Chapter 14

UWB Coexistence with 3G and 4G Cellular Systems

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Additional information is available at the end of the chapter

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1. Introduction

The Federal Communications Commission (FCC) agreed in February 2002 to allocate 7.5 GHz of spectrum, in the 3.1 GHz to 10.6 GHz frequency band, for unlicensed use of ultra wide band (UWB) devices for communication applications. The move represented a victory in a long hard-fought battle that dated back decades. With its origins in the 1960s, when it was called time-domain electromagnetics, UWB came to be denoting the operation of sending and receiving extremely short bursts of RF energy. With its outstanding ability for applications that require precision distance or positioning measurements, as well as high-speed wireless connectivity, the largest spectrum allocation ever granted by the FCC is unique because it overlaps other services in the same frequency of operation. Previous spectrum allocations for unlicensed use have opened up bandwidth dedicated to unlicensed devices based on the assumption that operation is subject to the following two conditions:

1. The device will not cause harmful interference to other systems. Thus, the UWB interferences should not seriously degrade, obstruct, or repeatedly interrupt other radio communication systems.
2. The device must accept any interference received from any licensed system, including interference that may cause undesired operation. This means that devices using unlicensed spectrum must be designed to coexist in an uncontrolled environment.

Devices using UWB spectrum operate according to similar rules, but they are subject to more stringent requirements because UWB spectrum underlays other existing licensed and unlicensed spectrum allocations. In order to optimize spectrum use and reduce interference to existing services, the FCC's regulations are very conservative and require very low emitted power.

The UWB spectrum consists of three different parts as given below:

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- The main spectrum extending from 3.1 GHz up to 10.6 GHz.
- The lower residual spectrum extending from 0 Hz up to 3.1 GHz.
- The upper residual spectrum extending from 10.6 GHz upwards.

The main objective of this chapter is to study the UWB coexistence with the 3G and 4G Cellular Systems. UMTS in the 2 GHz and in the 450 MHz are two examples of the 3G cellular systems while the WiMAX system is one of 4G cellular systems.

WiMAX (Worldwide Interoperability for Microwave Access) is a 4G wideband cellular communication system that can provide up to 70 Mbps in 20 MHz bandwidth. The spectrum of WiMAX at 3.5 GHz lies between 3300 to 3800 MHz. Thus, WiMAX receivers are affected by UWB interference from the UWB main part spectrum. For WiMAX at 2.5 GHz, the spectrum lies between 2300 to 2700 MHz. In this case, WiMAX receivers are affected by the interference from the lower residual part of the UWB spectrum. Table 1 shows the WiMAX modulation schemes and the necessary Signal to Interference and Noise Ratio (SINR) required to support them.

The UMTS (Universal Mobile Telecommunications System) is a 3G cellular system that can support voice, data and video services. The downlink frequency used by the UMTS systems lies between 2110 to 2170 MHz.

Deployment of UWB systems creates a "forbidden zone" around the UWB transmitter in which the receivers of WiMAX or UMTS systems can be drastically affected. In practice, the radius of the forbidden zone should be the minimum possible. In our work we will consider a forbidden zone within 1 to 2 m radius (other values such as 0.5 m can be considered) assuming that the maximum accepted downlink range reduction of the WiMAX systems at any moment is 1%. The maximum accepted reduction of the capacity of UMTS systems is assumed to be also 1%.

Order	Modulation	Required SINR (dB)
1	BPSK 1/2	6.4
2	QPSK 1/2	9.4
3	QPSK 3/4	11.2
4	16 QAM 1/2	16.4
5	16 QAM 3/4	18.2
6	64QAM 1/2	22.7
7	64QAM 3/4	24.4

Table 1. WiMAX Modulation Schemes.

2. Related work

In (Hamalainen et al., 2002) the coexistence of the UWB system with GSM900, UMTS/WCDMA, and GPS has been investigated. They have evaluated the level of the interference caused by different UWB signals to the three above mentioned systems. Also they have evaluated the performance degradation of UWB systems in the presence of narrow bandwidth interference and pulsed jamming. They gave the bit error rate (BER) of the above mentioned systems for different pulse length.

In (Hamalainen et al., 2004) the coexistence of the UWB system with IEEE802.11a and UMTS in Modified Saleh-Valenzuela Channel has been studied as well as the UWB system performance in the presence of multiband interference. The interference sources considered were WiFi and UMTS operating simultaneously with their maximum system bandwidths. The UWB system under consideration was single band and single user operating at a data rate of 100 Mbps without error correction coding. They gave the bit error rate (BER) of the UWB system for different types of modulation (Direct Sequence and Time Hopping).

The interference between the UMTS and the UWB systems has been studied in (Giuliano et al, 2003). The free space propagation model was used to calculate the UWB signal propagation loss. It has been concluded that the minimum allowable central frequency value for UWB device, transmitting at 100 Mbps, has to be 3.5 GHz in order to avoid harmful interference with UMTS. In (Hamalainen et al., 2001a), the effect of the in band interference caused by different types of UWB signal to the UMTS/WCDMA uplink and downlink was investigated. UWB frequency spectra have been produced by using several types of narrow pulse waveforms. They have concluded that one can reduce interfering UWB power by using different waveforms and pulse widths avoiding the UMTS frequencies without any additional filtering. In (Hamalainen et al., 2001 b) the effect of the in band interference power caused by three different types of UWB signals to GPS L1 and GSM-900 uplink band was studied. UWB frequency spectra were generated again using several types of narrow pulse waveforms based on Gaussian pulse. In band interference power has been calculated over the IF bandwidth of the two victim receivers as a function of the UWB pulse width. Also the signal attenuation with distance was presented.

In (Ahmed et al., 2004) the effect of the UWB on the DCS-1800 and GSM-900 macrocell downlink absolute range, using the Line of Sight propagation model between the UWB transmitter and the mobile receiver, was studied (without taking into account the shadowing factor within the propagation loss model).

The effect of the UWB emission on the UMTS and CDMA-450 macrocell downlink performance (range and capacity) has been given in (Ahmed et al., 2008). The effect of the UWB emission on the WiMAX macrocell downlink range has been studied by (Ahmed et al., 2010). In (Chiani et. al., 2009) an overview about the coexistence between UWB and narrow-band wireless communication systems has been presented. In (Chóliz et. al., 2011) the coexistence between UMTS and UWB has been evaluated and cooperative mitigation techniques have been proposed and implemented. In (Das et. al., 2010) an interference cancellation schemes in UWB systems used in wireless personal area network based on wavelet based pulse spectral shaping have been presented.

The effect of the UWB on fixed service system (point to point and Fixed Wireless Access (FWA) systems in bands from 1 to 6 GHz) has been investigated in (ITU, 2003). It was concluded that, when the UWB transmitter is in LOS with the two systems antennas, the effect is very high when the UWB power density is higher than -41.3 dBm/MHz.

3. Effect of UWB Interference on the portable WiMAX downlink range

For each WiMAX downlink channel, the UWB interfering signal is due to only a given part of the total UWB spectrum. To account for UWB interference, an extra source of interference is added to the WiMAX noise. Here we consider the UWB interference as a Gaussian signal. The WiMAX technology is based on Orthogonal Frequency Division Multiplex (OFDM) technique. Thus we will calculate the Signal to interference plus noise (SINR) on a single subcarrier, not in the overall bandwidth.

The interference power is calculated by assuming an UWB interfering source at different distances from the WiMAX receiver. Therefore, the interference power generated by a UWB device, I_{UWB}, is given (in dBm) by:

$$I_{UWB} = P_{UWB} - L_{UWB}(d) + G_{RX\_WiMAX} \tag{1}$$

where:

- P_{UWB} is the UWB Effective Isotropic Radiation Power (EIRP) in dBm in the WiMAX bandwidth.
- $L_{UWB}(d)$ is the path-loss between the UWB device and the WiMAX receiver which varies with the separation distance d in m.
- G_{RX_WiMAX} is the antenna gain of the WiMAX system in the receiving end.

Taking into account that UWB devices are short range, the quasi free space path-loss model with shadowing is often most appropriate, especially when the distance between the UWB transmitter and the mobile receiver is lower than 8 m. Thus, in the WiMAX downlink frequency band, the UWB signal propagation loss $L_{UWB}(d)$, measured in dB at a distance d in meters from the UWB transmitter, is calculated as:

$$L_{UWB}(d) \approx 20\log_{10}\left(\frac{4\pi}{\lambda}\right) + 10\,n\,\log_{10}(d) + N(0,\sigma) \tag{2}$$

Where λ is the operating wavelength at the WiMAX frequency, n is the indoor propagation exponent (1.8 to 2.0) and N(0, σ) is a Gaussian variable of zero mean and a standard deviation of σ, representing the deviation from the path loss mean value (shadowing). Practical values of σ are in the range 1.8 to 3 dB in the line of sight LOS environment. Here we assume that the Gaussian variable N(0, σ) is truncated at ±4**σ**. In our case **σ** is assumed to be 2 dB.

In the calculation of the propagation loss of the WiMAX signal we use the two-slope propagation loss model. Thus, for a distance higher than 100 m, the WiMAX signal propagation loss in dB is given as:

$$L_{WiMAX} = A + 10\,\gamma\log_{10}\left(\frac{d}{d_o}\right) + s + L_{glass} + 6\,\log_{10}\left(\frac{f}{1900}\right) - 10.8\log_{10}\left(\frac{h_{RX}}{2}\right) \tag{3}$$

Where:

- A is the free space propagation loss at a distance of 100 m.
- d is the distance between the WiMAX transmitter and the WiMAX receiver.
- γ is the propagation exponent with a typical value of 3.9 to 4.7.
- s is the shadowing margin assumed to be 10 dB.
- L_{glass} is the wall insertion loss assumed to be 5 dB.
- f is the operating frequency of the WiMAX system given in MHz.
- h_{RX} is the WiMAX antenna height in the receiving end.

The thermal noise of the WiMAX receiver Nrec_sc per subcarrier is given by:

$$N_{rec\_sc}(dBm) = -114 + 10\log_{10}\left(B_c\right)_{MHz} + NF \tag{4}$$

where:

- B_c is the WiMAX band width of a single carrier.
- NF is the WiMAX receiver noise figure in dB assumed to be constant within the WiMAX bandwidth of 20 MHz.

The WiMAX received power per subcarrier S_{WiMAX_sc} is given as:

$$S_{WiMAX\_sc} = P_{WMAX\_sc} + G_{Tx\_WiMAX} - L_{WiMAX} + G_{Rx\_WiMAX} \tag{5}$$

where:

- P_{WiMAX_sc} is the WiMAX transmitted power per subcarrier.
- G_{TX_WiMAX} is the antenna gain of the WiMAX in the transmitting end assumed to be 18 dB (antenna for a macrocell with 3 sectors).

The WiMAX cochannel interference due to the macrocells using the same frequency band that exists within the three nearest clusters of 4 macrocells is given by:

$$I_{cc-WiMAX} \approx S_{WiMAX\_sc} + 10\log_{10} 3\left(\frac{d}{\sqrt{12}\,R}\right)^{\gamma} \tag{6}$$

where R is the radius of the WiMAX macrocell.

For the UWB system the propagation loss with 99.995% confidence is given by:

$$L_{UWB}(d) \approx 20\log_{10}\left(\frac{4\pi}{\lambda}\right) + 10\,n\log_{10}(d) - 4\,\sigma \tag{7}$$

For the WiMAX receiver, the signal to interference plus noise ratio SINR per subcarrier is given by:

$$SINR = 10\log_{10}\left(\frac{S_{WiMAX\_sc}}{I_{CC-WiMAX} + N_{rec\_sc} + I_{UWB}}\right) \tag{8}$$

where $I_{cc\text{-}WiMAX}$ is the WiMAX cochannel interference, N_{rec} is the receiver thermal noise, and I_{UWB} is the UWB interference all given in real numbers.

4. Effect of UWB Interference on the UMTS and CDMA-450 macrocell downlink performance

To account for the UWB interference, an extra source of interference is added linearly to the UMTS and the CDMA-450 intra-system interference. The interference power is calculated by assuming the UWB source to be at different distances from the UMTS receiver (the mobile station). Therefore, the interference power generated by a UWB device, I_{UWB}, is given by (in dBm):

$$I_{UWB} = P_{UWB} - L_{UWB}(d) + G_{UMTS} \tag{9}$$

Where:

- P_{UWB} is the mean UWB EIRP in dBm in the UMTS band.
- $L_{UWB}(d)$ is the path-loss between the UWB device and the UMTS receiver which varies with the separation distance, d in m, and
- G_{UMTS} is the UMTS antenna gain.

As the UWB devices are typically low power and short range devices the line-of-sight path-loss model is often most appropriate. Then the UWB signal propagation loss in dB is calculated as:

$$L_{UWB}(d) \approx 39.03 + 20\log_{10}(d) - 4\sigma \tag{10}$$

The effect of the UWB interference is to reduce the UMTS macrocell range or/and the macrocell capacity.

The normalized range is given as (Ahmed et. al., 2008):

$$\frac{R_{UMTS}}{R_{UMTS,o}} = \left(\frac{I_{UMTS}}{I_{UMTS} + I_{UWB}}\right)^{1/\gamma} \tag{11}$$

The normalized capacity C_n is given as (Ahmed et. al., 2008):

$$C_n = \left(\frac{I_{UMTS}}{I_{UMTS} + I_{UWB}}\right) \tag{12}$$

The interference power generated by a UWB device that affects the CDMA-450 receiver, IUWB, is given by (in dBm):

$$I_{UWB} = P_{UWB} - L_{UWB}(d) + G_{CDMA} \tag{13}$$

where:

- P_{UWB} is the UWB EIRP in dBm in the CDMA-450 band.
- $L_{UWB}(d)$ is the path-loss between the UWB device and the CDMA-450 receiver which varies with the separation distance, d in m, and
- G_{CDMA} is the CDMA-450 antenna gain .

In the frequency band used by CDMA-450, the UWB signal propagation loss in dB is calculated as:

$$L_{UWB}(d) \approx 25.7 + 20\log_{10}(d) - 4\sigma \tag{14}$$

The normalized range is now given by (Ahmed et. al., 2008):

$$\frac{R_{CDMA}}{R_{CDMA,o}} = \left(\frac{I_{CDMA}}{I_{CDMA} + I_{UWB}}\right)^{1/\gamma} \tag{15}$$

where:

- $R_{CDMA,o}$ is the CDMA-450 macrocell initial range without the UWB interference.
- R_{CDMA} is the CDMA-450 macrocell range with the existence of the UWB interference.

The normalized capacity of the CDMA-450 system Cn is given by (Ahmed et. al., 2008):

$$C_n = \left(\frac{I_{CDMA}}{I_{CDMA} + I_{UWB}}\right) \tag{16}$$

5. Results for a WiMAX system and a single UWB interferer

Fig. 1 represents the scenario of the studied WiMAX system. It shall be mentioned that the receiver is an indoor portable WiMAX. The UWB transmitter is also indoor within a distance of 0.5 to 5 m from the WiMAX receiver.

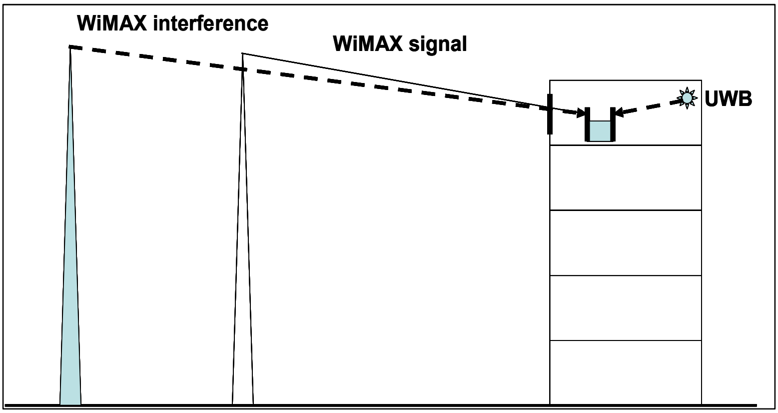

Figure 1. WiMAX studied scenario.

Let us study the case of 3.5 GHz WiMAX assuming that the WiMAX transmission power is 40 dBm/sector. Fig. 2 shows the WiMAX downlink modulation modes, as a function of distance between the WiMAX transmitter and receiver, for three different UWB power densities. It can be noticed that, without UWB interference, the WiMAX will have a range of 1481 m for the second modulation scheme. With a UWB power density of -88.5 dBm/MHz the range will be reduced by 2% and with a UWB power density of -41.3 dBm/MHz (recommended by FCC), the range will be only 213 m. Such a reduction drastically degrades the WiMAX performance.

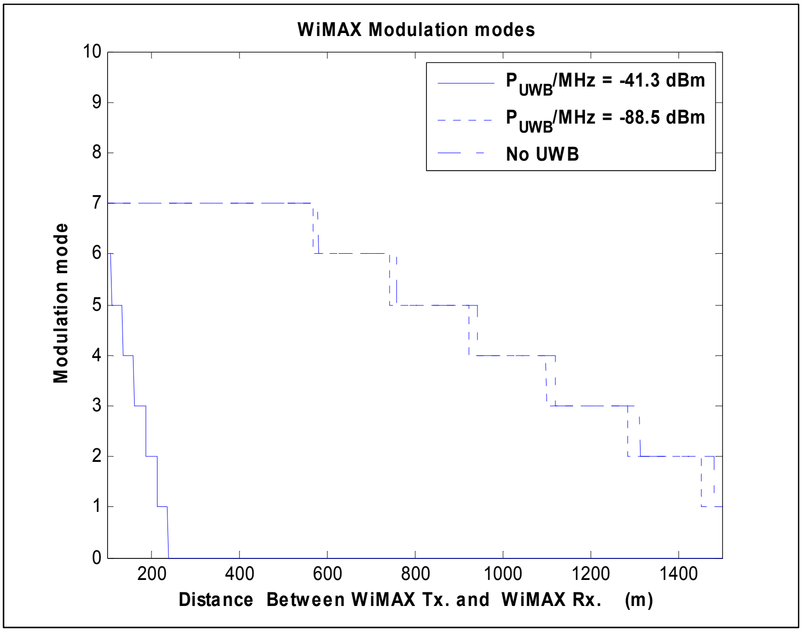

Figure 2. 3.5 GHz WiMAX modulation modes for different UWB power densities with a 1 m distance between the UWB transmitter and the WiMAX receiver assuming a WiMAX transmitted power of 40 dBm/sector.

Let us consider now the case when the WiMAX signal and also the interference are received through an open window. Fig. 3 shows the WiMAX downlink modulation modes, again as a function of distance between the WiMAX transmitter and receiver, for three different UWB power densities. As can be seen, without UWB interference, the WiMAX will have a range of 1930 m for the second modulation scheme. With a UWB power density of -88.5 dBm/MHz the range will be reduced by 2%. And for a UWB power density of -41.3 dBm/MHz (recommended by FCC), the range will be 310 m. Again the WiMAX range performance is drastically degraded.

Let us now study the case presented in Fig. 2 but assuming this time that the maximum allowed WiMAX reduction range is 1%. Fig. 4 shows the WiMAX downlink modulation modes as a function of distance between the WiMAX transmitter and receiver for three different UWB power densities. It is clearly seen that, without UWB interference, the WiMAX will have a range of 1481 m for the second modulation scheme. The range will be reduced by 1% when the interfering UWB power density is -91.5 dBm/MHz.

Let us consider now the case when the WiMAX system operates in the 2.5 GHz band. Fig. 5 shows the WiMAX downlink modulation modes as a function of distance between the

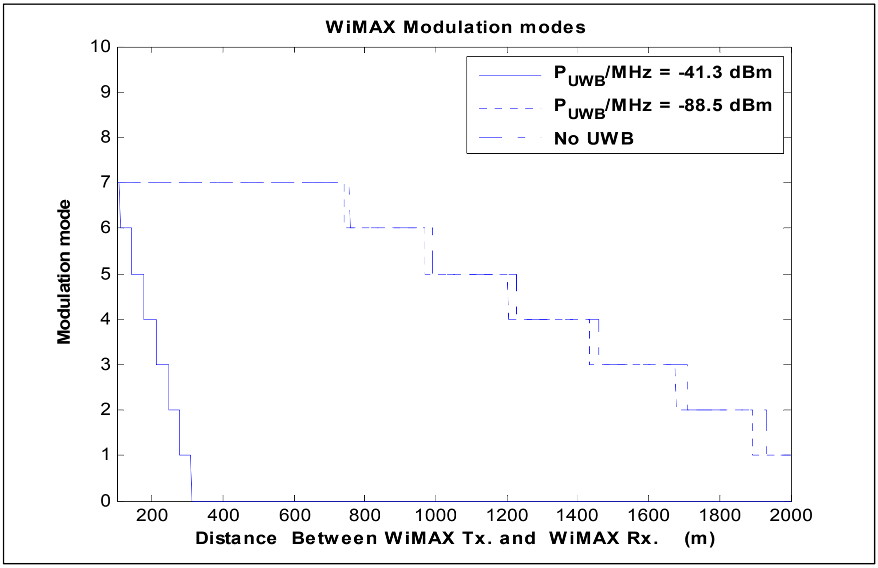

Figure 3. 3.5 GHz WiMAX modulation modes for different UWB power densities with a 1 m distance between the UWB transmitter and the WiMAX receiver assuming a WiMAX transmitted power of 40 dBm/sector and that the WiMAX signal and interference are received through an open window.

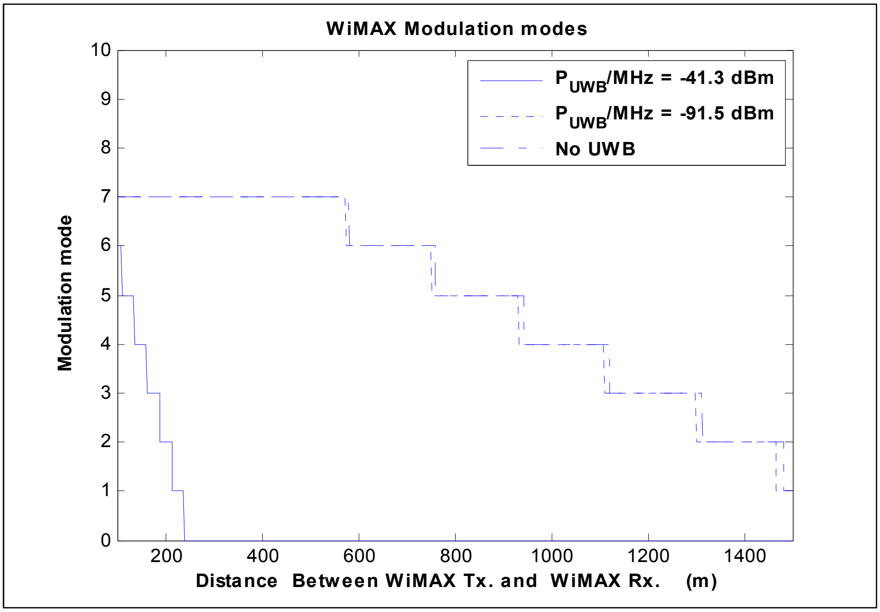

Figure 4. 3.5 GHz WiMAX modulation modes for different UWB power densities with a 1 m distance between the UWB transmitter and the WiMAX receiver assuming a WiMAX transmitted power of 40 dBm/sector.

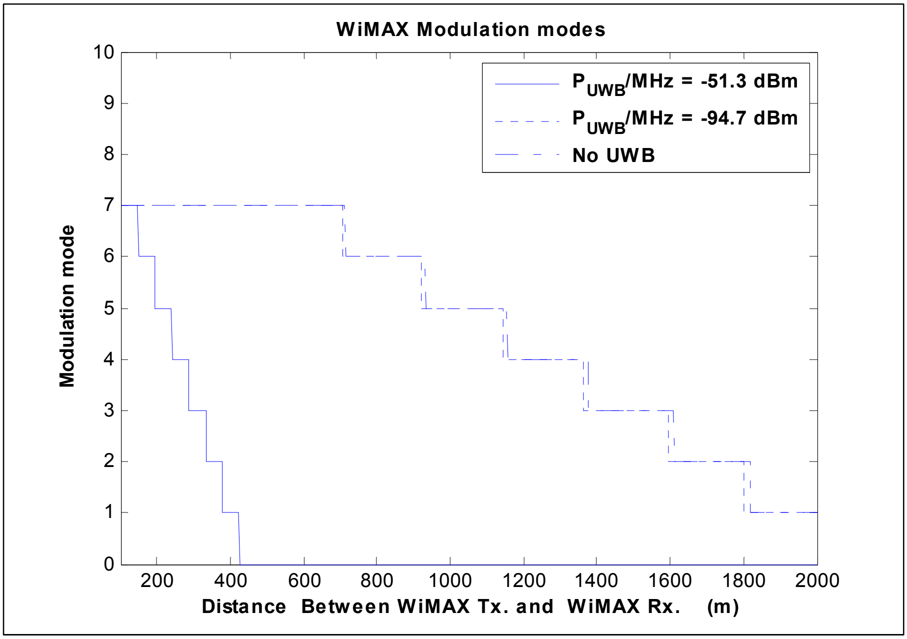

Figure 5. 2.5 GHz WiMAX modulation modes for different UWB power densities with a 1 m distance between the UWB transmitter and the WiMAX receiver assuming a WiMAX transmitted power of 40 dBm/sector.

WiMAX transmitter and receiver for three different UWB power densities. Notice that, without UWB interference, the WiMAX will have a range of 1817 m for the second modulation scheme. With a UWB power density of -94.7 dBm/MHz the range will be reduced by 1%. For a UWB power density of -51.3 dBm/MHz (recommended by FCC), the range will be 378 m and such a reduction represents a drastic degradation of the WiMAX performance. In this case an UWB with a power density of -91.5 dBm/MHz will reduce the WiMAX range by 2%.

6. Results for a WiMAX system and multi UWB interferers

We will consider now the case of multi-UWB transmitters, assuming the case that 4 UWB are located at a distance of 1m from the WiMAX receiver. Fig. 6 shows the WiMAX downlink modulation modes as a function of the distance between the WiMAX transmitter and receiver (WiMAX link length) for three different UWB power densities. It can be noticed that, without UWB interference, the WiMAX will have a range of 1481 m for the second modulation scheme. The range will be reduced by 1% when the UWB power density is higher than -97.5 dBm/MHz. In this case, an UWB power density of -94 dBm/MHz will reduce the WiMAX range by 2%.

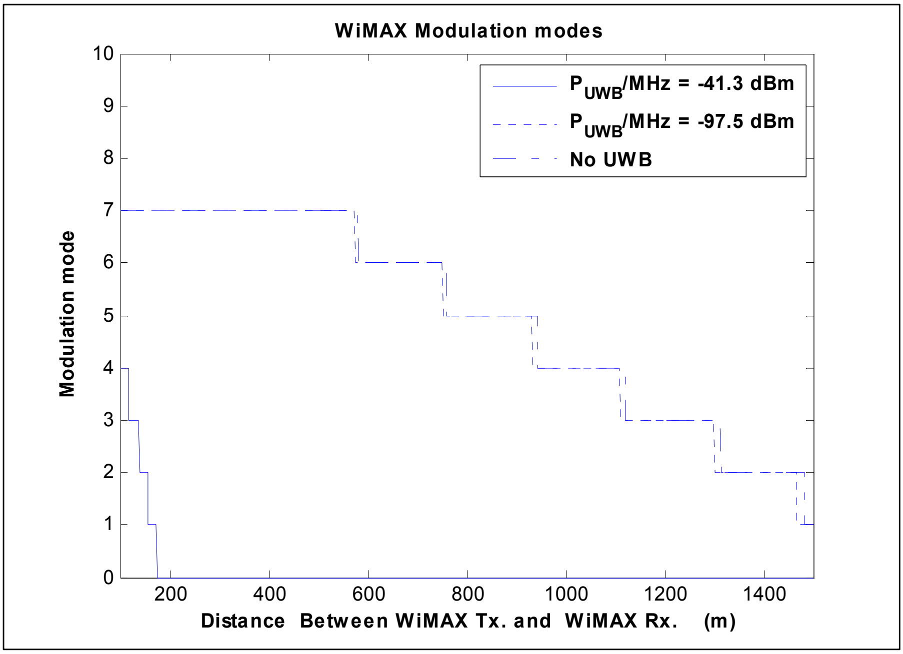

Figure 6. 3.5 GHz WiMAX downlink modulation modes versus distance between the WiMAX transmitter and receiver, for different UWB power densities from 4 UWB transmitters at 1 m distance to the WiMAX receiver and assuming a WiMAX transmitted power of 40 dBm/sector.

A band rejection up to 56 dB is needed for the DS-CDMA UWB system, while for the MB-OFDM UWB system a 51 dB band rejection is needed and can be obtained by nulling 16 subcarriers with a 40 dB notch filter.

We study now the same scenario but for the 2.5 GHz WiMAX. Fig. 7 shows the WiMAX downlink modulation modes as a function of the distance between the WiMAX transmitter and receiver for three different UWB power densities. It can be noticed that for the second modulation scheme without UWB interference, the WiMAX will have a range of 1817 m. At a UWB power density of -100.7 dBm/MHz, WiMAX range will be reduced by 1%.

In summary, from the results presented in Figures 2, 3, 4 and 5 it can be concluded that the power density of -41.3 dBm/MHz recommended by FCC, implies a very high range reduction, unless Detect and Avoid (DAA) techniques are implemented.

Fig. 8 represents the DAA requirement for Multiband OFDM UWB (MB-OFDM UWB) system and the Direct Sequence CDMA system (DS-CDMA UWB), with activity factors (fraction of the time they work at the 3.5 GHz band) of 32% and 100% respectively.

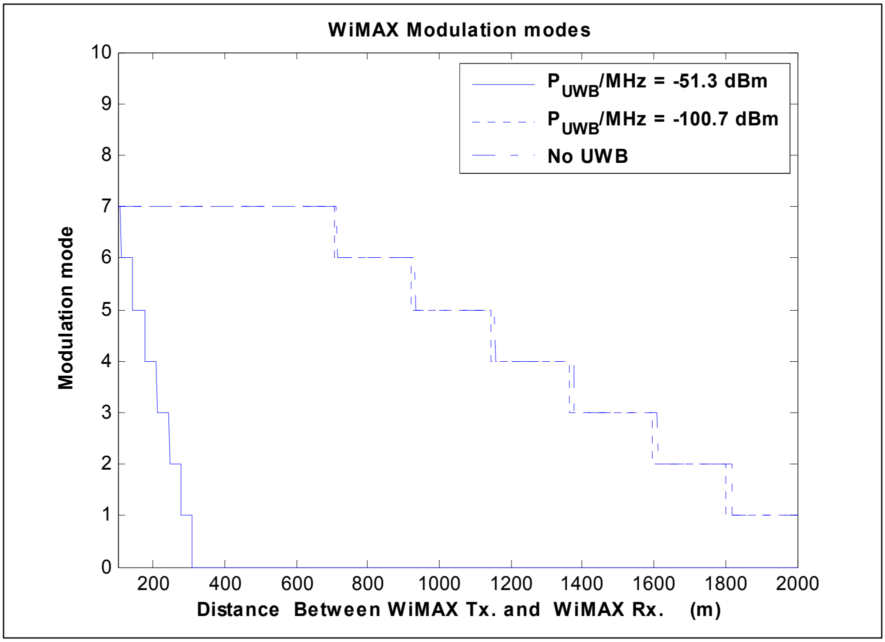

Figure 7. 2.5 GHz WiMAX modulation modes for different UWB power densities with a 1 m distance between the 4 UWB transmitters and the WiMAX receiver assuming a WiMAX transmitted power of 40 dBm/sector.

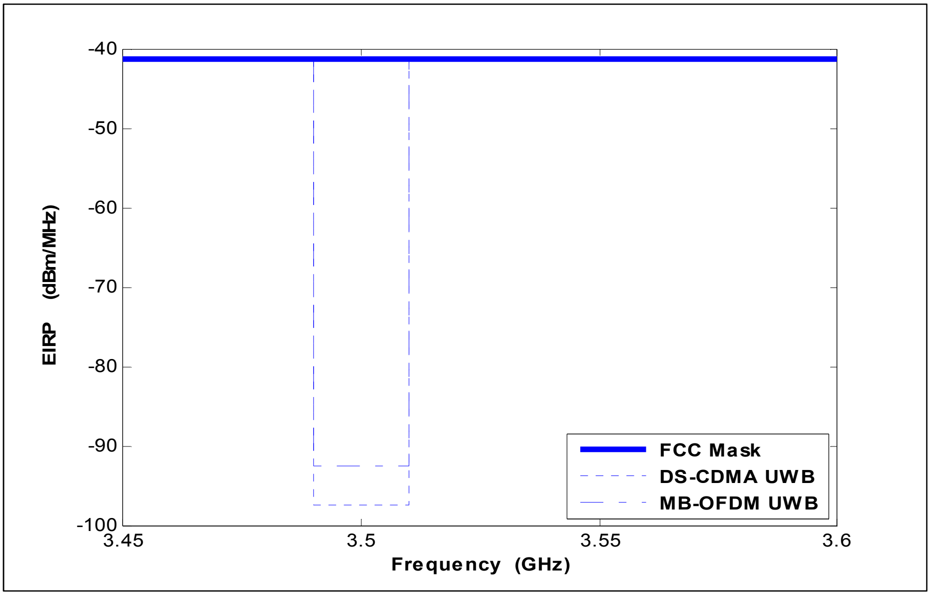

Figure 8. DAA requirements within the 3.5 GHz band.

7. Results for UMTS or CDMA-450 systems and single UWB interferer

Let us now study the coexistence of UWB systems with the UMTS (working at the 2 GHz band) and CDMA-450 systems. In the analysis we assume that the UWB data rate is higher than the UMTS or CDMA-450 chip rate. In this case, the UWB interference can be considered as a Gaussian noise. We address here the effect that the UWB system produces on the downlink of the UMTS and CDMA-450 systems. In Fig. 9, the UWB interference power on the UMTS downlink (i.e. interference as seen at the mobile) is plotted assuming a UWB power density (P_{UWB}) of -51.3 dBm/MHz within the UMTS bandwidth.

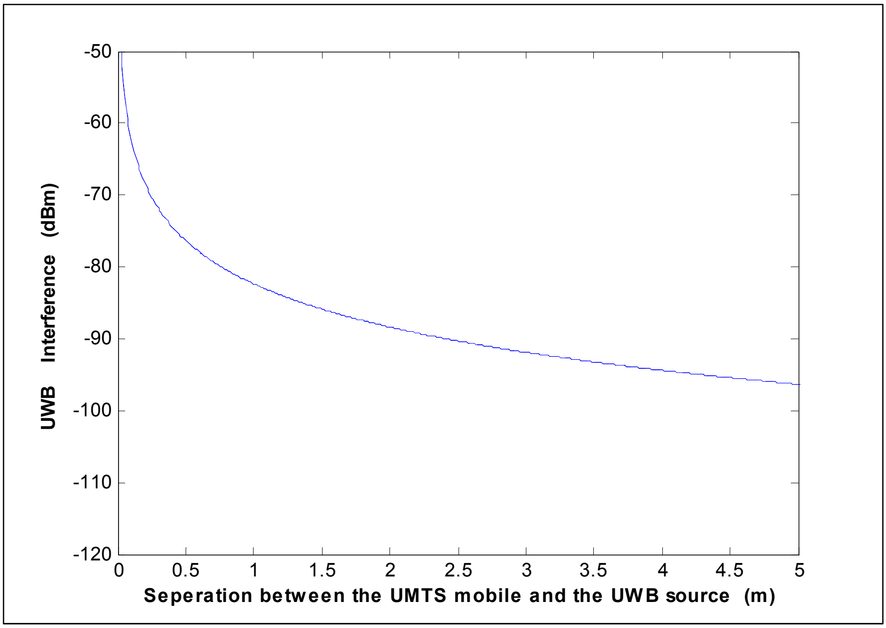

Figure 9. UWB interference as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -51.3 dBm/MHz).

Lets us study now the case of voice service [G_p = 256 and $(E_b/N_o)_{req}$ = 6 dB] assuming an UMTS interference of -88 dBm (14 dB Rise-Over-Thermal ROT). Fig. 10 shows the downlink macrocell normalized range as a function of the separation between the UMTS mobile and the UWB transmitter for three different values of the propagation exponent γ. It can be noticed that the UWB signal creates a high interference (which reflects a macrocell normalized range reduction of 35.6%) when the separation is 1 m. For larger separation, the interference is lower and thus the range reduction is also lower.

Fig. 11 shows the downlink macrocell normalized capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the UWB signal creates a high interference (which reflects a macrocell normalized capacity reduction of 78.6%) when the separation is 1 m. For larger separation, the interference is lower and thus the normalized capacity reduction is also lower.

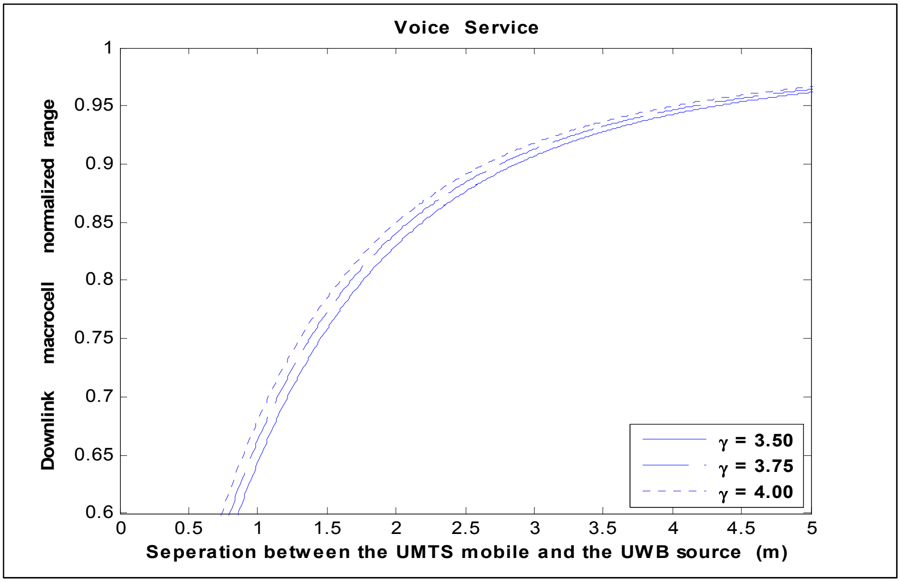

Figure 10. Effect of the UWB interference on the macrocell range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -51.3dBm/MHz).

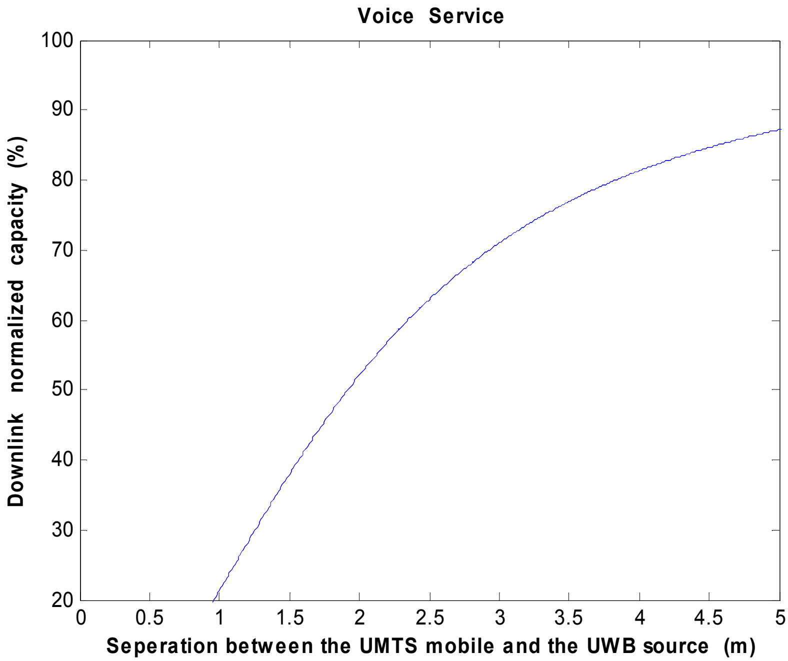

Figure 11. Effect of the UWB interference on the macrocell normalized capacity as a function of the separation between the UWB transmitter and the UMTS mobile (PUWB = -60 dBm/MHz).

Next let us study the data service case [G_p = 32 dB and $(E_b/N_o)_{req}$ = 5 dB] assuming an UMTS total interference of -92.5 dBm (9.5 dB Rise-Over-Thermal ROT), representing a highly loaded macrocell. Fig. 12 shows the downlink macrocell normalized range as a function of the separation between the UMTS mobile and the UWB transmitter for three different values of the propagation exponent s. It can be noticed that the UWB signal creates a high interference (which reflects a high macrocell normalized range reduction of 50.5%) when the separation is 1m. For larger separation, the interference is lower and thus the range reduction is also lower.

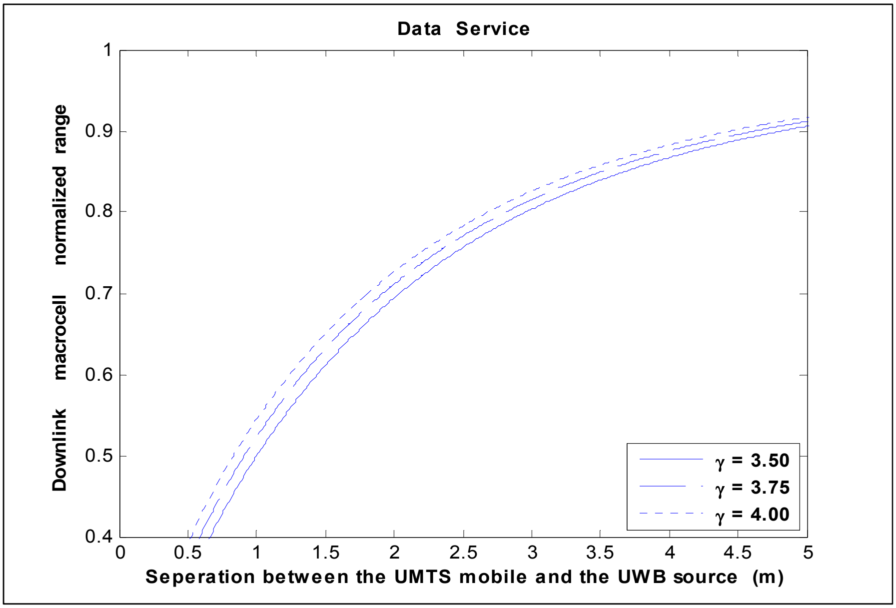

Figure 12. Effect of the UWB interference on the macrocell normalized range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -51.3 dBm/MHz).

Fig. 13 shows the downlink macrocell normalized capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the UWB signal creates a high interference (which reflects a high macrocell normalized capacity reduction of 91%) when the separation is 1 m. For larger separation, the interference is lower and thus the normalized capacity reduction is also lower.

It is obvious that such reductions (in range and capacity) are unacceptable. Thus the EIRP power density should be reduced to get an acceptable range and capacity reduction.

Let us consider now the data service case assuming a P_{UWB} of -81.4 dBm/MHz. Fig. 14 shows the downlink macrocell normalized range as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the UWB signal creates a high interference (which reflects a high macrocell normalized range reduction) when the separation is lower than 0.25 m. For larger separation, the interference is lower and at a distance higher than 1m, the effect of the interference is quasi null.

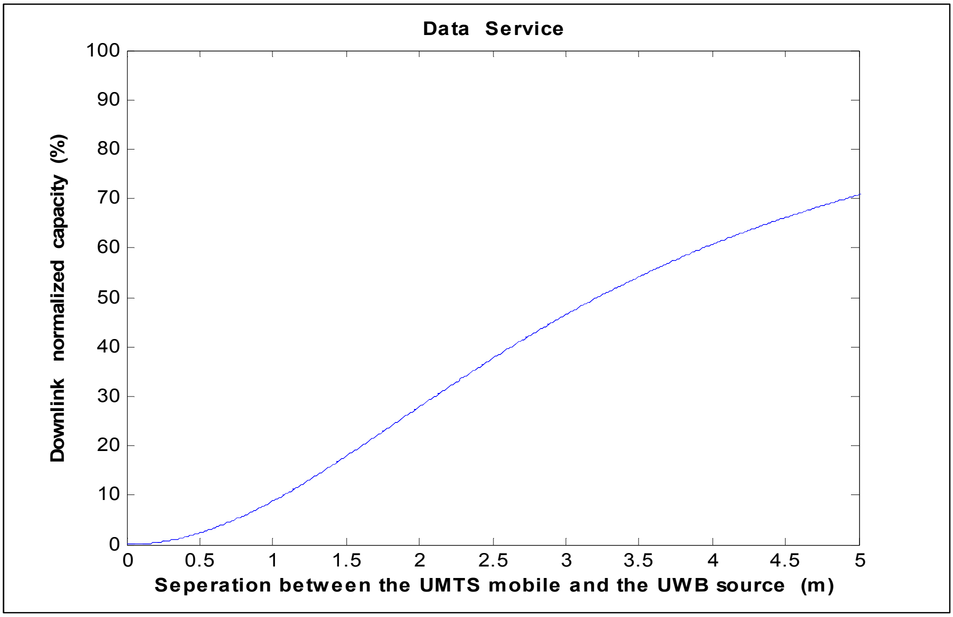

Figure 13. Effect of the UWB interference on the macrocell normalized capacity as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -51.3 dBm/MHz).

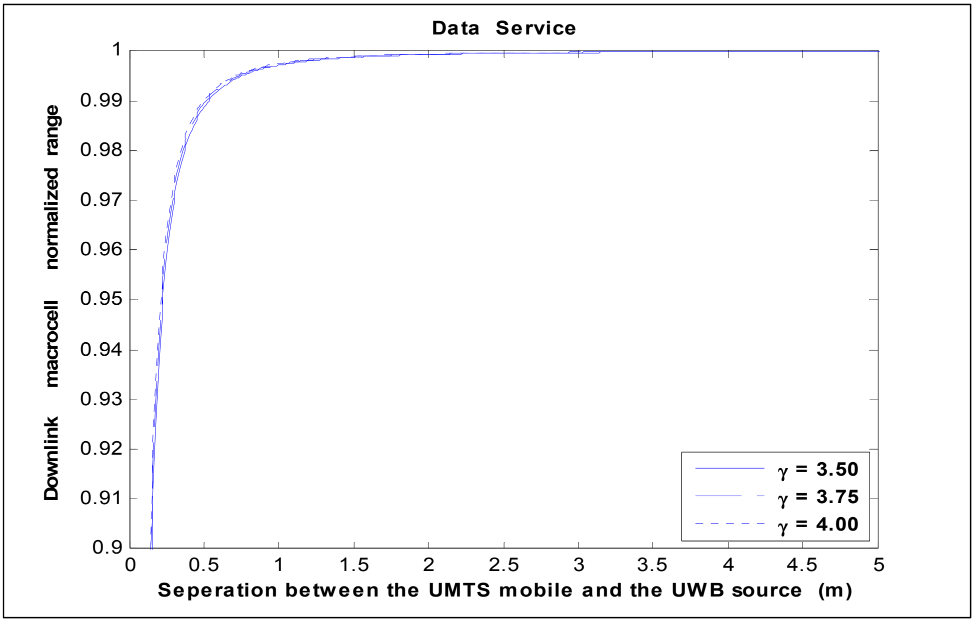

Figure 14. Effect of the UWB interference on the macrocell range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -81.4 dBm/MHz).

Fig. 15 shows the downlink macrocell capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the UWB signal creates a high interference (which reflects a high macrocell capacity reduction) when the separation is less than 0.4 m. For larger separation, the interference is lower and at a distance higher than 1.0 m, the effect of the interference is to reduce the cell capacity by 1%.

Next we study the case of data service (G_P = 32 dB and $(E_b/N_o)_{req}$ = 5 dB) of the CDMA-450 3X assuming that the CDMA-450 total interference of -92.5 dBm (9.5 dB Rise-Over-Thermal ROT) and UWB power density of -95 dBm/MHz. The frequency of operation is assumed to be 450 MHz.

Fig. 16 shows the CDMA-450 downlink macrocell normalized range as a function of the separation between the CDMA mobile and the UWB transmitter. It can be noticed that the UWB signal creates a low interference when the separation is 1m which reflects a normalized range reduction of less than 0.3%.

Fig. 17 shows the CDMA-450 downlink macrocell normalized capacity as a function of the separation between the CDMA-450 mobile and the UWB transmitter. It can be noticed that the UWB signal creates a low interference when the separation is 1m which reflects a normalized capacity reduction of 1%.

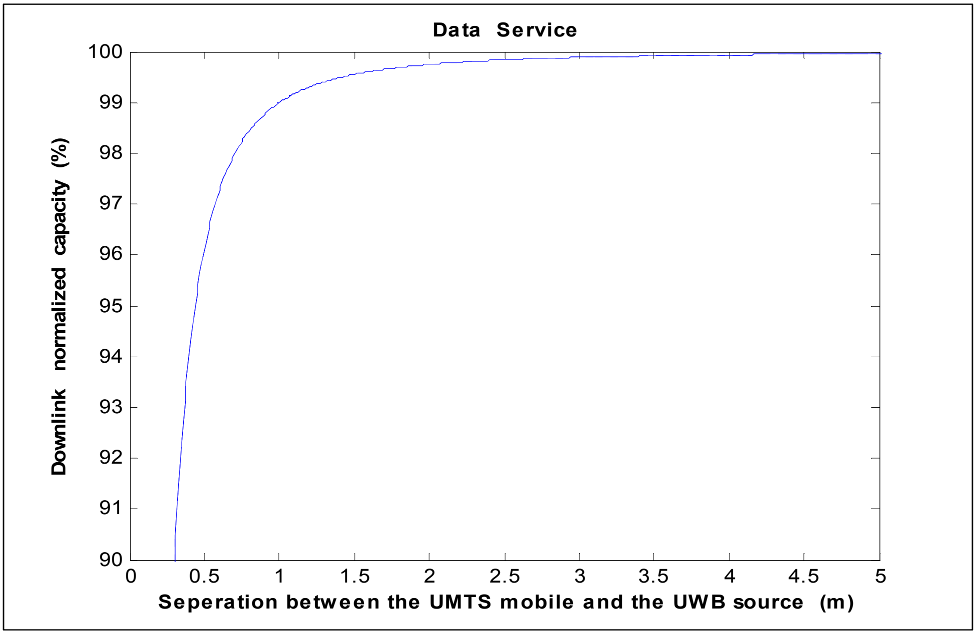

Figure 15. Effect of the UWB interference on the macrocell normalized capacity as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -81.4 dBm/MHz).

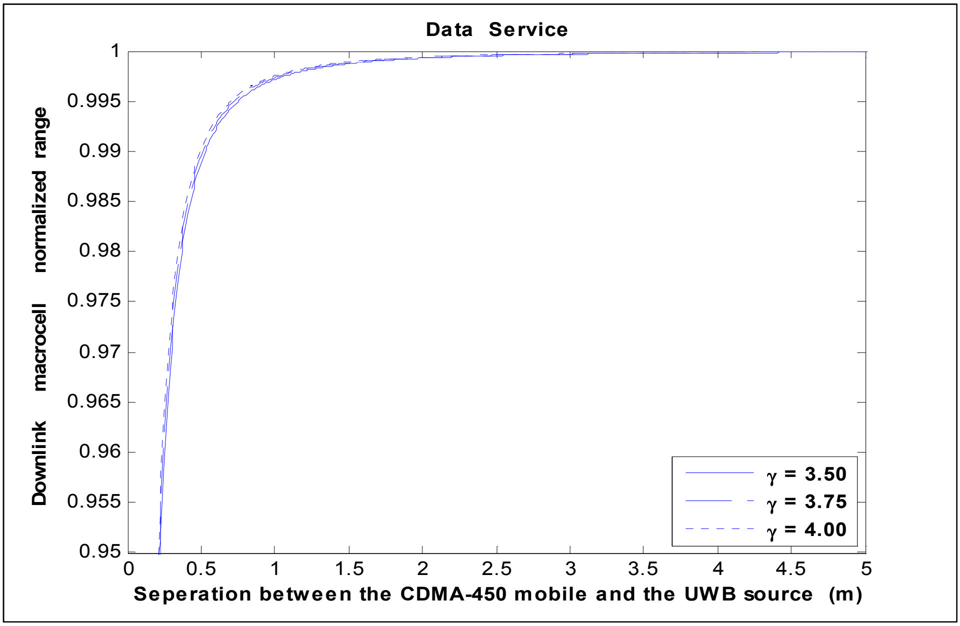

Figure 16. Effect of the UWB interference on the macrocell normalized range as a function of the separation between the UWB transmitter and the CDMA450 mobile (P_{UWB} = -95 dBm/MHz).

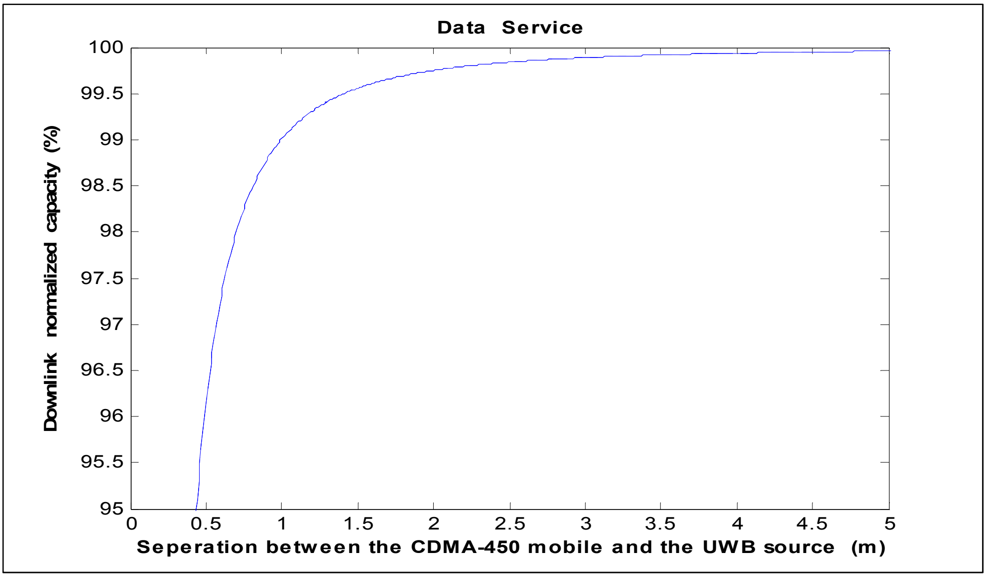

Figure 17. Effect of the UWB interference on the macrocell normalized capacity as a function of the separation between the UWB transmitter and the CDMA450 mobile (P_{UWB} = -95 dBm/MHz).

8. Results for a UMTS or CDMA-450 systems and multi UWB interferers

Then we study the case of multiple UWB transmitters with four UWB transmitters at a distance of 1m around the UMTS receiver. Fig. 18 shows the downlink macrocell normalized range as a function of the EIRP power density in dBm/MHz. It can be noticed that the cell range reduction is always lower than 1%.

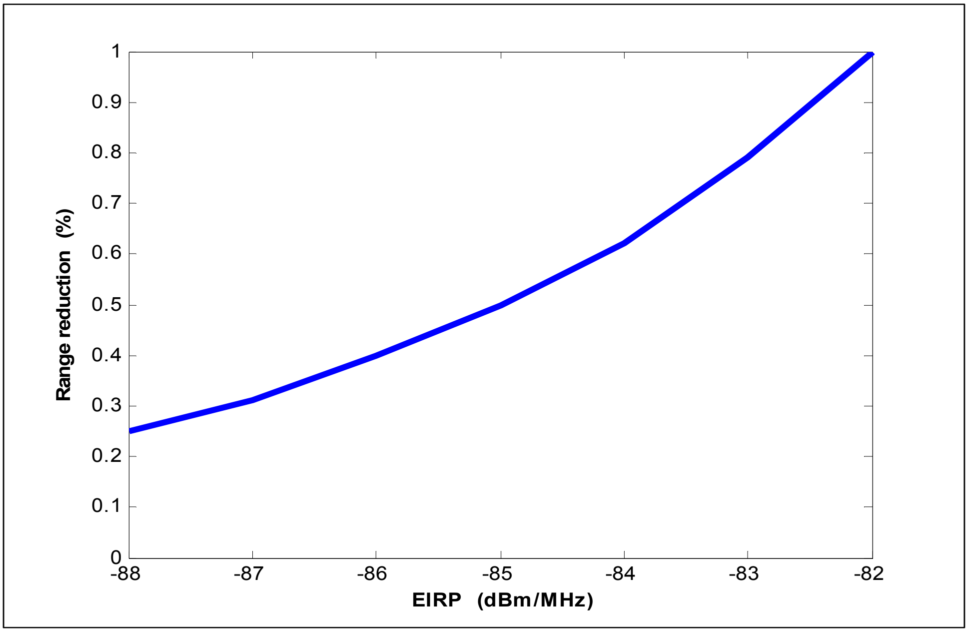

Figure 18. Range reduction as a function of the EIRP in (dBm/MHz) for multi UWB transmitters.

Fig. 19 shows the downlink macrocell normalized capacity as a function of the EIRP power density in dBm/MHz. It can be noticed that, for a capacity reduction of only 1%, EIRP should be -87.4 dBm/MHz. this represents a 6 dB reduction equal to [$10\log_{10}(4)$], where 4 is the number of the UWB sources. The conclusion is that, for the case of single UWB transmitter, the UMTS can easily tolerate the UWB interference when the UWB EIRP is lower than -81.4 dBm/MHz for 1m distance between the UWB transmitter and the UMTS mobile. For the multi UWB transmitter case, the UMTS can easily tolerate the UWB interference when the UWB EIRP is -87.4 dBm/MHz. When using a CDMA-450 system the maximum allowed EIRP reduces to -101 dBm/MHz.

Table 2 presents the maximum allowed EIRP for different frequency bands, for UWB activity factor of 100% and multi UWB transmitter scenario, for two different cases, (case A with 99.995% confidence and case B with 99% confidence respectively). Table 3 represents the maximum allowed EIRP for different frequency bands for UWB activity factor of 10% and multi UWB transmitter scenario for the two previous cases A and B.

It shall be mentioned that if the critical distance is reduced from the 1m already considered down to 0.5m, the maximum accepted UWB power densities should be decreased by 6 dB from the values given before.

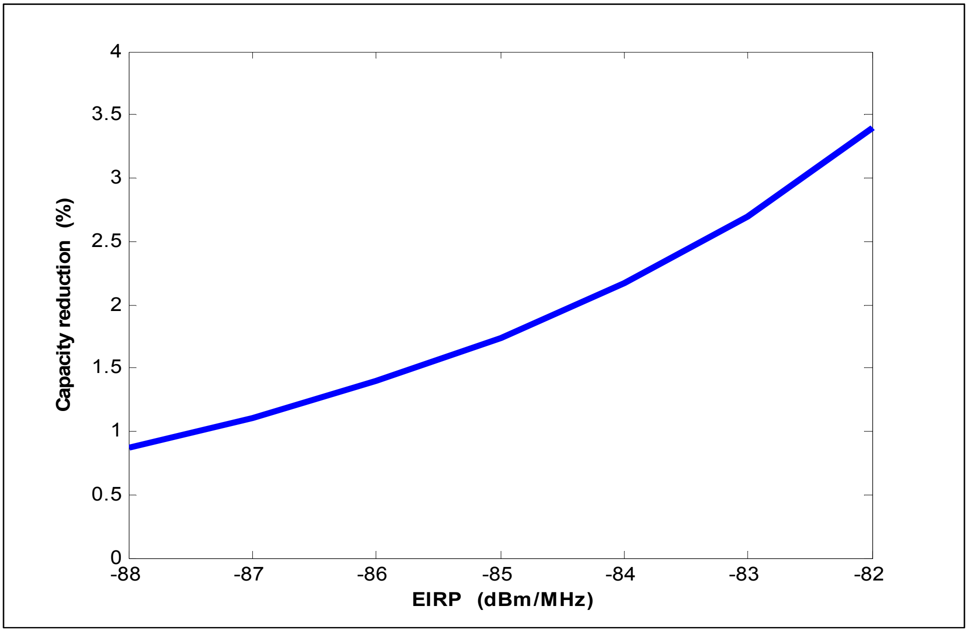

Figure 19. Capacity reduction as a function of the EIRP in (dBm/MHz) for multi UWB transmitters.

Frequency band in GHz	Maximum allowed UWB EIRP in (dBm/MHz) Case A		Case B
3.3-3.8	-98.0	(with DAA)	-94.7
2.5-2.7	-100.7		-97.4
2.1-2.2	-87.4		-84.1
0.43-0.47	-101.0		-97.7

Table 2. Maximum allowed EIRP for different frequency bands with UWB activity factor of 100%.

Frequency band in GHz	Maximum allowed UWB EIRP in (dBm/MHz) Case A		Case B
3.3-3.8	-88.0	(with DAA)	-84.7
2.5-2.7	-90.7		-87.4
2.1-2.2	-77.4		-74.1
0.43-0.47	-91.0		-87.7

Table 3. Maximum allowed EIRP for different frequency bands with UWB activity factor of 10%.

9. Conclusions

The coexistence of UWB with 3G and 4G Cellular Systems has been studied in this chapter. In particular UMTS in the 2 GHz and in the 450 MHz (CDMA-450) frequency bands have been selected as examples of 3G cellular systems and the WiMAX system as example of 4G.

The methodology used to account for the impact of UWB interference on the coverage range and capacity of the interfered systems has been explained in detail. Finally it has been applied in a set of study cases in scenarios involving the 3G and 4G selected systems.

From the above given results we can conclude that the spectrum mask proposed by the FCC for indoor application (-51 dBm/MHz in the UMTS band and -41 dBm/MHz for the CDMA-450 band) is very high and cannot be tolerated by the mobile systems. From the results obtained we conclude that another spectrum mask with lower UWB power density has to be used.

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