UWB coexistence measurements with IEEE802.11a

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Abstract

This paper discusses the experimental coexistence study work carried out with ultra wideband (UWB) and IEEE802.11a wireless local area network (WLAN). The measurement setup followed a realistic interference scenario inside a classroom where several UWB devices were spread over the room; there was one UWB transmitter for each student position and the desired terminal was moved across the room. Another setup was for aggregate studies where numbers of UWB transmitters were located close to the desired WLAN receiver. In addition, temporary radio interference from the other sources was not controlled during the measurements. The results showed that the performance of a victim link depends mostly on the UWB activity factor and pulse repetition frequency. In short line-of-sight WLAN links, the degradation in measured data rate was typically less than 5% in usable activity factors if measured from uplink site. The corresponding degradation in downlink side is typically 5 – 10%. In through wall cases, with low WLAN signal-to-noise ratio, the impact of interference was higher.

1 Introduction

The knowledge of the coexistence between ultra wideband and existing radio systems is important issue in current UWB technology adoption processes globally. Due to the extremely large occupied bandwidth, UWB spectrum is overlapping with many other existing radio systems. For other systems, this unintentional in-band energy might cause performance degradation of different degree. In the worst case, the desired link can even be blocked.

In this paper, UWB impact on performance of IEEE802.11a [11] wireless local area network link is studied through experimental coexistence measurements. From public literature related reports can be found, e.g., [2],[5],[6]. The general conclusion of the other references is that the UWB impact on WLAN performance is rather small. The visible impact can be seen if a UWB transmitter and a victim receiver are close to each other. UWB impact on WLAN performance degradation can typically been observed if links are less than 30 – 40 cm. Simulations, like [1], also support this notification. In [1], the authors concluded that only in non line-of-sight (NLOS) conditions, a UWB signal can degrade the IEEE802.11a performance but when operating in a LOS, there should not be significant impact. The UWB seems to affect victim receiver's signal-to-noise ratio (SNR) more than the actual throughput, which does not drop so much under the UWB interference. This paper extends our corresponding experimental studies with UMTS/WCDMA system, which are reported in [7],[8]. Both of these victim systems (802.11a and UMTS) were sharing the same spectrum with UWB, and that is why they have been selected for detailed studies.

This paper is organized as follows: Section 2 introduces the UWB devices used in the study. In Section 3, the victim radio system and measurement setup are discussed. Section 4 gives the results, and finally in Section 5, the conclusions will be drawn.

2 UWB interference sources

In our experiments, the intentional interference against the victim radio system is generated using UWB pulse transmitters, which were generated for the interference studies. The radiated UWB signal is fulfilling the FCC demands [3],[4].

The centre frequency of the UWB transmission is about 3.5 GHz, and the conducted power measured from the output port of the transmitter via cable is about -11.8 dBm (0.0661 mW), measured within a 10 MHz ... 10 GHz frequency band. The UWB pulse generators were controlled by external control boards. The polarities (being bipolar) of the transmitted pulses are based on the polarities of the pseudo random maximum length noise code (PRN), i.e., the chip polarity defines the direction of the first slope of the transmitted pulse. A PRN code randomizes the transmission, thus smoothes the spectrum by reducing the arising line spectrum. In data communication applications, a PRN code provides also pulse repetition coding, which can be used to increase the received signal energy, and therefore to improve the system performance. UWB pulses, having length of less than 500 ps, are generated with step recovery diodes. Due to the programmable control, there is a possibility to turn several UWB transmission parameters.

The spectrum of the transmitted pulse train having a pulse repetition frequency (PRF) of 200 MHz is presented in Figure 1 in conjunction with the FCC masks for outdoors and indoors [3],[4]. The spectrum labelled as *conducted* has been measured using a cable connection between the UWB transmitter and the spectrum analyser. The other given spectra are based on the radiated measurements with the UWB antenna separations of 10, 20, 40 and 80 cm. Temporary background noise level, that is less than - 80 dBm, is also denoted in the figure. The UWB pulse transmitters were equipped with small bowtie type UWB antennas. All the spectra are time averaged due to the extremely large UWB bandwidth, which restricts the measurement of an instantaneous spectrum.

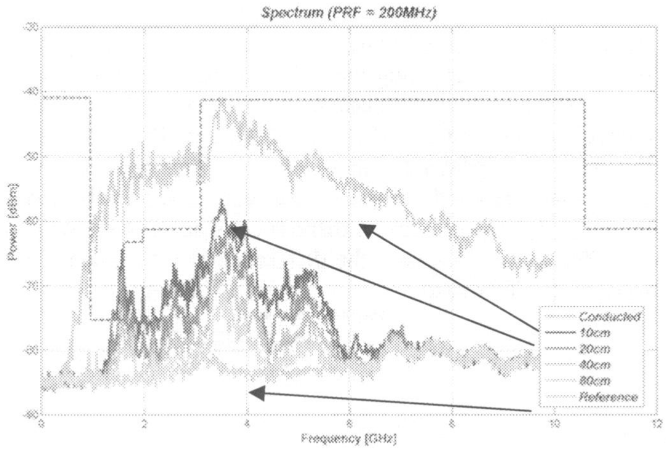

Figure 1. Measured UWB spectra; both conducted and radiated spectra are depicted.

As can be seen from the figure, the used antennas filter out the lower frequency parts, and the spectrum is matching the FCC mask. It should also be noted that the spectrum seen by the victim receiver is different from the ones from Figure 1 due to the smaller bandwidth and different antenna characteristics the victim receiver's antenna has.

The length of the PRN code is adjustable, and it can be as long as $2^{20} - 1 = 1048575$ chips. An activity factor (AF) of the transmission, i.e., the ON period within a specified timeframe, could be chosen between 0 … 100%. The frame length used in the measurements was set to 1 ms. The UWB interference was generated using both PRF = 100 and 200 MHz. A total number of active UWB devices used in the measurements was either 8, or up to 20 devices. There was no common clock between the different UWB transmitters, and therefore, the generated interference was asynchronous.

3 Victim systems and measurement setups

The victim radio system in this study was the IEEE802.11a wireless local area network link. Similar types of coexistence measurements in an anechoic chamber between UWB and UMTS using unrealistic interference assumptions (i.e., large amount of UWB transmitters in the close vicinity of the victim receiver) are reported in [7],[8]. This section discusses the measurement procedures and the hardware used in the experiments.

3.1 IEEE802.11a link

Two laptops operating in a peer-to-peer mode using the WLAN IEEE802.11a connection were used to create a desired data link. Both laptops were installed with D-Link AirXpert DWL-AG650 PCMCIA WLAN cards.

The parameters monitored during the measurements were signal level and bit rate of the desired WLAN link, both under the UWB interference. For each measurement, a related reference level without UWB interference was also measured.

Two layouts were defined: In a classroom, twenty UWB transmitters were spread over the room so that the scenario simulates 'one UWB device for each student' assumption. The position of the other WLAN laptop was fixed, and the other one was moved inside a room. This procedure allowed us to measure different WLAN link distances, and therefore different signal-to-interference-plus-noise ratios (SINR). In addition, the interference statistics was changed due to the change in an active link. The other scenario was focused on aggregate UWB interference to WLAN receiver in close vicinity. This setup, in general, was more theoretical than practical but it indicates how the aggregate interference affects the WLAN performance.

3.2 Measurement procedure

This section describes the measurement procedure followed during the measurements.

The WLAN channel used by the desired link was selected outside the operational WLAN network at the University building. When recording data, no movement inside a room was allowed. In a NLOS case, the moving laptop was outside a classroom, and the movement in a corridor was not rejected. The surrounding radio environment could not be controlled during the measurements, so the results are measurement time dependent ("real life" situation). However, a reference level with no UWB transmission was defined for each measurement to monitor the change in the radio environment, and therefore, the change in the desired link's nominal data rate.

Classroom measurements

In a classroom, there were several tables, each having two UWB transmitters. The moving laptop was located in three different distances measured from the fixed terminal. To improve the statistical behaviour, the laptop was moved so that one location consists of three positions within about 10 cm to improve the statistics. The link parameters were measured in both directions; uplink (UL) and downlink (DL) stand for the results measured at the WLAN transmitter and receiver site of the connection, respectively. In addition to a LOS link, a through wall NLOS link was also studied. Each recording in the classroom lasted three minutes, and each of the 20 UWB devices operates similarly. The measurement layout for the "real life scenario" is presented in Figure 2. The receiving (moving terminal) WLAN card was at the same height than the radiating UWB antennas.

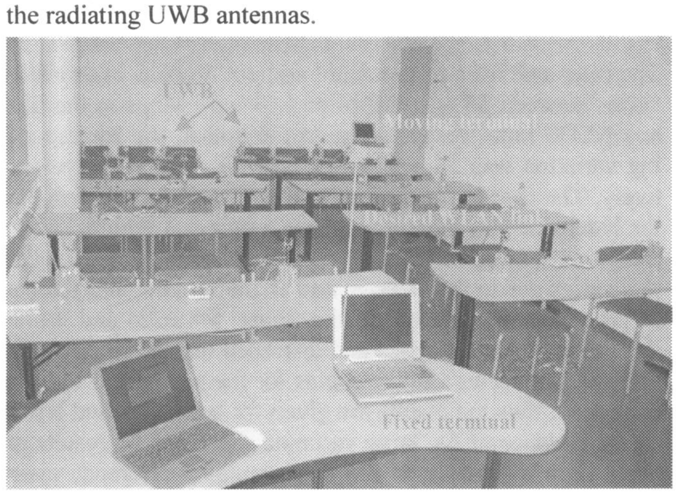

Figure 2. Measurement layout for "a real life" scenario.

Aggregate measurements

The other measurement setup consisted of a different number of active UWB transmitters that were 36 cm apart from the WLAN receiver. UWB transmitters were activated by either using blocks of two devices, or activating all the used devices simultaneously. The total number of the devices was 20. The UWB impact on WLAN throughput was simultaneously monitored. These measurements were carried out in a typical office room. Again, the measurements included the impact of the existing radio systems, which cannot be switched off during the measurements. In Figure 3, the layout of the aggregate noise measurements were presented. The UWB devices were set into the arc having radii of 36 cm.

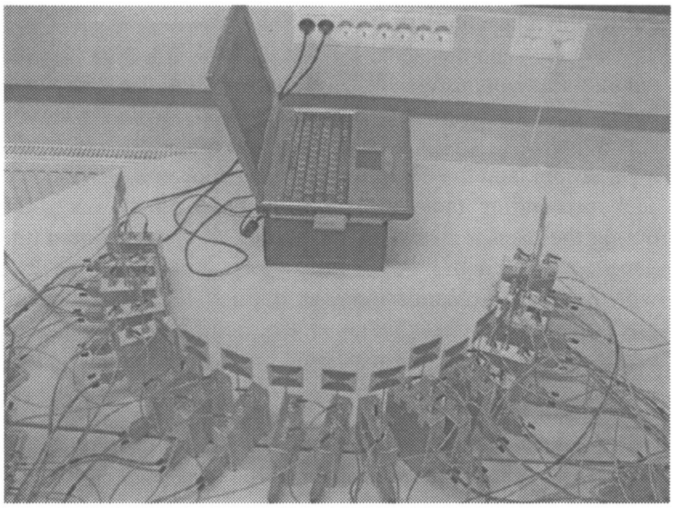

Figure 3. Measurement layout for the aggregate measurements.

4 Results

In this section, the measurement results are discussed. The classroom measurements were carried out using both a LOS and a NLOS WLAN connection. The aggregate noise measurements were carried out only with a LOS WLAN connection.

4.1 Real life scenario

The reference bit rate measured without a UWB in downlink varies between 34 – 36 Mbps and 17 – 35 Mbps in the LOS and NLOS links, respectively. In the uplink, the corresponding variation was 36 – 37 Mbps and 26 – 35 Mbps, respectively. The former link had distances from 2 m to 6.5 m, and the latter one was measured within a range of 9 m to 13.5 m. However, during the tests, it was found that the reference data rate varies due to the external and uncontrollable interference, as presented in Figure 4. In the figure, the solid and dashed lines represent a reference and disturbed results, respectively. The vertical bar in a figure stands for the location of the concrete wall, thus the results are given for both LOS and NLOS cases. Because of the large variation, later on, the results are given as a difference to the corresponding reference measurement.

In general, the measured signal level behaviour is quite similar in all the measured cases if compared to the signal levels from Figure 4. Increasing the link distance decreases the signal level, and with the interference, the level follows the reference independently of the used UWB activity factor. In uplink site, the differences in received LOS signal levels between interfered and reference cases can be seen only if AF = 50 or 100%. The maximum difference is about 4 dB with AF = 100%. In NLOS cases, the difference is insignificant even with AF = 100% case.

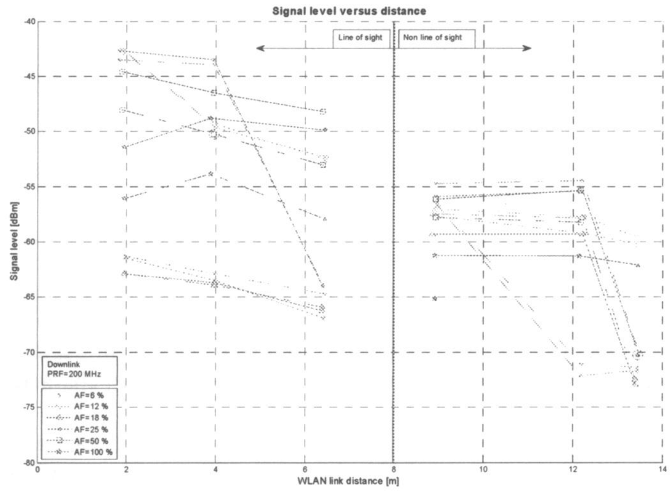

Figure 4. Measured WLAN signal levels.

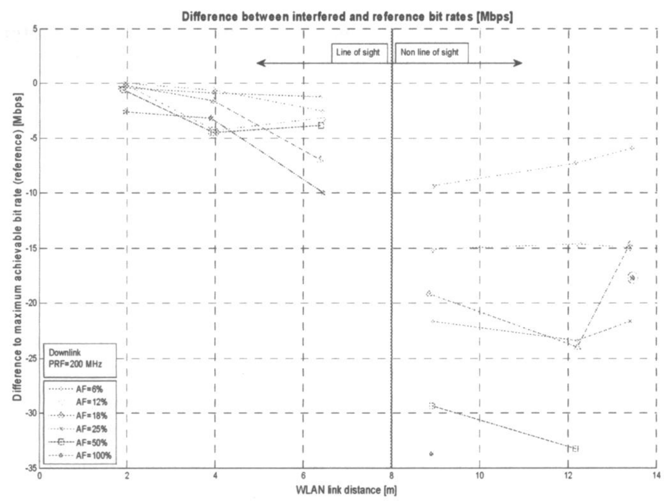

Figure 5. Difference in WLAN data rate between the reference and disturbed cases measured at the moving terminal.

In Figure 5, the impact of a UWB on data rates measured in a classroom are shown. The results indicate the difference between the reference and disturbed measurements. As pointed out above, the reference level changes within the measurements, so the difference to the reference was seen to be the most informative way to present the results. Data was recorded from the moving terminal (referred as a downlink). As the results show, in LOS link, the UWB impact on WLAN is insignificant in high WLAN SNRs (i.e., when the link is short) even if the high UWB activity factors were used. The degradation is less than 5 Mbps up to 4 m WLAN link. However, if compared to the percentual degradation, it can be as much as 14% at a 4 m. In a 6.5 m LOS link, the maximum percentual degradation is 28% when AF = 100%. If AF = 6%, the degradation is only 5% at maximum. In NLOS links, the percentual degradation is much higher, as can be noticed also from the decrease of the absolute data rates. When AF = 100%, the degradation was as high as 95% for a 12 m link. If AF = 6%, the WLAN data rate dropped 30%.

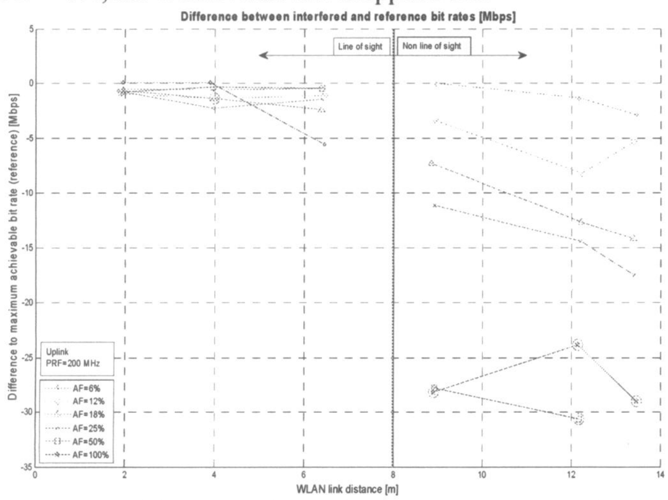

Figure 6. Difference in WLAN data rate between reference and interfered cases measured at the fixed terminal

In Figure 6, the corresponding results are given for the non-moving laptop side. Now, the generated UWB interference is far from the WLAN card of interest. The results differ only slightly from the results from Figure 5 but, in general, the UWB impact is smaller due to the longer distance to the closest UWB device. In other cases than AF = 100%, the degradation in data rate is less than 5% in a LOS WLAN link. The behaviour in a NLOS case improved slightly the corresponding results when the UWB transmitters were close to the victim receiver. When AF was 6%, the percentual degradation was about 5% but with AF = 100%, 99% degradation in the data rate was detected.

All of these results showed that the WLAN performance greatly depends on the UWB activity factor. In addition, if the SNR of the desired link is small, the impact of interference is bigger.

4.2 Aggregate noise effect

The impact of aggregate UWB noise on WLAN was measured inside an office using a fixed 4.6 m WLAN link. The measurements were carried out by changing the number of active UWB devices and activity factor. The UWB transmitters were in an arc having radii of 36 cm, and each has a LOS to the WLAN card.

As shown in Figure 7, the WLAN throughput is slightly affected by the UWB transmission when 20 devices were simultaneously activated. The figure show results from five independent measurements and the average of them. At the beginning of the measurement, a WLAN was turned on, and a reference level was measured. Next, the UWB devices were turned on for about 250 s, and then turned off again. The UWB impact is not dramatic when AF = 10%, even for the PRF = 200 MHz. If compared to the reference level, the degradation is only about 1 Mbps (2.7%). The WLAN link recovered after the interference is removed, as also can be seen from the figure.

The throughputs averaged over five independent measurements as a function of the activity factor are showed in Figure 8. As can be seen, pulse repetition frequency PRF = 100 MHz does not cause any impact on WLAN link performance when 20 UWB devices were ON. On the other hand, if PRF = 200 MHz, the dependence of the activity factor on the WLAN performance is significant. For PRF = 200 MHz, the impact of blocks of 10 and 20 UWB devices were measured. The figure shows also the reference levels, which were the same throughout the measurements.

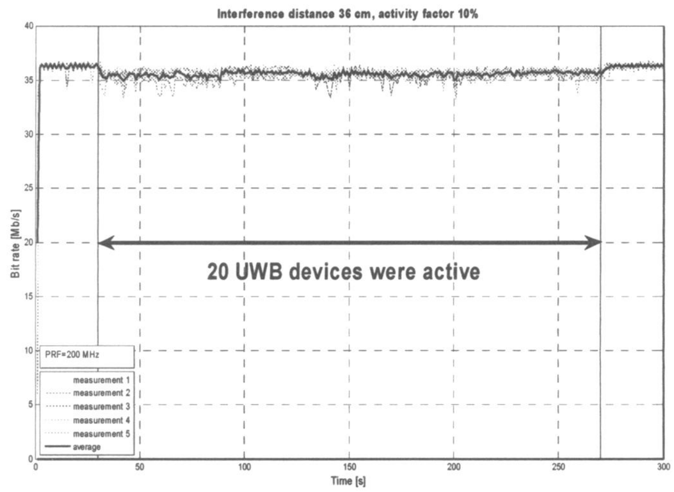

Figure 7. Measured bit rate, PRF = 200 MHz, AF = 10%, 20 simultaneously active UWB devices.

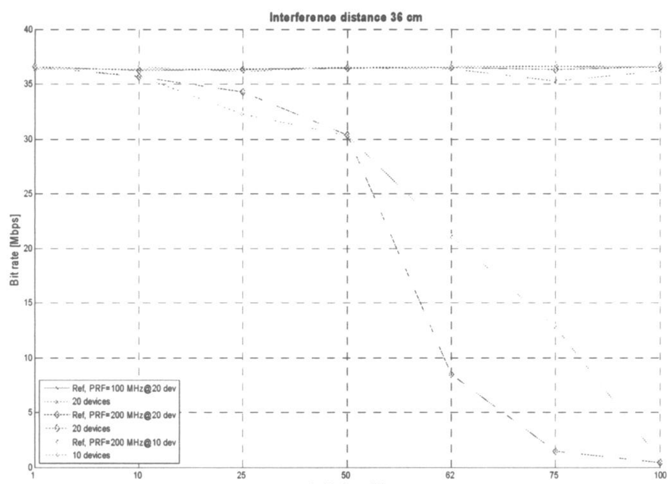

Figure 8. Measured average WLAN throughput as a function of activity factor.

The data rate drops 5 Mbps (corresponding 13.5%) when activity factor was higher than 25%. When increasing AF to 100%, the WLAN connection could serve as a data rate of 1 Mbps, which is 97% degradation to the non-interfered situation.

5 Conclusions

In this paper, the experimental coexistence measurements between UWB signal and the IEEE802.11a link were discussed. The measurements were performed in a classroom where numerous UWB transmitters were located over the tables in front of assumed student position. The victim WLAN receiver was moved inside a room. The other side of the victim link was fixed to the same position all the time. The results showed that in a LOS WLAN link, the degradation of achievable data rate is about 5 – 10%, and in a NLOS link, the degradation was more than 30% when UWB interference is present. In the worst case with AF = 100%, the WLAN link was almost blocked.

The other measurements that focused on aggregate effects showed that the activity factor has significant impact on IEEE802.11a performance if the pulse repetition frequency is high. If a low PRF is used, the UWB impact is insignificant independently of the AF used.

However, the realistic activity factor for UWB devices is assumed less than 5%, which does not cause any harmful performance degradation for a LOS WLAN link, according to these measurements.

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