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Real Co-existence Measurements between UMTS/WCDMA and Ultra Wideband Systems

***Abstract*— This paper presents results from co-existence measurements between multiple ultra wideband (UWB) transmitters and a UMTS mobile phone carried out at the Centre for Wireless Communications (CWC), University of Oulu, Finland. Two environments were explored with the measurements; an anechoic chamber, and inside a shelter (simulating cell boundary conditions). Large numbers of FCC compatible UWB transmitters were used to generate interference in the presence of the active UMTS connection. In the first scenario (anechoic chamber), the voice link was originated between a Universal Mobile Telecommunications Systems (UMTS) radio communication analyser (used as a base station) and a mobile terminal. In the cell edge scenario, measurements were performed using the operating UMTS network. In this case, all UMTS modes (idle, voice and data) were studied.**

The results clearly show that UMTS and high pulse repetition rate UWB devices can co-exist when a moderate number of simultaneously active UWB devices operate in close proximity of a UMTS terminal. If the number of simultaneously active UWB transmitters close to the UMTS terminal is large, the UMTS connection can be greatly impaired.

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 performance degradation. As the activity factors grow beyond 10%, the impact of the UWB interference becomes significant.

UWB shows itself to have benign coexistence properties for UMTS when activity factors are low or when the number of active devices is small. Like any technology, a large number of devices leads to significant interference.

***Index Terms* — bit error rate, direct sequence, interference, link quality.**

Introduction

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

Co-existence is considered by standardization authorities as a vital topic to be better understood. Before the FCC (Federal Communications Commission) finalized the UWB standardization process in the USA [1], coexistence phenomena were widely discussed. Later, in Europe this discussion has become lively, and several official reports and proposals have been recently released, e.g., [2]-[3].

Cellular network operators and network manufacturers have expressed concern that UWB will increase the aggregate noise level leading to a reduction in overall network ca-

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pacity, as well as degrading a single mobile link. Some studies within this issue have been carried out.

UWB impact on UMTS system has been reported in [4] based on the measurements in terms of bit error rate and noise rise. In this reference, both conducted and radiated tests were carried out using one UWB transmitter whose centre frequency is higher than used in our experiments. We extended these results to cover more interfering devices and also report more measured parameters.

Typically, the co-existence problem between different systems has been studied through simulations, as in [5]-[8]. The impact of UWB on other cellular systems has also been examined e.g., in [7]-[10].

This paper presents co-existence measurement results when UWB transmitters are used in close proximity with a 3G cellular mobile phone system. The measurements were carried out at the CWC, University of Oulu. In the measurements, the impact of UWB on the performance of the UMTS/WCDMA link was tested inside an anechoic chamber and also with the existing UMTS network.

Measurement description

This Chapter introduces the measurement procedure followed throughout the experiments. Firstly, the UWB transmitters used in the study are introduced and parameterised. The victim system is also described. The software used for monitoring the parameters reported by the mobile and the measurement environments are briefly explained.

UWB parameters

The measurements were carried out using different distances between the active UWB transmitters and the victim 3G device. The adjustable parameters were activity factor (AF) and a frame length of the UWB transmission.

Activity factor is defined within a transmission frame as presented in Fig. 1 by AF = *x*/*y*, where *x* and *y* represent the burst and frame lengths, respectively; AF = 1%, 5%, 10%, 20%, 50% and 100% were used. The other changeable parameter, frame length (can be selected between 1μs and 1ms), was set to 1 ms if not otherwise mentioned.

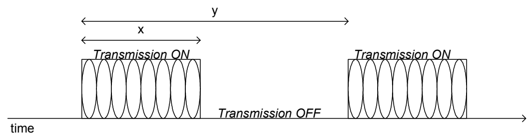

Fig. 1. Relation of activity factor and burst length.

Also, the pulse repetition frequency (PRF) could be controlled, e.g. the rate that the generated pulses is transmitted. In our case, the possible values are PRF of 100 and 200 MHz. The transmitted pulse train is scrambled with an m-sequence with a length of 2^{20} - 1 chips. No data modulation is included. When using a higher pulse repetition rate with the same energy per pulse, the total transmitted energy is doubled.

The UWB interference was generated using at most 24 FCC compatible UWB transmitters, which were activated in groups of four devices. However, the realistic amount of simultaneous active transmitters, that is 1…4 in the close vicinity of the victim, was separately studied as well. All the given results are based on radiated measurements.

UWB transmitter

The UWB transmitters and antennas used in the study have been designed and build by PJ Microwave (currently Elektrobit Microwave), Oulu, Finland. The devices are FCC compatible, thus adhering to the radiation mask from [1]. The UWB transmitter follows the original idea of impulse radio, being a single-band device but the canalisation is done using direct sequence (DS) approach instead of time hopping (TH) like in the original proposal.

Fig. 2 shows the UWB pulse transmitter used in the study. The box on the left (with a red connector) is a control board that is capable to drive simultaneously two pulse generators.

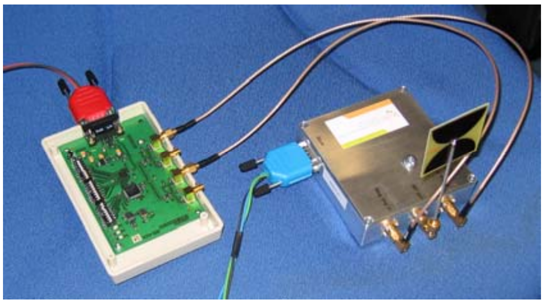

Fig. 2. UWB pulse generator.

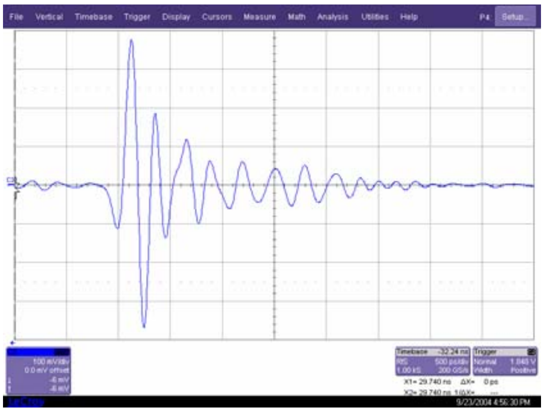

Fig. 3. Generated UWB pulse waveform.

Transmitted pulses are generated using step recovery diodes, and then combining two near Gaussian shaped pulses in opposite polarities with a specified delay between the replicas, a monocycle that is presented in Fig. 3 is achieved. In the figure, time grid is 500 ps. Depending on how to define pulse width we are dealing with less than 500 ps pulses. In general, the measured spectrum lies well below the FCC radiation mask even without the filtering effect of the antennas. The centre frequency of UWB transmission is about 3.41 GHz.

The output power measured at the same port is $P_{tx,UWB}$ = 0.0661mW (-11.8 dBm) within a band from 10 MHz to 10 GHz. The polarities of the transmitted pulse train are controlled by a pseudo random (PR) maximum length code. For every chip of PR code, one pulse is generated. The randomisation due to the PR code can be used for spectral smoothening, as well as user separation in multi-user case. In the latter case, each user has a different spreading code, like in conventional spread spectrum systems.

The antennas used in the system have very wide radiation bandwidth, as presented in Fig. 4. The lower part of the generated spectrum is also filtered out when the signal is passing through the antenna.

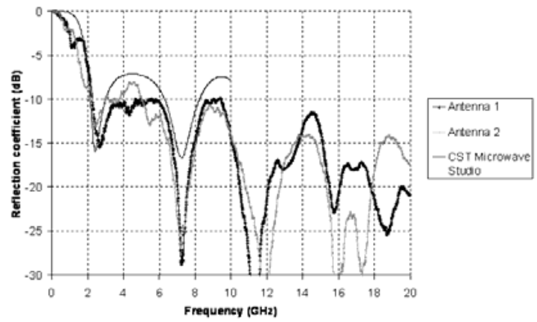

Fig. 4. Measured S_{11} for the used antenna.

The UWB transmitters are asynchronous due to the absence of common clock. Also, the two pulse generators driven by the control board are asynchronous due to the used cables which are different in length.

UMTS/WCDMA system

During the measurements two different cases were studied: anechoic chamber and real UMTS network.

The UMTS system used in the anechoic chamber consists of a commercial mobile phone (MS) and UMTS network simulator. The other results are based on the measurements carried out in a shelter using a connection to the real operational UMTS network. In all the cases, power control was set active in the mobile terminal.

Base station (Network)

The first measurement set-up was a connection to the real UMTS network that was in commercialised use. The link distance was about 300 m and MS was located at a shelter (thick concrete walls and metal shields in front of windows and door).

The other approach was used in an anechoic chamber where Anritsu MT8820A Radio Communication Analyser (RCA) [11] was used to simulate the operation of the UMTS network, i.e., 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 measurements were carried out using the following band allocations; in EMC-room, uplink (UL) and downlink (DL) bands were 1950 MHz and 2140 MHz. The corresponding band allocations for the measurements in a shelter were 1970 MHz and 2165 MHz, respectively. UMTS bandwidth in all cases was 5 MHz.

The use of RCA makes it possible to monitor, e.g., bit and block error rates (BER, BLER, respectively) for downlink pilot channel, E_c/N_0 that is chip energy divided by the noise spectral density measured from the common pilot channel (CPICH) and received signal code power (RSCP) from the active UMTS/WCDMA CPICH-channel. Anritsu MT8820A reports power levels using 0.5 dB grid. Received signal strength indicator for the carrier (RSSI) gives the total power measured within 5 MHz band. RSCP indicates the received signal power at a dedicated physical channel, i.e., the detected signal power. Typically it is calculated from the other parameters that are measured as

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

Bit error rate is calculated using loop-back test mode defined in the 3GPP standards. The antenna used in the base station site in an anechoic chamber was wideband CMA-118/A by Antenna Research, Inc.

Mobile side

The mobile terminal used in the studies was a commercial UMTS phone having development software allowing the real in-system parameter reporting. The MS position was kept the same during the measurements. This was done to keep the propagation channel characteristics constant (link between MS and BS). If moving MS, the channel propagation characteristics would change and the results would not be comparable.

Power control was activated in all measurements. The *inner loop power control* (fast closed loop power control) was utilizing Algorithm 1. This meant that the output power of the terminal was changed if only one request per slot is given by the network.

Measurement software

The mobile parameters were measured using Nemo Outdoor Field Measurement™ software that is a portable engineering tool designed for measuring and monitoring the air interface of wireless networks [12]. The parameters collected were RSSI, RSCP and E_c/N_0. The software reports power levels using 1 dB grid. RSCP is calculated from the other parameters as shown by (1).

Environments

The measurement layout for the anechoic chamber is presented in Fig. 5.

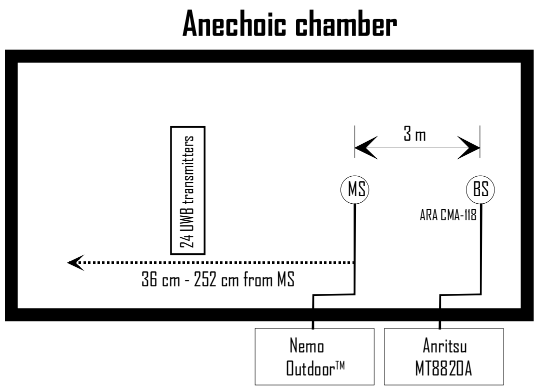

Fig. 5. Layout for anechoic chamber measurement.

In the chamber, the UMTS link distance is fixed to three meters 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, measured at the middle of the UWB generator row.

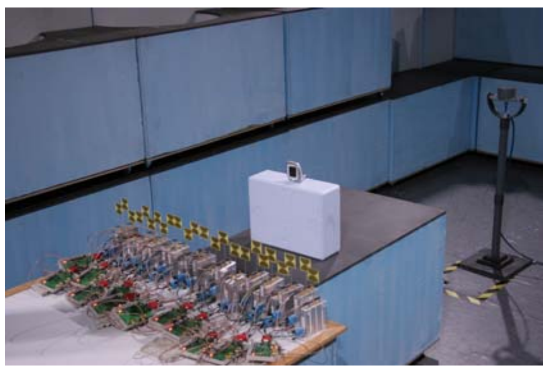

Fig. 6. Real measurement set-up.

In a shelter, the procedure was the same. MS position was fixed and the change in the interference distance was based on the movement of the UWB devices. The layout differed from Fig. 5 so that the BS antenna was located in a mast about 300 m from the measurement site. Otherwise there was no difference in the measurement procedures.

For each case and distance, a reference results were recorded. Then, the UWB boxes were in their nominal positions but they were all inactive. Zero active devices corresponds to “interference” from metal boxes alone which can be seen as additional signal multipath.

Results

Anechoic chamber measurements

In this Chapter, the co-existence results based on the measurements carried out at the anechoic chamber will be discussed. This Section will discuss all the parameters; E_c/N_0, RSSI and RSCP, to give a wider view for the topic. Because these parameters are related to each others through (1), the real network section gives only E_c/N_0.

E_c/N_0

This Section presents measured E_c/N_0 results that are based on the measurements at the anechoic chamber. The results are given as a function of interference distance and number of active devices.

In Fig. 7, the measured E_c/N_0 reported by the mobile terminal 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. AF = 100% do not correspond to the typical activity factor. For AF = 10% and 5%, which are more realistic values, the corresponding results can be seen from Fig. 8 and Fig. 9, respectively. In the case of AF = 1%, the results are overlapping with the case of zero active devices (i.e. no measurable interference).

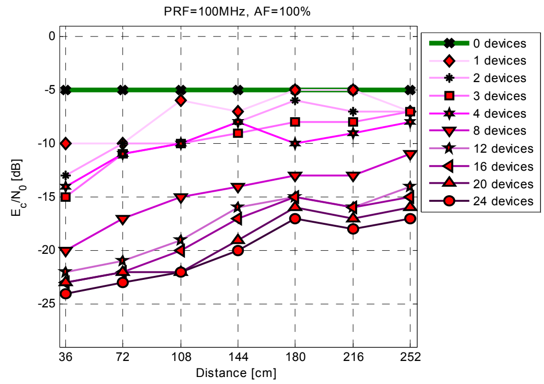

Fig. 7. E_c/N_0, PRF = 100 MHz, AF = 100%.

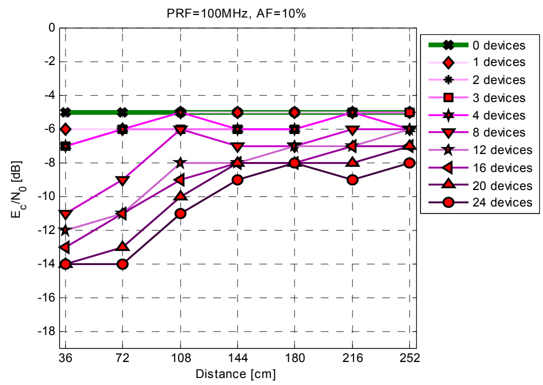

Fig. 8. E_c/N_0, PRF = 100 MHz, AF = 10%.

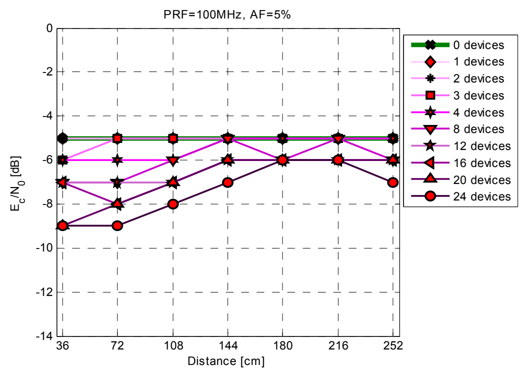

Fig. 9. E_c/N_0, PRF = 100 MHz, AF = 5%

As can be seen from the figures, the measured E_c/N_0 is affected by the UWB interference. With a separation distance of 36 cm, the degradation to the UMTS system is about 19 dB when all 24 transmitters are simultaneously active. If only one device is active, the decrease is still 5 dB. With increasing interference separation, the measured E_c/N_0 improves, however, at a separation of 252 cm, the degradation is still approximately 10 dB with a large number of simultaneously active devices.

By decreasing the AF to 5%, only 4 dB degradation in the worst case scenario was observed. Importantly, the difference between the reference case (0 active UWB devices) and interfered cases reduces to less than 1 dB in all cases for separation distances greater than 1 m as can be seen from Fig. 9.

In Fig. 10, the E_c/N_0 results based on the measurements carried out with both PRFs are collected into the same plot. The maximum difference is noticed when all 24 UWB transmitters were active. When decreasing the number of UWB interferers, the UMTS performance is significantly improved. Thus the results represent the extreme worst case scenario from our measurements. Minimum and maximum distances in the legends are 36 cm and 252 cm, respectively.

As can be seen, the UMTS saturates faster when higher pulse repetition rate is used in UWB transmission. The results also implicitly show the impact of UWB activity factor on UMTS system performance.

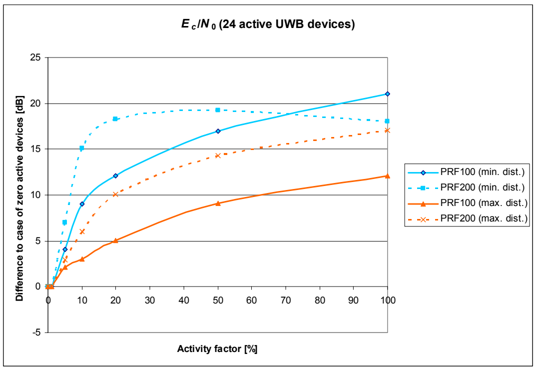

Fig. 10. Comparison of E_c/N_0 reduction with PRF of 100 and 200 MHz for 24 simultaneously active UWB devices.

RSSI

In this Section, we discuss the UWB impact on the received signal strength indicator (RSSI) reported by the mobile. This parameter reports all the received wideband signal power within the 5 MHz band. The parameter does not directly reflect the system performance but is quite a good indicator due to (1). Fig. 11 - Fig. 13 illustrate the measured RSSI behaviour as a function of distance for different number of UWB devices and activity factor.

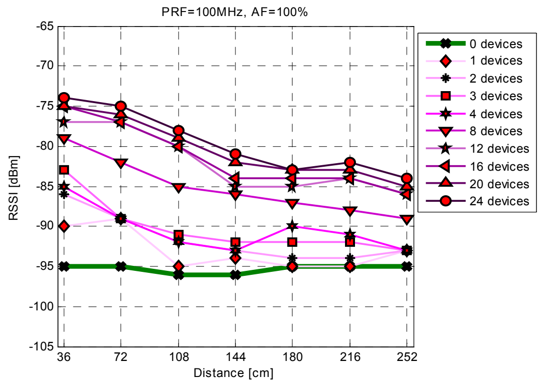

Fig. 11. RSSI, PRF=100 MHz, AF=100%.

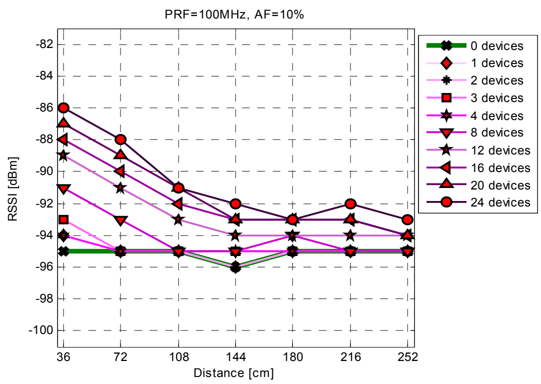

Fig. 12. RSSI, PRF=100 MHz, AF=10%.

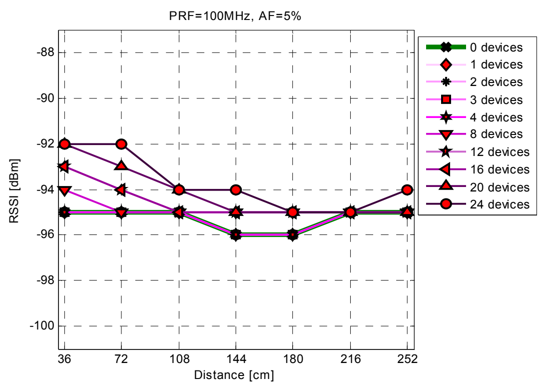

Fig. 13. RSSI, PRF=100 MHz, AF=5%.

For AF of 5%, the RSSI degradation is less than 3 dB and after 1 m less than 1 dB. Similar comparison than presented for E_c/N_0 in Fig. 10 can be found for RSSI in Fig. 14. The higher is the activity factor, the more performance degradation can be seen at the UMTS system performance. If AF = 1%, the results are the same than in the case of zero active devices.

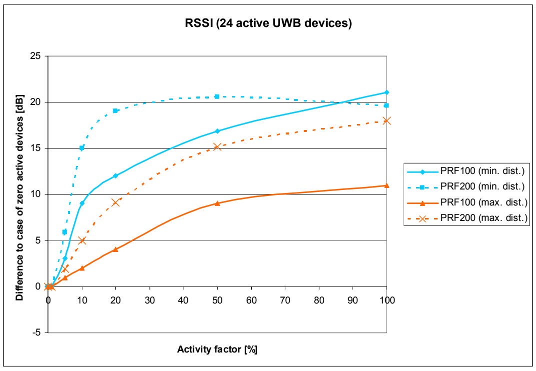

Fig. 14. Difference in measured RSSI compared to the zero UWB case for PRF of 100 and 200 MHz.

RSCP

This Chapter introduces the received signal code power (RSCP) which is calculated after decoding of the UMTS signal at CPICH-channel. Fig. 15 and Fig. 16 present RSCP for the mobile terminal when PRF = 100 MHz and AF = 100% and 50%. As can be seen, the deviation is less than 2 dB in most of the cases. When increasing the interference distance, RSCP is getting closer to the reference value (case with zero active UWB devices).

Again, the case of AF = 1% corresponds to the case of zero active UWB devices (Fig. 17). The deviation is less than 2 dB if AF = 5% even in the short interference separation.

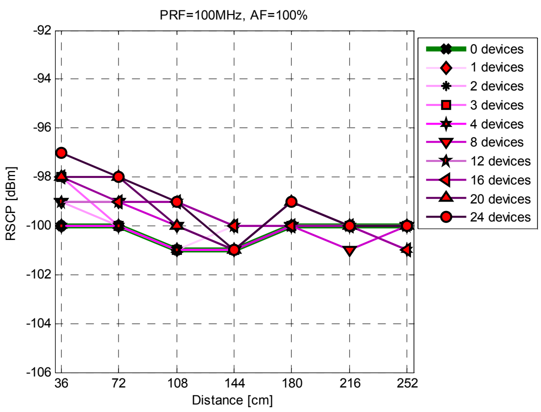

Fig. 15. RSCP, PRF=100 MHz, AF=100%.

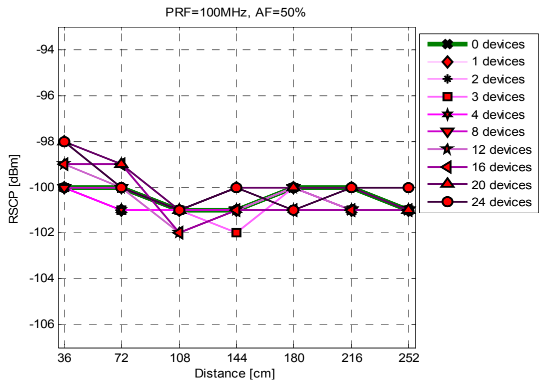

Fig. 16. RSCP, PRF=100 MHz, AF=50%.

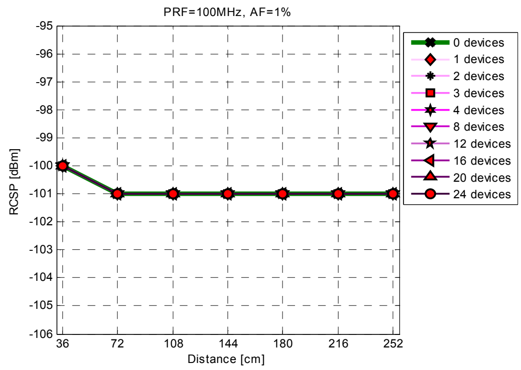

Fig. 17. RSCP, PRF=100 MHz, AF=1%.

BER

In this Chapter, bit error rate behaviour in downlink pilot channel for the previous cases is presented. With an Anritsu MT8820A, BER measurements can be performed for a 3GPP based system. In the following examples, each measured BER value is calculated from 240 000 bits. The RCA used also allows block error rate (BLER) measurements but obtain sufficient statistical reliability, the measurement time should be increased (thus receiving more blocks). For these measurements, only 1000 blocks were received and so is too small to get statistically reliable results for BLER. Therefore these results are now omitted.

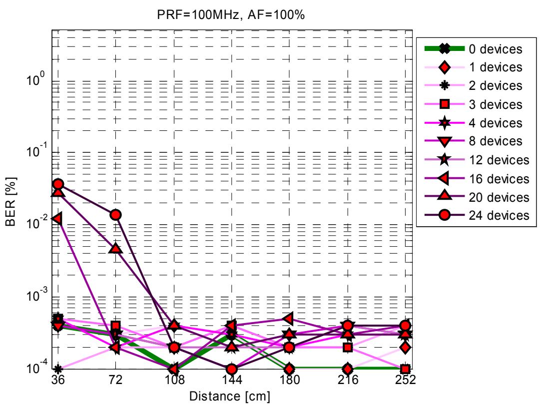

Fig. 18. BER, PRF=100 MHz, AF=100%.

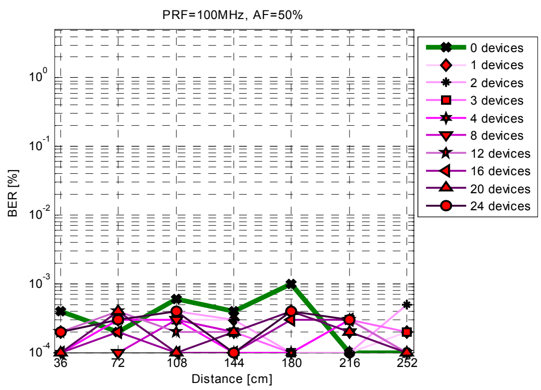

Fig. 19. BER, PRF = 100 MHz, AF = 50%.

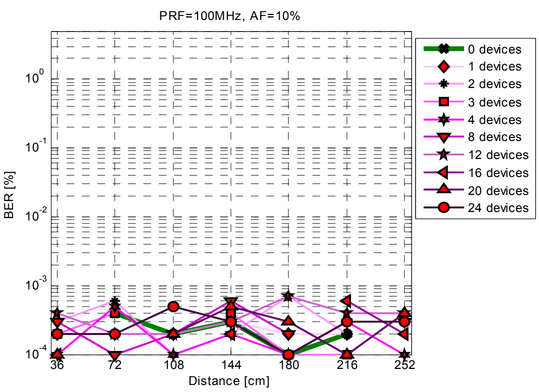

Fig. 20. BER, PRF = 100 MHz, AF = 10%.

As shown in the figures, UWB has no significant effect on the measured downlink pilot channel BER if the activity factor is less than 50% (no measurements done within 50% and 100%). If AF = 100%, more than 20 active devices cause UMTS performance degradation until 72 cm. If the distance is 1 m, the impact is insignificant. The distance grid in our measurement was 36 cm.

In [4], similar BER behaviour is presented but the results are given as a function of UWB power which reflects to the distance that we have used.

Cell Edge Conditions with Operational UMTS network

In this Chapter, the results of the coexistence measurements carried out at the shelter in the CWC premises are discussed. The victim UMTS link is part of an operation UMTS network. Again, the location of the mobile terminal 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 parameters were collected using Nemo Outdoor Field Measurement™ software.

In Fig. 21, the measured parameters when only one UWB transmitter is active are presented for all the measured parameters.

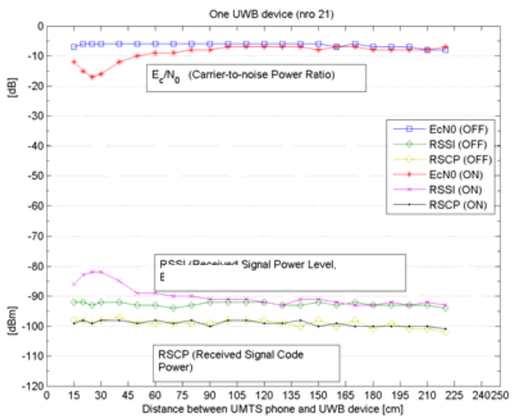

Fig. 21. Measured parameters of the UMTS terminal connected to the real network.

In Fig. 22 and Fig. 23 the measured E_c/N_0 are given for two pulse repetition frequency; PRF = 100 MHz and 200 MHz, respectively. The distance between the UMTS terminal and the block of UWB sources was 1 m, in both cases. Based on the measurements, the data and voice connection to the network was lost if E_c/N_0 < -20 dB. This limit is depicted in the figures. Different frame lengths for UWB pulse train were also tested and the effect is found to be insignificant.

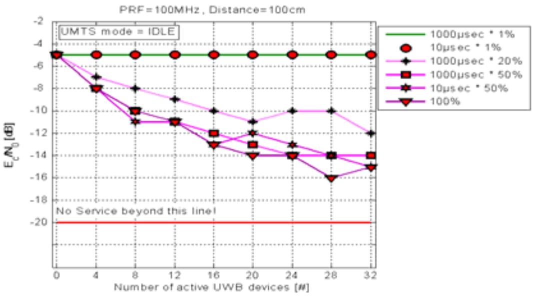

Fig. 22. PRF = 100 MHz, distance between interferers and UMTS mobile is 1 m (IDLE-mode).

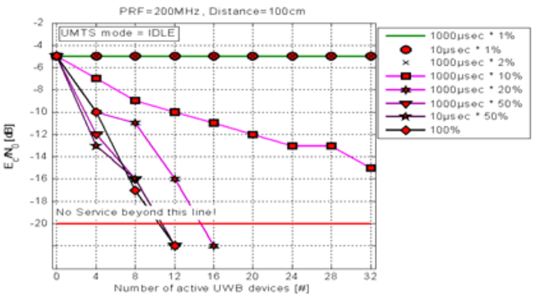

Fig. 23. PRF = 200 MHz, distance between interferers and UMTS mobile is 1 m.

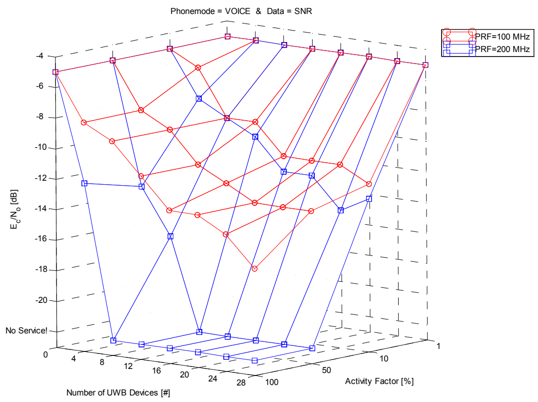

Fig. 24. Real UMTS network; SNR in voice-mode. PRF = 100 and 200 MHz.

In Fig. 24, the results are collected from the measurements where PRF = 100 and 200 MHz and activity factor gets values from 1% to 100%. The voice connection was established between the MS and BS. As can be seen, the increase in PRF makes UWB transmission more harmful to the UMTS system. However, if AF < 20%, the single UMTS link can survive even if the number of active UWB devices is highest.

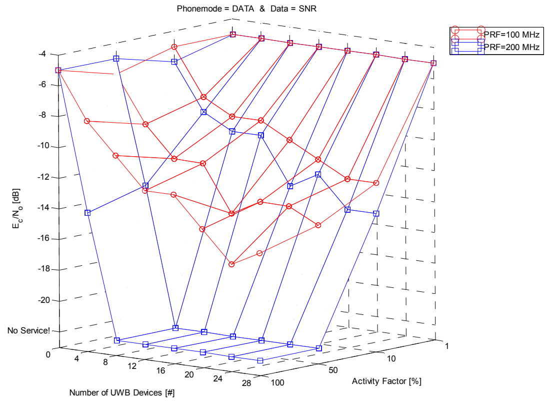

Fig. 25. Real UMTS network; SNR in data-mode. PRF = 100 and 200 MHz.

Corresponding results for data -mode are given in Fig. 25. The general UMTS response to the interference is similar in data -mode than in voice-mode. If using higher PRF in UWB system, the UMTS performance degrades easily with increasing AF and number of simultaneously active devices, and the connection to the network will also be lost in worst case. However, low AF in UWB terminals allows the use of also higher pulse repetition rates without any harmful UMTS performance degradation.

As the figures 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 coexist.

Conclusion

Based on the measurements, it seems that UWB devices can co-exist with UMTS/WCDMA 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%). Though, severe performance degradation has been observed if large numbers 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 to not 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 pico-nets. 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 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 these high speed UWB systems can utilize discontinuous transmission allowing for a reduction in the activity factor. This can also be affected by the UWB system design.

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