Co-existence measurements between UMTS and UWB systems

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Abstract: The paper presents results of a co-existence measurement study between multiple ultra wideband (UWB) transmitters and a Universal Mobile Telecommunications System (UMTS) mobile phone. Two environments were explored: an anechoic chamber with one operating UMTS link and a true operational UMTS network. A large number of FCC compatible UWB transmitters were used to generate interference for an active UMTS connection. In an anechoic chamber, only the voice service was studied between a radio communication analyser (used as a base station) and a mobile terminal. In the true commercial UMTS network case, both the voice and data services were investigated in a shelter having a low UMTS signal level. The results clearly show that UMTS and high pulse repetition rate UWB devices can co-exist at link level when a moderate number of simultaneously active UWB devices operate in close proximity of the UMTS 'victim' receiver. The results also show that the activity factor of the UWB transmitter disproportionately impacts the effective interference. When using low activity factors, even with high pulse repetition rates and very large numbers of UWB devices, it is difficult to detect UMTS link performance degradation. As the activity factors grow beyond 5%, the impact of the UWB interference becomes visible. However, this study covers only one active UMTS link in both environments but does not report on the UWB impact on the UMTS radio access network.

1 Introduction

Ultra wideband (UWB) is a promising technology with a wide range of applications. Understandably, the impact of UWB interference has recently been seen as a threat for existing or future radio systems. This raises the need for real co-existence studies to a high level. One particular area of interest is the impact of UWB interference on the Universal Mobile Telecommunications System (UMTS) that is based on wideband code division multiple access (WCDMA) technique [1].

Co-existence is an essential issue to be better understood if UWB is to be permitted by the European regulators. Before the FCC (Federal Communications Commission) finalised the UWB standardisation process in the USA [2], co-existence phenomena were widely discussed. More recently in Europe, this discussion has become lively and several substantial official reports and proposals have been released; for example, [3–5]. The lack of the proposed radiation masks from the reports is that they are based only on theoretical calculations. The accuracy of the results depends directly on the accuracy of the assumptions used in the calculations. Therefore, there is an obvious need for real co-existence measurements.

Cellular network operators and manufacturers have expressed concern that UWB will increase the aggregate noise level leading to a reduction in overall network capacity, as well as degrading a single mobile link. UWB impact on the UMTS system has been reported in [6] based on the measurements in terms of bit error rate (BER) and noise level rise. In [6], both conducted and radiated tests were carried out using one UWB transmitter whose centre frequency is higher than that used in our experiments. In our paper, we extended these results to include a larger number of interfering devices and report more measured parameters from the operational UMTS link.

The co-existence problem between different systems has, however, typically been studied through simulations, as in [7–11]. The impact of UWB on other cellular systems than UMTS has also been examined; for example, in [10–13].

This paper presents co-existence measurement results when numerous real UWB transmitters are used in close proximity with a commercial UMTS cellular phone system. The measurements were carried out at the Centre for Wireless Communications (CWC), University of Oulu, Finland. In the measurements, the impact of UWB on the performance of the UMTS voice link was tested inside an anechoic chamber and within the existing network. In the latter case, both voice and data services were utilised during the measurements.

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2 Interfering UWB devices

2.1 UWB transmitter

The UWB devices used in the measurements are FCC compatible, thus adhering to the radiation mask from [1], and are built only for the interference measurements by [14]. The UWB transmitters follow the impulse radio concept, with a single-band device. Spectrum scrambling is performed using a direct sequence (DS) approach [7] instead of time hopping (TH) as described, for example, in [15].

Transmitted pulses are generated using step recovery diodes, and then combining two near Gaussian shaped pulses in opposite polarities. A delay having a length of one pulse is inserted between the two replicas to produce a monocycle waveform. Depending on how to define the entire pulse width we are dealing with less than 500 ps pulses as can be seen from Fig. 1. The ringing increases the length of the main monocycle. In our experiment, the transmission was continuous (i.e., activity factor is 100%), representing the worst case scenario from an interference viewpoint.

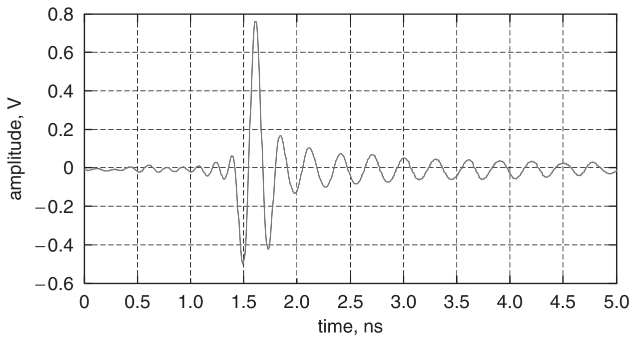

Fig. 1 *The generated UWB waveform*

The power measured at the output port of the transmitter is $P_{tx,UWB} = 0.0661$ mW (−11.8 dBm) within a band from 10 MHz to 10 GHz and the nominal centre frequency of the UWB signal is about 3.4 GHz. The polarities of the transmitted pulses are controlled by a pseudo random (PR) maximum length sequence having length of $2^{20} - 1$. For every chip of PR code, one UWB pulse is generated. The randomisation due to the PR code can be used for spectral smoothening, as well as for user separation in a possible multi-user case.

The UWB antennas used in the study were omni-directional small dipole antennas whose reflection coefficient $S_{11} < -10$ dB in the frequency range 2–20 GHz. The lower part of the generated UWB spectrum is therefore filtered out by passing the signal through the antenna. The UWB transmitters are asynchronous due to the absence of a common clock in a system. In addition, the two pulse generators driven by one control board are asynchronous due to the use of cables of different lengths.

2.2 UWB parameters

The impact of the UWB interference was measured by varying the number of UWB devices, and the distance between the UWB devices and the victim UMTS terminal. The adjustable parameters on the UWB devices were activity factor (AF), frame length and pulse repetition frequency (PRF). At the measurements, PRF reached values of 100 MHz or 200 MHz.

Activity factor is defined within a transmission frame as $AF = x/y$, where x and y represent the burst and frame lengths, respectively; AF = 1%, 5%, 10%, 20%, 50% and 100% were used in the study. The frame length (selectable between 1 μs and 1 ms), was set to 1 ms if not otherwise stated. Although realistic AF values in operating UWB systems are expected to be less than 5% [3], high AF values were examined to simulate the worst case (but unrealistic) interference scenario.

No data modulation is imposed on the transmitted UWB pulse stream. The spectrum dithering is based only on the bipolar pulse transmission controlled by the PR code. Note that when using the 200 MHz pulse repetition frequency with the same transmitted energy per pulse, the total average transmitted power is doubled if compared to the PRF = 100 MHz case.

3 Measurement setup

During the measurements, two different cases were studied: an anechoic chamber and a real UMTS network. The UMTS system used in the anechoic chamber consists of a commercial mobile station (MS) and UMTS base station (BS) hardware simulator. The other results are based on the measurements carried out in a shelter using a connection to the real operational UMTS network.

3.1 Base station

The first measurements were carried out in an anechoic chamber where Anritsu MT8820A Radio Communication Analyser (RCA) [16] was used to simulate the operation of the UMTS communication link; that is, the physical channels between BS and MS. Parameters were monitored from voice call-mode and in idle-mode, the former being the more interesting case. The focus during the measurements was on the UMTS link parameters, not on the radio access network side.

The other measurement set-up was a connection to the real commercial UMTS network with a mix of voice and data traffic. Due to the commercial operation, the other traffic in the network could not be controlled. The link distance was about 300 m with the MS located inside a shelter (thick concrete walls and metal shields in front of the windows and door). The concrete wall shelter made sure that the UWB devices induced interference could be measured in only one victim UMTS terminal operating in a multi-user UMTS network.

The measurements were carried out using the following band allocations; in the anechoic chamber, the uplink (UL) and downlink (DL) bands of 5 MHz channels were 1950 MHz and 2140 MHz, respectively. The corresponding band allocations for the measurements in a shelter were 1970 MHz and 2165 MHz, respectively.

The use of RCA made it possible to monitor bit and block error rates (BER, BLER, respectively) for downlink pilot channel, E_c/N_0 that is a chip energy divided by the noise spectral density measured from the common pilot channel (CPICH) and the received signal code power (RSCP) from the active UMTS CPICH-channel. The Anritsu MT8820A reports power levels using a 0.5 dB grid. The received signal strength indicator for the carrier (RSSI) contains the total power measured within the 5 MHz band. The RSCP indicates the received signal power at a dedicated physical channel that is, the detected signal power. Typically, it is not reported by the measurement device and is calculated from the other measurable parameters as

$$\mathrm{RSCP} = \mathrm{RSSI} + E_c/N_0 \quad (1)$$

The bit error rate is calculated using loop-back test mode defined in the 3GPP standards [1, 17]. The antenna used in the base station site in an anechoic chamber was wideband CMA-118/A by Antenna Research Associates Inc. CMA-118/A is an omni-directional biconical antenna that covers the frequency range 1–18 GHz. The real network used commercial UMTS antenna located on the mast.

3.2 Mobile terminal

The mobile terminal used in the studies was a commercial UMTS phone having development software allowing a real in-system parameter reporting. The MS position was kept the same during all the corresponding measurements. This was to maintain the propagation channel characteristics constant between MS and BS. If the MS moved during the measurements, the channel propagation characteristics would change and the results would not be comparable anymore. Of course, more comprehensive measurement campaign would be needed to average out the channel influence on the results.

Power control was operational in all measurements. The inner loop power control (fast closed loop power control) was utilising Algorithm 1 specified for UMTS [17]. This meant that the output power of the terminal was changed if only one request per slot is given by the network. Due to the active power control, the base station could increase the transmission power when the noise level around the MS increases to maintain the quality of service (QoS). However, this increase is not favourable by the entire network that might suffer from the inter-cell interference, and in the worst case, the increase of the UMTS signal level can be seen as a reduction at the network capacity.

The parameters reported by the mobile terminal were measured using commercial mobile terminal measurement software [18]. The collected parameters were RSSI, RSCP and E_c/N_0. The software reports the MS power levels using a 1 dB grid. RSCP is again calculated from the other measured parameters as shown by (1).

3.3 Measurement cases

The UWB interference was generated using a maximum of 24 FCC compatible UWB transmitters, which were activated in groups of four devices. A more realistic number of simultaneous active transmitters, in this case four or less, were also separately studied. That is, groups of 1, 2, 3, 4, 8, 12, 16, 20 and 24 devices were activated. All the given results are based on radiated measurements, which means that the interconnection between the desired UMTS signal and interfering UWB signals was in the air. The measurement layout for the anechoic chamber is presented in Fig. 2.

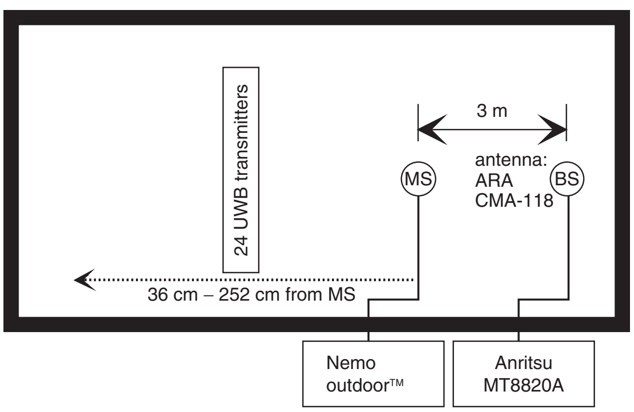

Fig. 2 *Layout for anechoic chamber measurements*

In the anechoic chamber, the UMTS link distance is fixed to 3 m and the UWB transmitters were placed in a row. The distance between the victim MS and the variable number of active UWB transmitters varies from 36 cm to 252 cm with a step of 36 cm, measured from the middle of the row of the UWB devices.

In the real UMTS network measurements, the procedure was the same but with lower UMTS signal power strength. The layout differed from Fig. 2 so that the BS antenna was located on a mast about 300 m from the measurement site. After closing the windows and doors of the shelter, the measured UMTS SNR was decreased from the unshielded case. The MS position was fixed and the change in the interference distance was based on the movement of the UWB devices. Otherwise, there was no difference in the measurement procedures.

For each case and distance, the reference results were also recorded. The UWB devices were then in their nominal positions but they were all inactive. Results for zero active devices corresponds to 'interference' from UWB devices alone which can be seen as additional signal multipath.

4 Results

4.1 Anechoic chamber measurements

At this measurement setup, E_c/N_0, RSSI and BER reported by the UMTS mobile terminal were studied. In Fig. 3, the measured E_c/N_0 for the UWB set-up with AF = 100% and PRF = 100 MHz are presented as a function of interference distance using different number of active UWB devices.

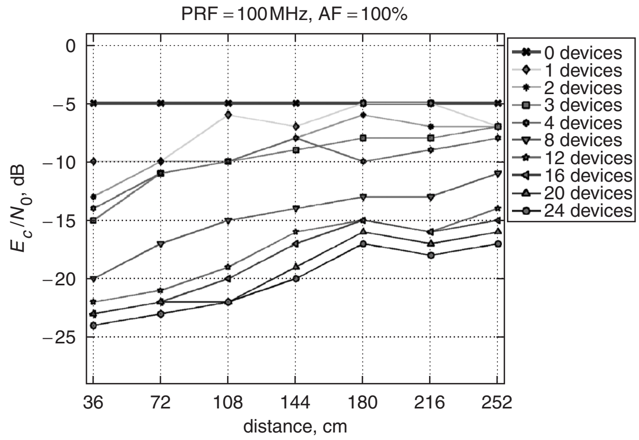

Fig. 3 *Measured E_c/N_0 as a function of distance; PRF = 100 MHz, AF = 100%*

As can be seen from Fig. 3, with AF = 100% and PRF = 100 MHz, the E_c/N_0 as reported from the mobile device is affected by the UWB interference. With a separation distance of 36 cm, the degradation is about 19 dB when all 24 UWB transmitters are simultaneously active. If only one device is active, the degradation is still 5 dB at 72 cm. Having the separation distance of 1 m or more, the impact of one UWB device is insignificant. With three active UWB devices, the difference at 252 cm to the non-interfered case is 2 dB.

By decreasing AF to 5%, only 4 dB degradation is observed in the worst case scenario with 24 simultaneously active UWB devices as seen from Fig. 4. Importantly, the difference between the reference case (zero active UWB devices) and the interfered cases reduces to about 1 dB in all the cases when the separation distance increases, as can also be seen from Fig. 4. If the number of active UWB devices is less than four, there is no difference to the non-interfered case.

In Fig. 5, the change in E_c/N_0 results based on the measurements carried out with both PRFs are collected into the same plot as a function of AF. All 24 UWB transmitters were active in this case and the reference case is zero active UWB devices. If the number of UWB interferers is decreased, the UMTS performance is also degraded less than shown in Fig. 5. Thus, the results represent the extreme worst case scenario from the measurements. Minimum and

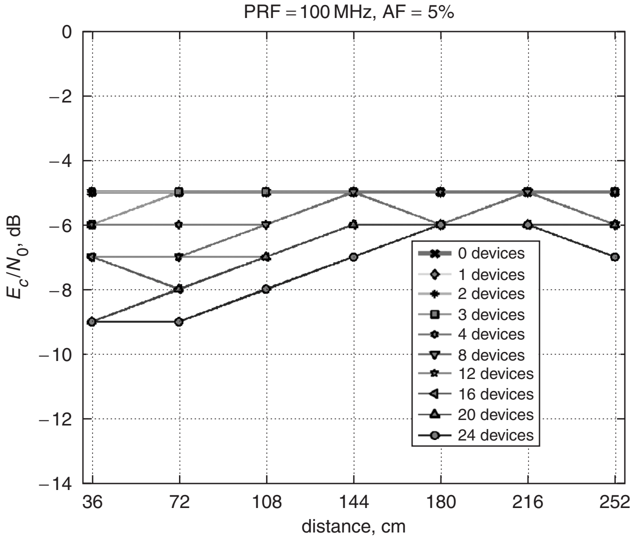

Fig. 4 *E_c/N_0 as a function of distance; PRF = 100 MHz, AF = 5%*

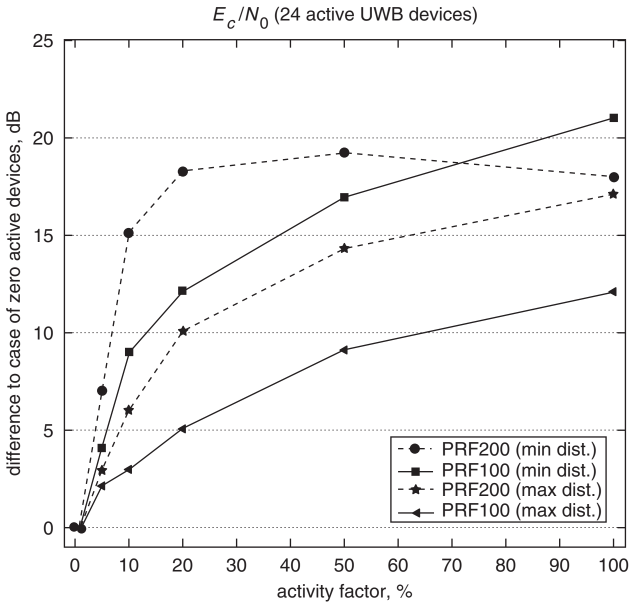

Fig. 5 *Change in E_c/N_0 versus AF with PRF of 100 and 200 MHz for 24 simultaneously active UWB devices*

maximum distances in the legends correspond to separation of 36 cm and 252 cm, respectively. As can be seen, the received E_c/N_0 saturates faster when higher pulse repetition rate is used in UWB transmission. This is based on the fact that the generated pulses have equal power, and higher PRF means that the average transmission power is increased due to the increased number of transmitted pulses within the same time frame. The results also implicitly show the impact of UWB activity factor on UMTS system performance. In the case of AF = 1% and large number of active devices, the results are indistinguishable from the case of zero active devices (i.e., no measurable interference).

The received signal strength indicator (RSSI) reported by the mobile indicates the overall interference collected over the 5 MHz band. Figure 6 illustrates the measured RSSI behaviour as a function of distance for different number of UWB devices for AF = 5%.

A similar comparison as presented for E_c/N_0 in Fig. 5 can be found for RSSI in Fig. 7. Again, the higher the activity factor, the higher the increase in RSSI at the UMTS carrier. For an AF = 1%, the results are indistinguishable from the case of zero active devices.

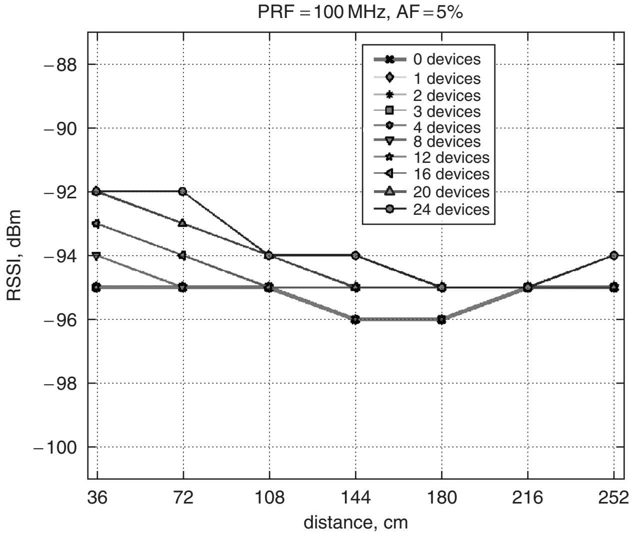

Fig. 6 *RSSI as a function of distance; PRF = 100 MHz, AF = 5%*

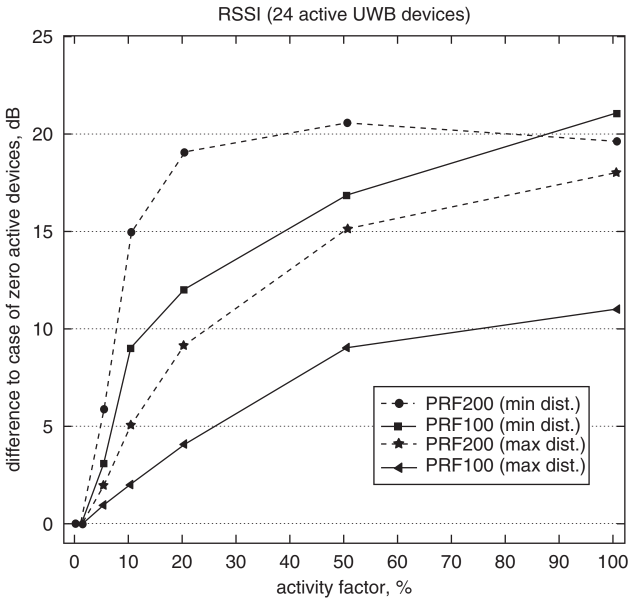

Fig. 7 *Change in RSSI versus AF with PRF = 100 and 200 MHz for 24 simultaneously active UWB devices*

Finally, the BER behaviour in the downlink pilot channel for the previous cases is discussed. In the following example, each measured BER value is calculated from 240 000 bits. As shown in Fig. 8, for AF = 100%, more than 20 active devices cause UMTS performance degradation at separation distances of less than 72 cm. If the separation distance is more than 1 m, the impact of UWB interference on UMTS link performance is insignificant. Measurements using AF from 1 to 50% had no impact on the measured BER levels that were between 10^{-3} and 10^{-4} as can be seen in Fig. 8. BER also tends to saturate at the level of 10^{-4}. However, no measurements were performed using AF values between 51% and 99%. In [6], similar BER behaviour is presented but the results are given as a function of UWB signal power.

4.2 Measurements with operational UMTS network

In this Section, the results of the co-existence measurements carried out at the shelter are discussed. The victim UMTS device is part of an operational UMTS network in an

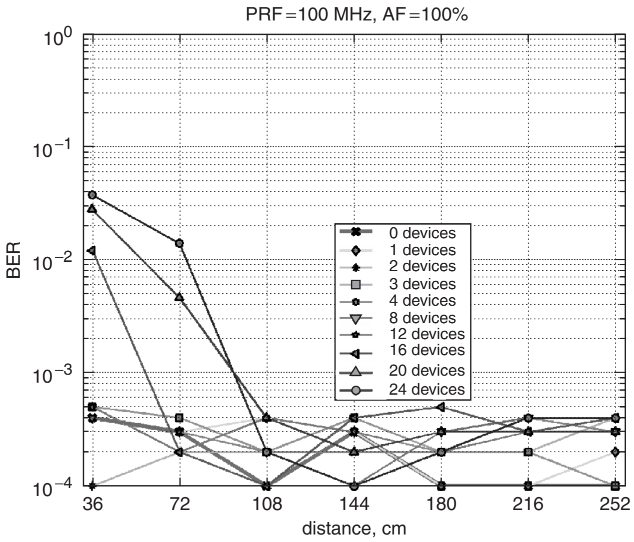

Fig. 8 *BER as a function of distance; PRF = 100 MHz, AF = 100%*

environment where UWB interference could be controlled and induced only against one victim terminal. Again, the location of the MS was fixed and the distance between the victim UMTS terminal and UWB transmitters were changed by moving the UWB devices. Locating the measurement set-up inside a shelter simulates a cell boundary condition where the received UMTS signal is weak. Within these measurements, all the UMTS modes (idle, voice and data) were monitored independently.

The results measured from a commercial UMTS network are shown in Figs. 9 and 10. In Fig. 9, the measured E_c/N_0 are given for two pulse repetition frequencies: PRF = 100 MHz and 200 MHz. The distance between the UMTS terminal and the blocks of four UWB sources was 1 m. Based on the measurements, the terminal lost its connection to the network if E_c/N_0 drops below −20 dB.

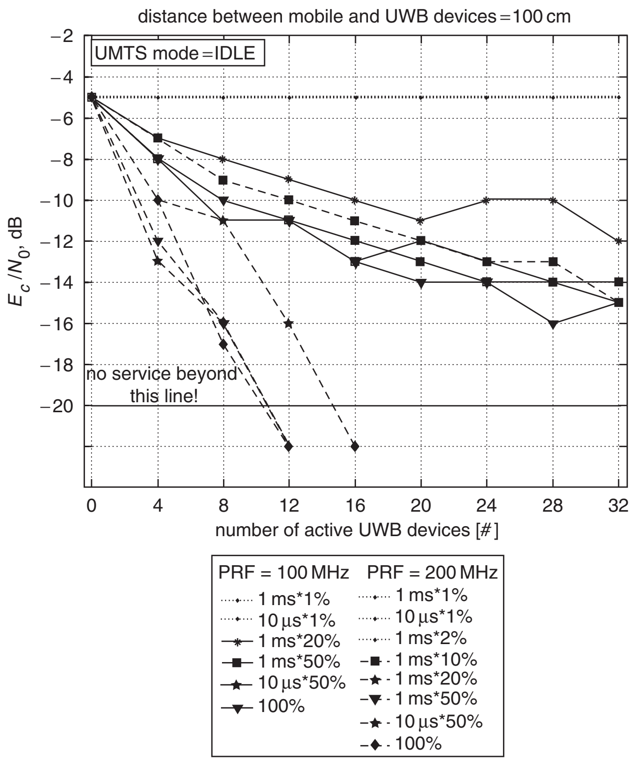

Fig. 9 *Measured E_c/N_0, PRF = 100 and 200 MHz, distance between interferers and victim receiver is 1 m*

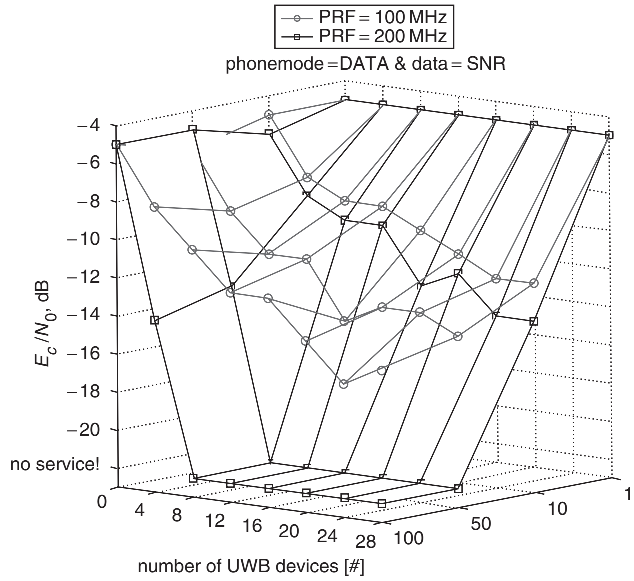

Fig. 10 *Measured SNR in data mode with PRF of 100 and 200 MHz, distance 1 m*

This level is shown as a 'No service' limit in the figures. The UMTS terminal lost the network connection only under the most extreme interference conditions. Taking a PRF of 200 MHz, the real network connection is lost in the presence of 12 active devices with an AF of greater than 50%, or 16 devices with an AF of more than 20%. In other cases examined, the network connection was maintained. Different frame lengths for UWB pulse train were also tested and their effect is found to be insignificant.

In Fig. 10, the results are summarised from all the measurements: PRF = 100 and 200 MHz and activity factor values ranging from 1% to 100%. The results are produced from the co-existence measurements where data connection was established between the MS and BS. As can be seen, changing the PRF considerably affects the measured E_c/N_0 of the UMTS system. At low levels of AF or small numbers of active devices, no measurable impact is seen at a separation of 1 m even for high PRF. For AF values of less than 20%, the single UMTS link in real network conditions can survive even if the number of active UWB devices is very high. For voice connections, the behaviour was the same. However, when using a PRF of 200 MHz, and activity factor being more than 20%, the connection was lost after more than 12 active UWB devices become active, as pointed out also in Fig. 9 for idle mode.

The general UMTS response to the interference is similar in both data and voice modes. If using the higher PRF in the UWB system, the UMTS performance degrades with increasing AF and number of simultaneously active devices, and the connection to the network will also be lost in the worst case. However, the use of low AF in UWB terminals allows the use of higher pulse repetition rates without any harmful UMTS performance degradation. As the results show, the impact of UWB interference on UMTS system is higher when PRF or AF is higher. With reasonable number of UWB transmitters, UMTS connection is not blocked and these two systems can co-exist.

5 Conclusions

Based on the measurements, it seems that FCC compliant UWB devices can co-exist with UMTS under practical scenarios; with a realistic number of simultaneously active UWB devices in the vicinity of the victim system (1–4) and realistic activity factor (<5%). However, severe performance degradation in UMTS link has been observed if a large number of UWB devices are simultaneously active with very high pulse repetition rates close to the victim receiver. In a realistic use-case, there would be significantly fewer than 24 active UWB devices in a very close proximity of the victim transceiver. In order for the UWB devices not to interfere with each other, such densities of devices are not practical. In practice, only a few devices will be simultaneously operational corresponding to simultaneously operational piconets. Large uncoordinated deployment scenarios such as UWB sensor networks would utilise low activity factors and so again limit the number of simultaneously active devices.

The range of results presented in this paper cover the range from a realistic UWB usage to very worst case, highly overloaded scenarios. The activity factor of the UWB devices was seen to have very significant impact on the victim systems performance. Reducing the activity factor was seen to lead to disproportionately less interference for the victim system. Packet-based transmission in high speed UWB systems can utilise discontinuous transmission allowing for a reduction of the activity factor. Activity factor can also be reduced by the UWB system design. Though the UMTS link can co-exist with the UWB, this study does not cover the impact of UWB on the radio access network. To maintain the UMTS link might affect to increase in downlink power level which could be seen as a decreasing network capacity. Therefore, further studies for the impact of UWB on the cellular network capacity are needed. In addition, the co-existence research between the forthcoming high data rate standards, like 3GPPP Rel. 5, and UWB are needed.

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