has been monitored by customised software. The Bluetooth network is based on the integrated Bluetooth chips on two laptops. The operating system of the laptops on both of these independent networks is Linux, which allows more tailoring of the monitoring tools.

The UWB transmitters used in the study were designed and built by PJ Microwave Ltd., Oulu, Finland. These signal sources are simple short pulse waveform generators without data transmission capabilities. The pulse generators are based on a technique introduced in [2] and are generating a train of short pulses, called monocycles. The measurement configuration with a victim WLAN receiver is presented in Figure 1.

The UWB transmitters are encapsulated in metal boxes to reduce the unintentional radiations so all the radiation comes through the antenna.

The pulse generator is built on a single sided circuit board alongside a free running oscillator which is used to trigger the pulse that is generated using a step recovery diode. In the time domain, the generated pulses have approximately a width of T_p = 500 ps. The pulse repetition frequency in the first prototypes is fixed at 87 MHz due to the non-adjustable voltage controlled oscillator. The characteristics of the received signal have been measured using a digital sampling oscilloscope with the same antenna type as used at the transmitter as stand-alone WLAN antennas were not available. Generated and received pulse waveforms are presented in Figure 2. The received waveform seen by the WLAN or Bluetooth is different to that presented due to the narrower bandwidths of their antennas. However, the figures indicate the spectral characteristics of the transmitted UWB pulse in the channel.

The generated waveform is measured using a digital sampling oscilloscope directly from the output port of the circuit board. The centre frequency of the transmission is around 1.8 GHz (Figure 3). The frequency domain presentation is calculated from the measured pulse waveform using the Fourier transform. The pulse train is also regenerated in Matlab.

The peak-to-peak voltage for the pulse measured from the output port of the circuit board is approximately 300 mV. The circuit board uses a 9 volt power source, with a total power consumption of less than 300 mW.

The antennas have an omni-directional radiation pattern and they are manufactured using standard PCB processes. The EIRP power depends on the pulse repetition frequency and it is approximately -2 dBm ... +3 dBm. It should be noted that these first prototypes are not compatible with the FCC regulations, and they are classified as an "**extremely high power**" UWB devices. The total number of UWB transmitters available at present at CWC is 20. The FCC radiation mask is exceeded approximately 30 dB at the WLAN band.

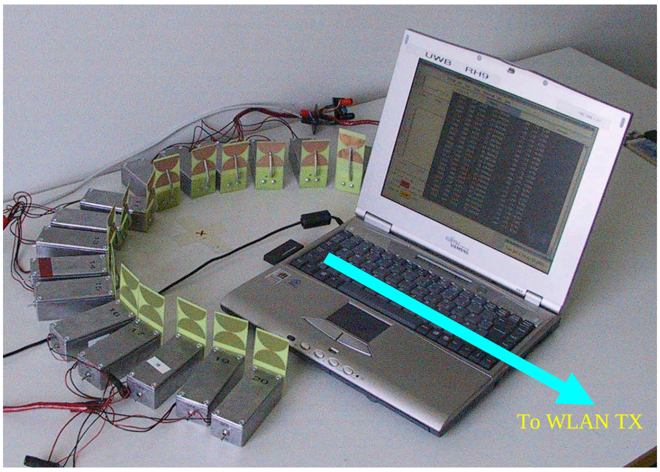

Figure 1. UWB transmitters with victim WLAN receiver, an actual measurement setup.

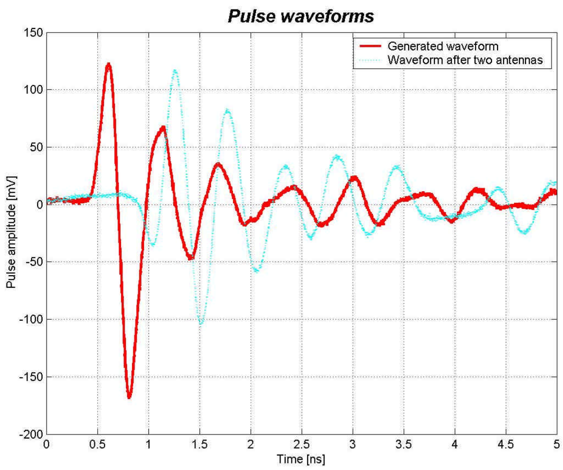

Figure 2. Generated and received UWB pulse waveforms.

III. Test Network

The UWB coexistence performance measurements were conducted for two different networking technologies; IEEE 802.11b WLAN and Bluetooth. The WLAN measurements were performed in an anechoic chamber and a typical office environment while the Bluetooth measurements were carried out only in office environment during office hours. The basic setup for both of these tests were however the same; two laptops with either WLAN or Bluetooth network cards communicating with each other using TCP protocol in peer-to-peer mode.

The IEEE 802.11b WLAN operates at 2.4 GHz ISM frequency band. The supported bit rates are 11 Mbps, 5.5 Mbps, 2 Mbps, and 1 Mbps depending on the available link quality. However, even in the no interference case, the highest data rate achieved was 5.5 Mbps.

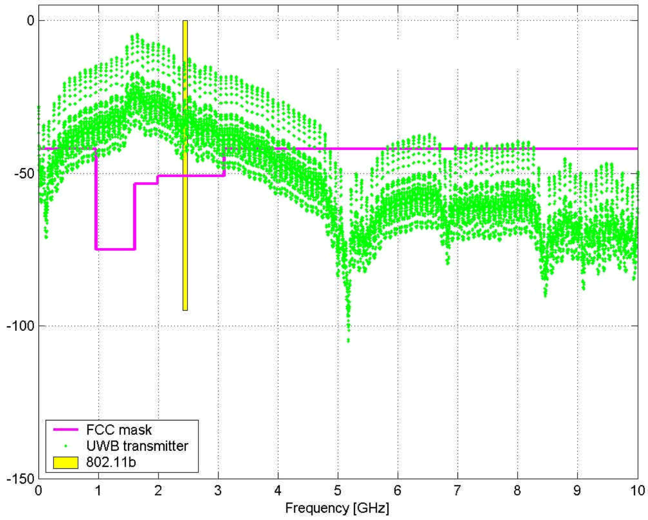

Figure 3. Spectrum of the train of UWB pulses with the FCC radiation mask. The 2.45 GHz ISM band is highlighted.

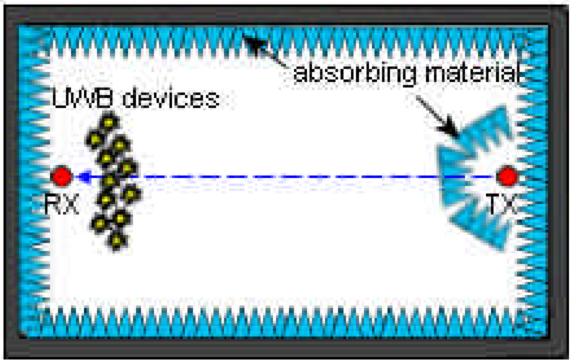

Figure 4. Measurement layout used in an anechoic chamber. TX and RX present the laptop locations and the circles illustrate the UWB transmitters.

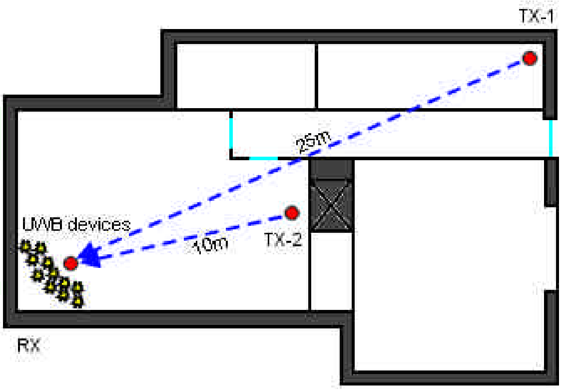

Figure 5. Measurements layout for the office environment.

The WLAN network cards reported measured of signal-to-noise ratio, signal quality, and the number of successfully received packets of the local and remote device both in managed and peer-to-peer modes. In order to measure higher layer performance, additional network traffic analyzing tools are required. In this work, TTCP [3] is used. MGEN [4] is used in one example.

The theoretical maximum bit rate for Bluetooth is 1 Mbps. The signal centre frequency is also approximately 2.4 GHz. During the study, the maximum payload data rate achieved without interference was 545 kbps. Including packet overhead, this data rate was 721 kbps. At present, the Bluetooth cards do not report any lower physical layer measurements making it necessary to rely solely on the network traffic analyzing tool to investigate the effect of UWB disruption on Bluetooth throughput.

All the results discussed in this paper are based on the information reported by the network cards themselves. Payload packet size during the both studies was 1472 bytes which is the maximum UDP payload packet size. With IP- and UDP –headers, the packet size is 1514 bytes.

A. Measurement scenarios

Connections between the two laptops were established in a peer-to-peer unmanaged mode without any connection to the access point. The distance between the communicating devices was set at the limit of performance for the selected data rate to more readily see the impact of the UWB devices.

Figure 4 shows the locations of the WLAN transceivers and the UWB interferers during the experimental tests in the anechoic chamber. The distance between the communicating WLAN devices was 8 m. The transmitted signal power was attenuated by placing absorbing material near the WLAN transmitter.

In the office environment, the WLAN link distance was 25 m in the NLOS connection (TX-1 in Figure 5). Another case examined corresponded to a typical LOS office installation with a WLAN link distance of 10 m (TX-2).

IV. MEASUREMENT RESULTS

Whilst WLAN throughput measurements were being undertaken, spectrum analysis of the relevant radio frequencies was also performed. Figure 6 shows the IEEE802.11b spectrum with WLAN connection in Channel 1 (f_c = 2.412 GHz) with 20 active UWB transmitters at distances of 100 cm and 15 cm from the measurement antenna in the anechoic chamber (log-periodic reference antenna). This figure clearly shows the spectrum of the UWB interferers as they are moved closer to the antenna of the spectrum analyzer. The stationary WLAN transmitter operates with a constant power at all times.

The Bluetooth measurements followed the same procedure as the WLAN measurements described above. The test site in this case was a typical office environment during working hours which implies that other, unintentional radio interference sources, cannot be controlled during the measurements.

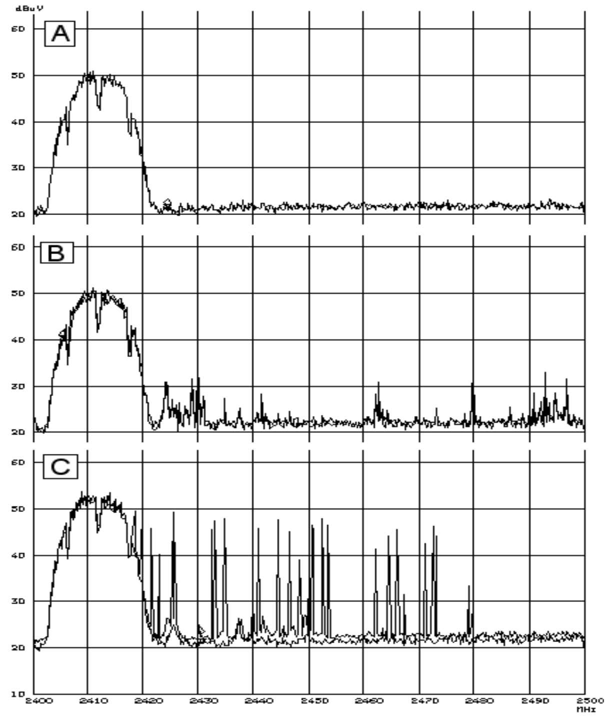

Figure 6. Received signal spectrum (Channel 1)
A) without UWB transmission B) 20 active UWB transmitters 100 cm from the measuring antenna and C) 20 active UWB transmitters 15 cm from the measuring antenna.

A. Signal-to-Noise Ratio

As the current Bluetooth setup does not allow measurements of the physical properties of the connection, measured SNR results are only presented for the 802.11b system.

Figure 7 shows the instantaneous and averaged SNR values reported by the IEEE802.11b network as reported by the device in the NLOS configuration. Between minutes 0 and 18, all the 20 UWB transmitters were active, and between minutes 18 and 36 only 10 UWB sources were used. The active/inactive intervals were 3 minutes. The distance from the UWB transmitters to the victim WLAN card was approximately 50 cm. Average SNR degradations of 4 dB and 2 dB were observed for 20 and 10 UWB sources respectively. The averaged SNR presented in Figure 7 is calculated using a moving averaging process over 1024 packets. The measurement tool used was MGEN.

Without UWB interference, the maximum instantaneous variation of the measured SNR in the 802.11b network was almost 10 dB (with MGEN running). However, when the UWB interference is present the instantaneous variation is smaller, with maximum variations of approximately 7 dB.

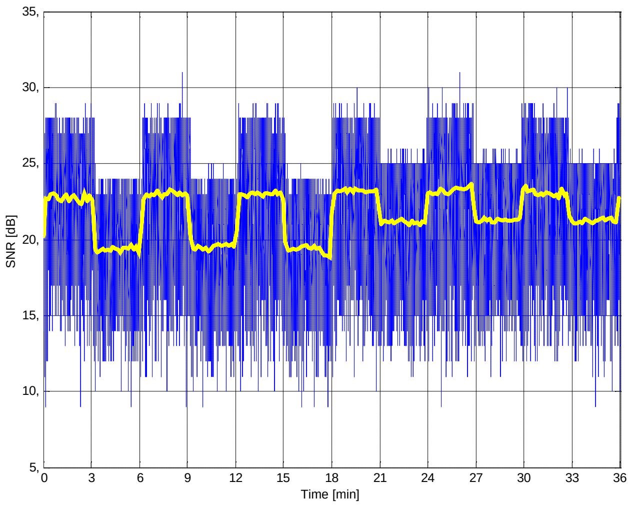

Figure 7. Averaged and instantaneous SNR values reported by the 802.11b card when 20 or 10 UWB transmitters are active / inactive with 3 minutes intervals.

SNR values have also been examined as a function of distance between the UWB interferers and the victim system for various numbers of UWB interferers. The results are presented in Figure 8 where the solid lines and dashed lines represent NLOS and LOS links, respectively. The legend indicates the number of active UWB devices used in the measurement (15/20 means that 15 active devices out of 20 devices were used).

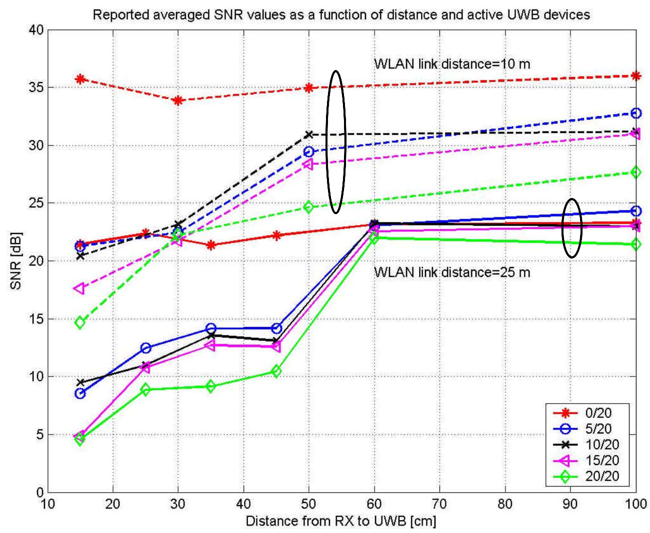

Figure 8. Average reported SNR values as a function of UWB-802.11b victim system distance.

The results show that if the distance between the extremely high powered UWB devices is greater than 50 cm, no significant reduction occurs in the reported SNR. For distances less than 50 cm, the SNR reduction was as much as 10-15 dB. SNR is however only one performance measure. The throughput of the network is the most measure and is discussed in the following chapter.

B. 802.11b and Bluetooth Throughput

Figure 9 shows the throughput achieved for the 802.11b connection as a function of the number of active UWB transmitters. These results correspond to the SNR results presented in Figure 8. In the no-interference case, the throughput achieved are approximately 4100 kbps both in LOS and NLOS links. In the LOS case, the impact of the UWB interferers on 802.11b throughput is insignificant even for very short distances.

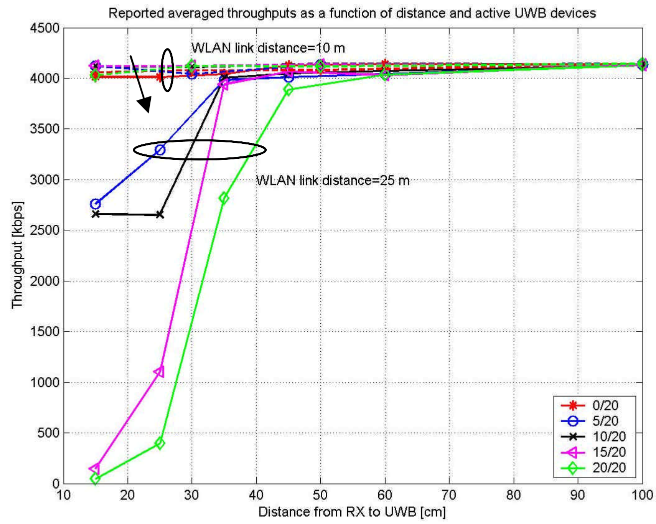

Figure 9. Averaged throughputs reported by the WLAN card are presented as a function of the number of active UWB transmitters and an interfering distance.

When the available SNR degreases, e.g. in a NLOS link, the network throughput decreases as well and is more readily affected by the UWB interference. If the distance between the 802.11b receiver and UWB transmitters is small (<30 cm in our study) the WLAN throughput drops dramatically when 15 or more active "high power" UWB devices were used. If the distance is greater than 40 cm, the deterioration is negligible and the throughput is the same as the no-interference case.

In Figure 10, the measured throughputs are presented for four 802.11b channels. The UWB and 802.11b link distances were 5 cm and 4 m, respectively. The 20 UWB devices were divided into blocks of 5 devices. A block of 5 devices can all be turned on or off at the same time. The results indicate that there is also some difference between the individual UWB devices, and also the different WLAN channels are affected differently in the presence of UWB interference.

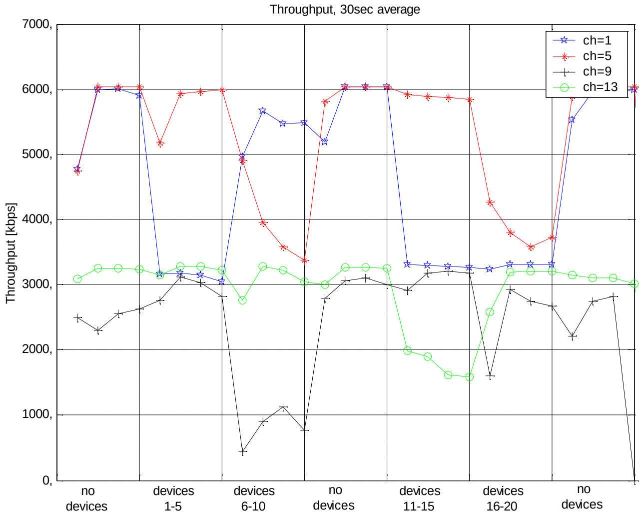

Figure 10. Measured throughputs for the 802.11b channels 1, 5, 9 and 13.

The throughput of the Bluetooth network has also been examined at two selected interference distances, 3 m and 10 m. The results are presented in Figure 11 as a function of the number of active UWB devices. The throughput reduction in the Bluetooth connection is much milder even under heavy interference conditions. The effective TCP peer-to-peer throughput without any interference is around 500 kbps and remains approximately constant when all 20 high power UWB transmitters were active. The UWB devices were placed in an arc 15 cm from the Bluetooth receiver.

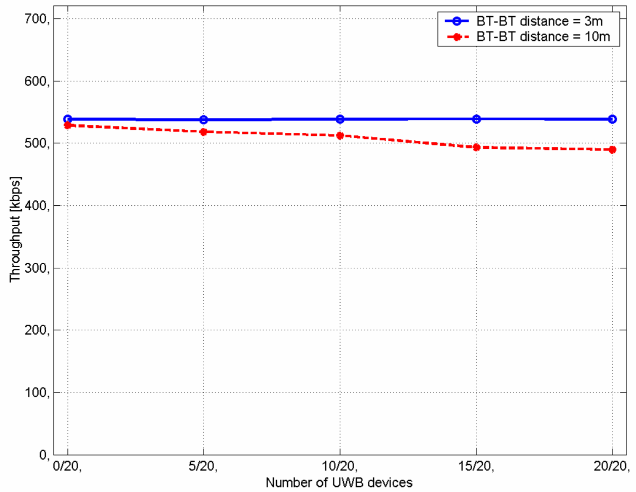

Figure 11. Throughput of the Bluetooth network as a function of the number of UWB transmitters. Distances between the communicating Bluetooth devices are 3 m and 10 m.

These results show the relative insensitivity of the frequency hopping Bluetooth devices to UWB interference. As seen earlier, the fixed pulse repetition interval of the UWB transmitters leads a distinct line spectrum. The Bluetooth system is able to monitor individual channel states and can avoid the bad channels. A small degradation in the throughput is noticed when the link distance is increased to 10 m, which is also the maximum distance for the 1 mW Bluetooth system as defined by the specifications.

V. CONCLUSION

At present, 10's of millions of IEEE802.11b and Bluetooth enabled devices have been installed worldwide. This study has highlighted the level of impact of simple UWB devices on 802.11b and Bluetooth connections. TCP throughput and SNR results are based on the value reported from the network cards. Effectively, one UWB device used in our study corresponds to hundreds of FCC compliant UWB devices due to its high transmitted power level in the 2.45 GHz ISM band.

The results showed that, under the *extreme interference* conditions examined, the UWB devices had an impact on both IEEE802.11b and Bluetooth networks.

As shown in Figure 8, for interference distances of less than 50 cm, the UWB interferers impacted the reported SNR for both LOS and NLOS cases. The worst case degradation of the received SNR in the IEEE802.11b was up to 15 dB for 20 UWB devices (equivalent to several thousand FCC compliant UWB devices) at 10 cm distance. A corresponding drop in network throughput was observed only for the NLOS case and only for distances of less than 35 cm. In the LOS case, the impact of the UWB devices was insignificant.

The Bluetooth connection examined did not suffer significantly from the UWB interferers. The resulting decrease in throughput was approximately 20 kbps in the worst case.

It should be remembered that the UWB devices used in this experiment generate many hundreds of times more interference power in the ISM band than devices operating in accordance with the FCC UWB spectral mask limits. It is only under these extreme interference cases that any noticeable impact is discerned from the UWB sources.

A next phase of this work will result in new devices with variable pulse repetition frequency and transmit power and FCC compliant spectral characteristics.

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