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2

Impact of ultra wide band (UWB) on highways microcells downlink of UMTS, GSM-1800 and GSM-900 systems

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1. Introduction

The Federal Communications Commission (FCC) agreed in February 2002 to allocate 7.5 GHz of spectrum for unlicensed use of ultra-wideband (UWB) devices for communication applications in the 3.1–10.6 GHz frequency band. 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 known for 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, such as the Unlicensed National Information Infrastructure (UNII) band have opened up bandwidth dedicated to unlicensed devices based on the assumption that "operation is subject to the following two conditions: This device may not cause harmful interference (harmful interference is defined as the interference that seriously degrades, obstructs or repeatedly interrupts a radio communication service), and this device must accept any interference received, including those interferences 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.

UWB has a number of advantages which make it attractive for consumer communications applications. In particular, UWB systems

- Have potentially low complexity and low cost;
- Have noise-like signal characteristics;
- Are resistant to severe multipath and jamming;
- Have very good time domain resolution.

The spectrum for the Universal Mobile Telecommunications System (UMTS), which support voice and data services, lies between 1900 MHz to 2025 MHz and 2110 MHz to 2200 MHz.

For the mobile satellite service a separated sub-band in the UMTS spectrum is reserved (uplink 1980 MHz to 2010 MHz, downlink 2170 MHz to 2200 MHz). The remaining spectrum for terrestrial use is divided between two modes of operation. In the FDD (Frequency Division Duplex) mode there are two paired frequency bands, for the uplink (1920 MHz to 1980 MHz) and for the downlink (2110 MHz to 2170 MHz). In the TDD (Time division duplex) operation mode, the uplink and downlink are implemented by using different timeslots on the same carrier. In his case there is no need for a paired spectrum and the remaining unpaired spectrum can be used.

To serve users in rural zone highways and nearby buildings, cigar-shaped microcells are used. They are produced by two directive antennas in a mast with a height of 5 to 10 m. located in the base station.

DCS-1800 is a Digital Communications System based on GSM, working on a radio frequency of 1800 MHz. Also known as GSM-1800, this digital network operates in Europe and Asia Pacific. The DCS-1800 band provides for a DCS uplink in the range 1710-1785 MHz, a DCS downlink in the range 1805-1880 MHz.

The GSM 900 band provides for a GSM uplink in the range 890-915 MHz, and a GSM downlink in the range 935-960 MHz. The GSM 900 band is used in all countries (more than 168 across the globe) in which GSM networks are found, except for the United States. In (Hamalainen et al., 2002) the coexistence of the UWB system with GSM900, UMTS/WCDMA, and GPS has been studied. The bit error rate (BER) of the above mentioned systems for different pulse length has been given. In (Hamalainen et al., 2004) the coexistence of the UWB system with IEEE802.11a and UMTS in a Modified Saleh-Valenzuela Channel has been studied. The bit error rate (BER) of the UWB system, for different types of modulation (Direct Sequence and Time Hopping), has been presented. In (Guiliano et al., 2003) the interference between the UMTS and the UWB system, for different UWB activity factors, has been investigated. They concluded that, the UWB allowable interference limit is in the order of -100 dBm. This limit is well below the interference due to UWB transmitter at a distance of about 1 m. In (Ahmed et al., 2007), the Impact of Ultra Wide Band (UWB) on macrocell downlink of CDMA-PCS system has been investigated. In (Ahmed et al., 2008), the Impact of Ultra-Wideband (UWB) on macrocell downlink of UMTS and CDMA-450 systems has been studied.

The aim of this chapter is to present the effect of UWB signal on UMTS and GSM microcell downlink performances. The rest of the chapter is organized as follows. In Section 2, the methodology for studying the effect of the UWB interference on the UMTS microcell downlink performance is presented. Section 3 presents the methodology for studying the effect of the UWB interference on the GSM microcells downlink performance. In Section 4 several results are given. Finally, Section 5 addresses the conclusions.

2. Methodology for Studying the Effect of UWB Interference on UMTS microcells downlink

The highway UMTS microcell downlink power budget used in this section adopts the approach given in (Holma & Toskala, 2002). The parameters used in the calculations are shown in Table 1.

A	Maximum link transmit power	dBm	33
B	Transmitter gains	dB	18
C	Transmitter local losses	dB	1
D	Transmitter EIRP	dB	A+B-C
E	Receiver noise figure	dB	6
F	Thermal noise density	dBm/Hz	
G	Noise power	dBm	E+F*log10(4x10[6])
H	Load value	0.5 to 1	
I	Noise rise	dB	-10*log10(1-H)
J	Interference power	dBm	10*log10(10^((G+I)/10) -10^(G/10))
K	Noise and interference	dBm	10*log10(10^(G/10)+10^(J/10))
L	Number of users = Noise rise	dB	
M	Processing gain (G_p)	dB	
N	$(E_b/N_o)_{req}$	dB	
O	Indoor loss	dB	10 dB
P	Maximum path loss	dB	D-L-K+M-N
Q	Log normal fade margin	dB	6 dB
R	Path-loss	dB	P-Q

Table 1. UMTS microcell downlink power budget

To account for UWB, an extra source of interference is added linearly to the UMTS interference. The power of this interference is calculated by assuming that the UWB source is located at different distances from the UMTS mobile receiver. Therefore, the interference power generated by a UWB device, I_{UWB}, is given (in dBm) by:

$$I_{UWB} = P_{UWB} - L_{UWB}(d) + G_{UMTS} \quad (1)$$

where

- P_{UWB} is the 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 receiver antenna gain.

Given that UWB devices are typically low power short range devices, then the line-of-sight path-loss model is often the most appropriate. In this case the UWB signal propagation loss in dB is calculated as:

$$L_{UWB}(d) \approx 39 + 20\log_{10}(d) + L_{extra} \tag{2}$$

where L_{extra} is the extra loss due to other propagation effects like shadowing.

The effect of the UWB interference reduces the microcell range and/or the microcell normalized capacity. The UMTS normalized capacity is the ratio between the UMTS capacity without UWB interference to its capacity with UWB interference. The normalized microcell capacity C_n is given as:

$$C_n = \left(\frac{I_{UMTS}}{I_{UMTS} + I_{UWB}} \right) \tag{3}$$

The calculation is carried for a range of values of d and for different UMTS service types.
To calculate the UMTS microcell propagation loss L_p we have used the two-slope propagation model) as given by:

$$L_p(dB) \approx L_b + 10 + 20\log_{10}\left(\frac{r}{R_b} \right) \quad r \le R_b \tag{4}$$

$$L_p(dB) \approx L_b + 10 + 40\log_{10}\left(\frac{r}{R_b} \right) \quad r > R_b \tag{5}$$

where r is the distance between the base station and the mobile at the point of observation, L_b is the propagation loss at the breaking point R_b and L_b and R_b are given by (Tsai & Chang, 1996):

$$L_b(dB) = \left| 10\log_{10}\left[\left(\frac{\lambda^2}{8\pi\, h_b\, h_m} \right)^2 \right] \right| \tag{6}$$

$$R_b \approx \frac{4h_b h_m}{\lambda} \tag{7}$$

where
- h_b is the base station antenna height = 7.5 m,
- h_m is the mobile antenna height = 1.5 m,
- λ is the wavelength.

In the two-slope propagation model, the exponent of the propagation loss distance dependent factor is assumed to be 2 till the break point R_b (equation 4) and then it converts to 4 (equation 5).

3. Methodology for Studying the Effect of UWB Interference on GSM microcells downlink

The highway GSM microcell downlink budget used in this section also adopts the approach given in (Holma & Toskala, 2002). The elements to the calculation are shown in Table 2.

A	Maximum link transmit power	dBm	30
B	Transmitter gains	dB	18
C	Transmitter local losses	dB	2
D	Transmitter EIRP	dB	A+B-C = 46 dBm
E	Receiver noise figure	dB	9
F	SNR_{req}	dB	10
G	Receiver sensitivity	dBm	-174+53+E+F = -102 dBm
H	Indoor loss	dB	10 dB
I	Maximum path loss	dB	D-G-H = 138 dB
J	Log normal fade margin	dB	6 dB
K	Compensated Path-loss	dB	I-J = 132 dB

Table 2. GSM microcell downlink budget

The effect of the UWB interference is to reduce the GSM microcell range.
The UWB signal propagation loss in dB at the GSM-1800 band is calculated as:

$$L_{UWB}(d) \approx 37.8 + 20\log_{10}(d) + L_{extra} \tag{8}$$

At the GSM-900 band the UWB propagation loss in dB is calculated as:

$$L_{UWB}(d) \approx 32 + 20\log_{10}(d) + L_{extra} \tag{9}$$

To calculate the GSM microcell range we also use the two-slope propagation model.

4. Results

In the analysis we assume that the UWB data rate is higher than the UMTS chip rate. We assume that the UMTS mobile is in a building, located near the highway microcell and thus served by this microcell. We will study the effects of the UWB transmitters on the UMTS handset assuming three different cases:

- Line of sight case, without shadowing (L_{extra} = 0 dB).
- Line of sight case, with shadowing (L_{extra} = 5 dB).
- UWB transmitter is shadowed by a person (L_{extra} = 10 dB).

In Fig. 1 the UWB interference power on the UMTS downlink (i.e. the interference seen at the UMTS mobile) is plotted for the three cases mentioned above, assuming voice service and a P_{UWB} of -60 dBm/MHz within the UMTS bandwidth of 5 MHz.

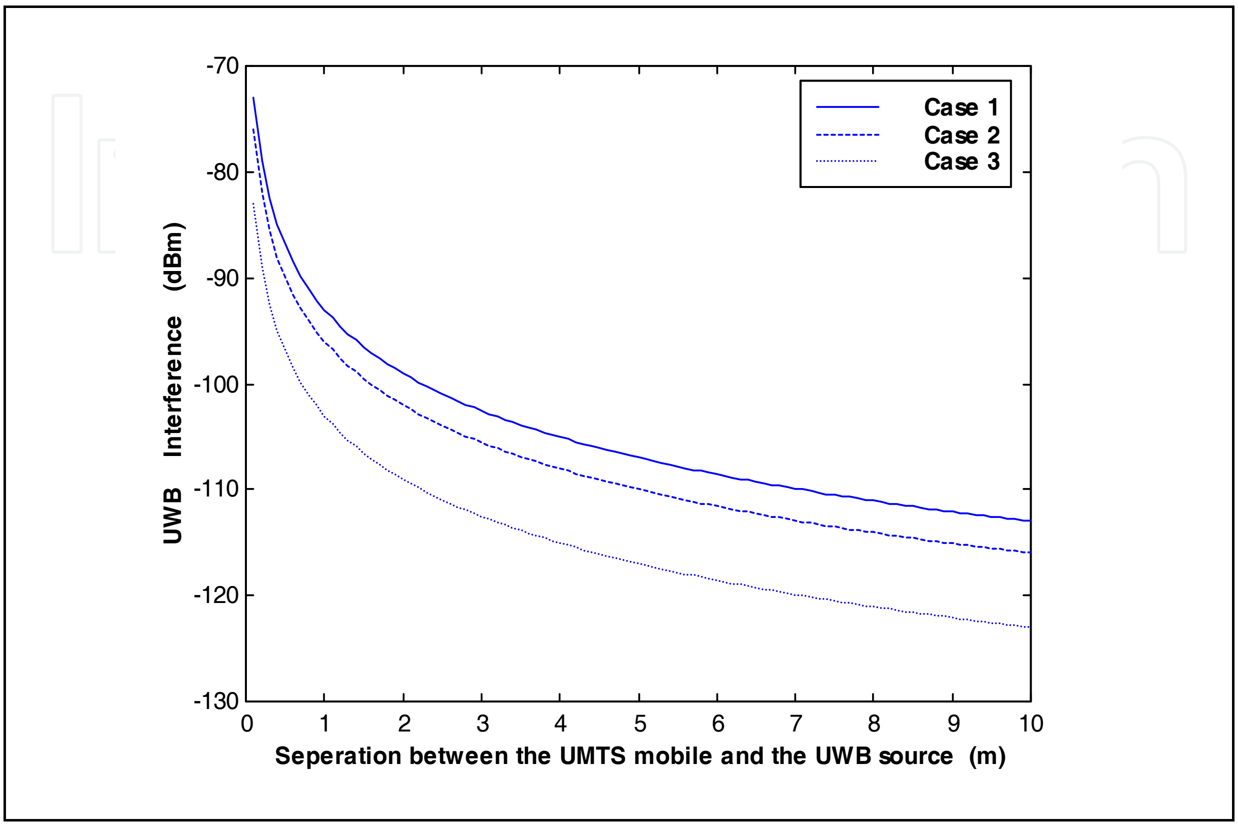

Fig. 1. UWB interference as a function of the separation between the UWB transmitter and the UMTS mobile (voice service and P_{UWB} = -60 dBm/MHz).

We study the case of voice service (G_p = 25 dB, E_b/N_o = 6 dB) assuming an UMTS total interference of -83 dBm (19 dB noise rise). In this case, the downlink microcell range is calculated to be 1.18 km. Fig. 2 shows the downlink microcell 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 microcell range reduction) when the separation is less than 0.5 m. For larger separation, the interference is lower and, at a distance higher than 2 m, the effect of the interference is quasi null.

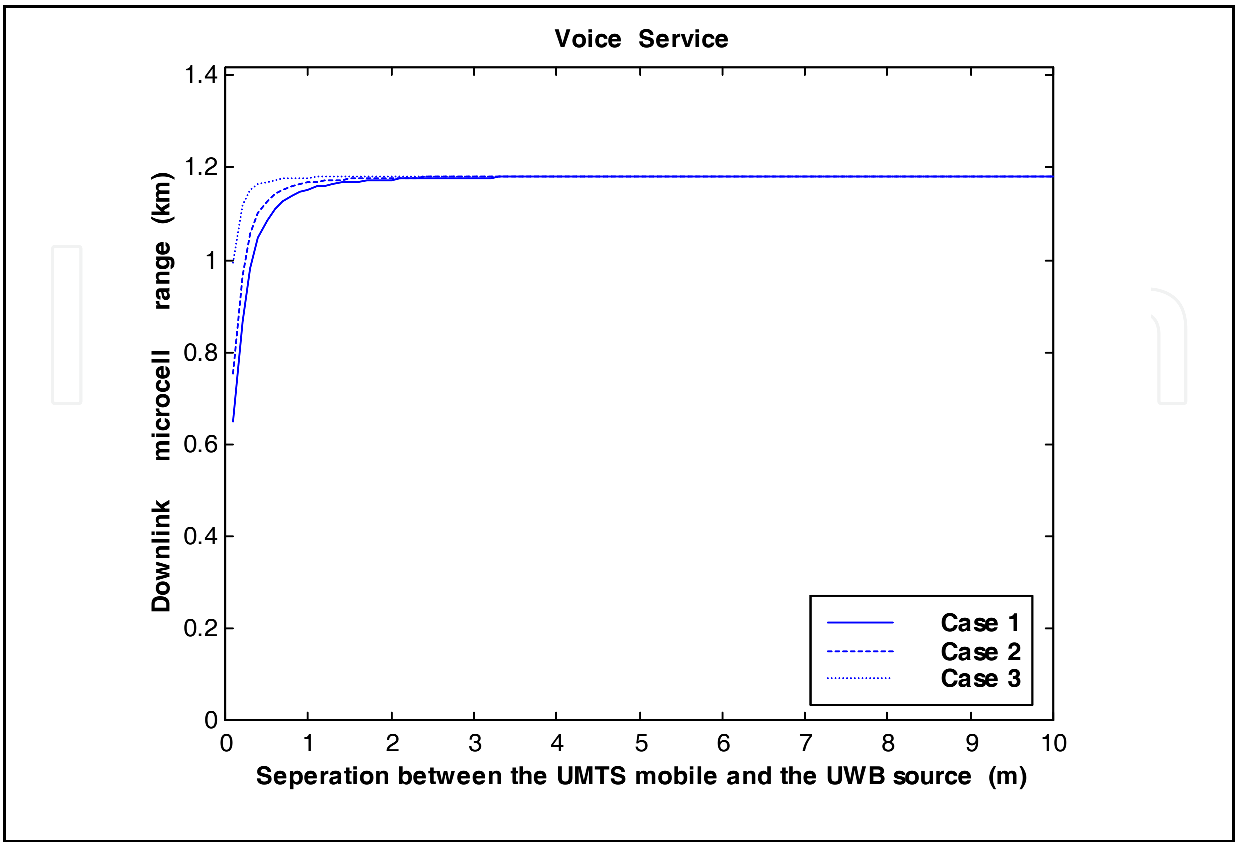

Fig. 2. Effect of the UWB interference on the UMTS microcell range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -60 dBm/MHz).

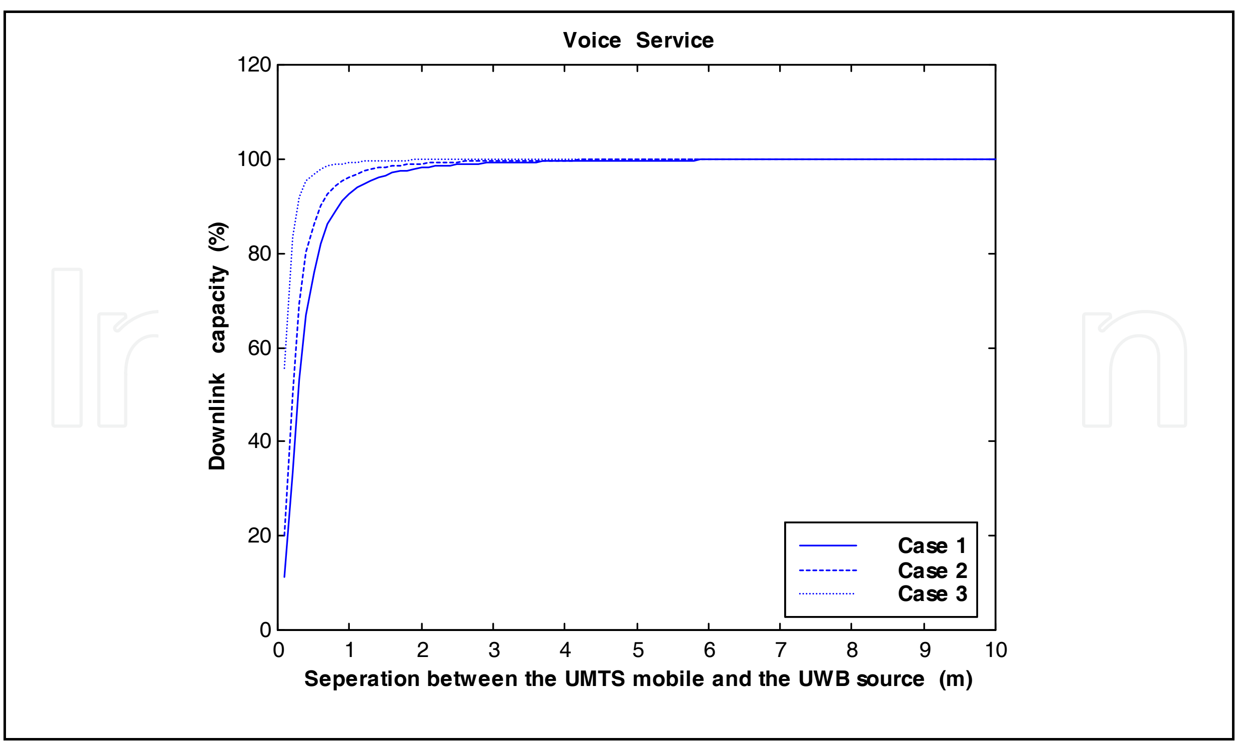

Fig. 3. Effect of the UWB interference on the UMTS microcell capacity as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -60 dBm/MHz).

Fig. 3 shows the downlink microcell normalized capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the microcell capacity reduction is high when the separation is lower than 0.5 m. For larger separation, the capacity reduction is lower and, at a distance higher than 3 m, the capacity reduction is negligible.

Next we study the case of a data service (G_p = 14.25 dB, E_b/N_o = 4.25 dB) assuming an UWB power density of -60 dBm/MHz and an UMTS total interference of -92 dBm (10 dB noise rise). In this case, the downlink microcell range is calculated to be 1.98 km. Fig. 4 shows the downlink microcell 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 as a microcell range reduction) when the separation is less than 1 m. For larger separations, the interference is lower. At a distance higher than 6 m, the effect of the interference is negligible.

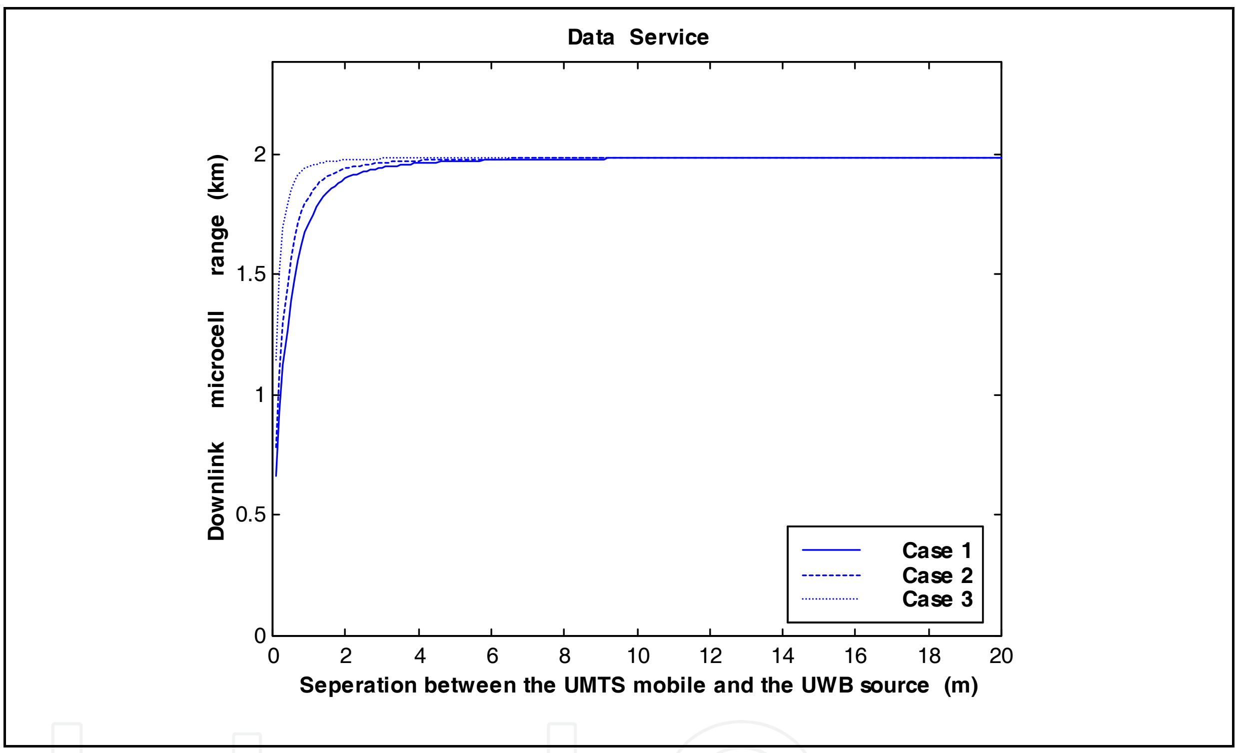

Fig. 4. Effect of the UWB interference on the UMTS microcell range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -60 dBm/MHz).

Fig. 5 shows the downlink microcell normalized capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be noticed that the microcell capacity reduction is high when the separation is less than 2 m. For larger separation, the reduction is lower and for a distance higher than 9 m, the capacity reduction is very small.

Let us now study the data service case assuming a P_{UWB} of -80 dBm/MHz. Fig. 6 shows the downlink microcell 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 microcell range reduction) when the separation is less than 0.1 m. For larger separation, the interference is reduced and for distances higher than 0.45 m, the effect of the interference is quasi null.

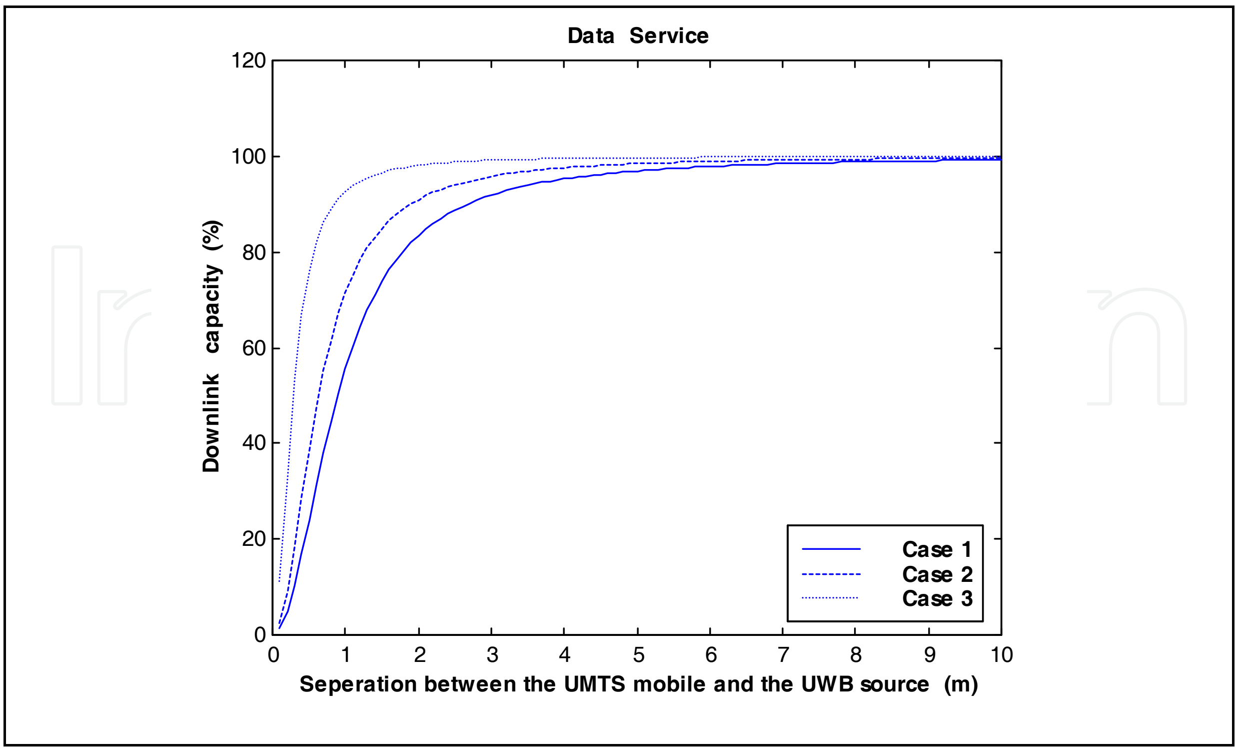

Fig. 5. Effect of the UWB interference on the UMTS microcell capacity as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -60 dBm/MHz).

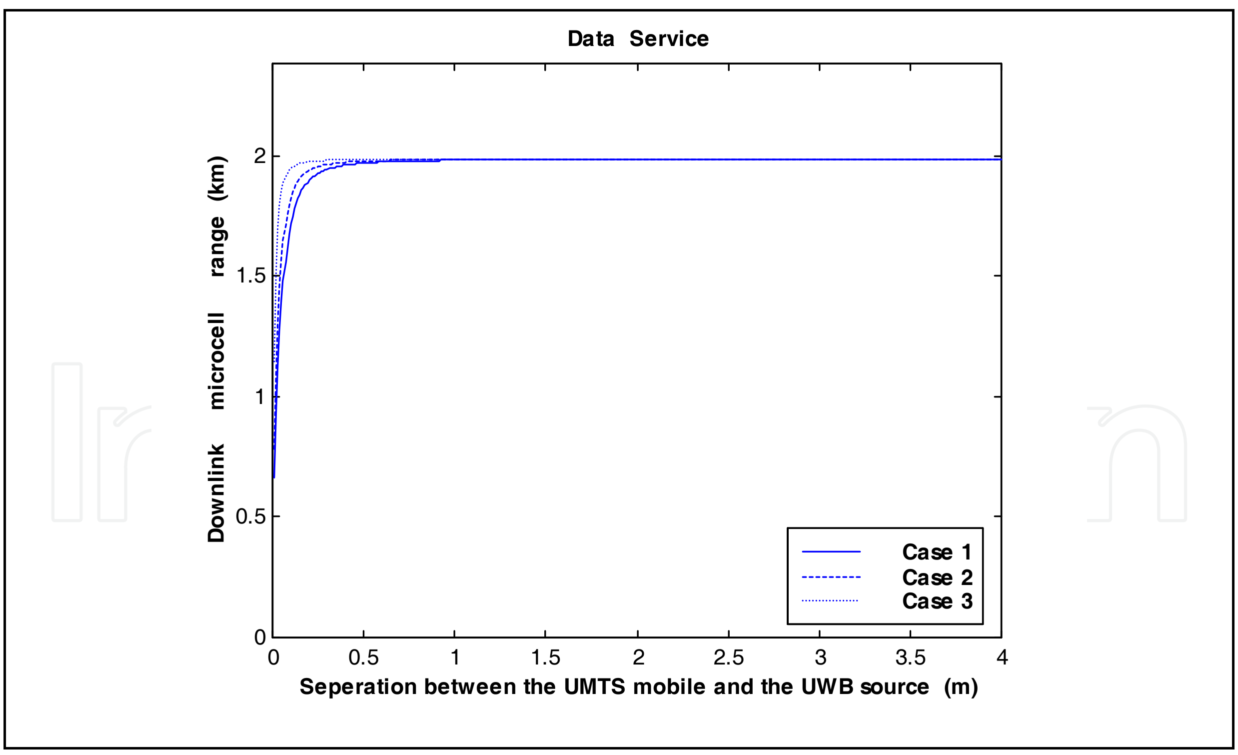

Fig. 6. Effect of the UWB interference on the UMTS microcell range as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -80 dBm/MHz).

Fig. 7 shows the downlink microcell normalized capacity as a function of the separation between the UMTS mobile and the UWB transmitter. It can be observed that the microcell capacity reduction is high when the separation is less than 0.2 m. For larger separation, the reduction is lower. At a distance higher than 0.9 m, the capacity reduction is negligible.

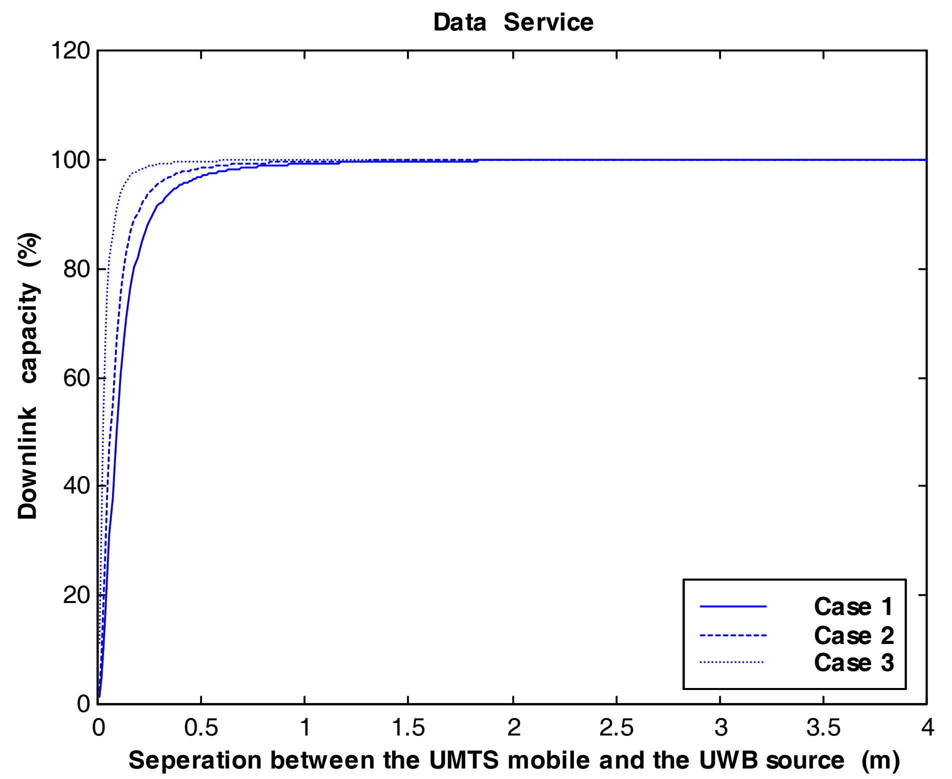

Fig. 7. Effect of the UWB interference on the UMTS microcell capacity as a function of the separation between the UWB transmitter and the UMTS mobile (P_{UWB} = -60 dBm/MHz).

Table 3 shows the distance d_C at which the microcell capacity is 95% of its value without the UWB interference. It also shows the distance d_R at which the microcell range is 95% of its value without the UWB interference.

Table 4 shows the distance d_C, between the UMTS mobile and the UWB transmitter, at which the microcell capacity is 99% of its value without the UWB interference. It also shows the distance d_R at which the microcell range is 99% of its value without the UWB interference. Form Table 4, it can be noticed that the UMTS system can easily tolerate a -80 dBm/MHz UWB interference with quasi null effect (less than 1% reduction in range or capacity) when the distance between the UWB transmitter and the UMTS receiver is higher than 1m.

UWB Power density (dBm/MHz)	$d_{R\ 95\%}$ (m)	$d_{C\ 95\%}$ (m)
-50	6.5	12.3
-55	3.7	6.9
-60	2.1	3.9
-65	1.2	2.2
-70	0.7	1.3
-75	0.4	0.7

Table 3. Distance d_C at which the microcell capacity is 95% of its value without the UWB interference and the distance d_R at which the microcell range is 95% of its value without the UWB interference.

UWB Power density (dBm/MHz)	$d_{R\ 99\%}$ (m)	$d_{c\ 99\%}$ (m)
-60	4.4	8.8
-65	2.5	5.0
-70	1.4	2.8
-75	0.8	1.6
-80	0.45	0.9
-85	0.25	0.5

Table 4. Distance d_C at which the microcell capacity is 99% of its value without the UWB interference and the distance d_R at which the microcell range is 99% of its value without the UWB interference.

Now we study the case when N_{UWB} transmitters are distributed uniformly within a circle around the UMTS mobile receiver (Multi transmitter case) assuming P_{UWB} of-55 dBm/MHz and six UWB transmitters. Fig. 8 shows the downlink microcell range as a function of the circle radius. It can be seen that the UWB signal creates a high interference (which reflects a microcell range reduction) when the circle radius is less than 5 m. At a radius of 20 m, the effect of the UWB transmitters is very small.

Fig. 9 shows the downlink microcell normalized capacity as a function of the circle radius. It can be noticed a high microcell capacity reduction when the circle radius is lower than 10 m. At a radius of 30 m, the capacity reduction is negligible.

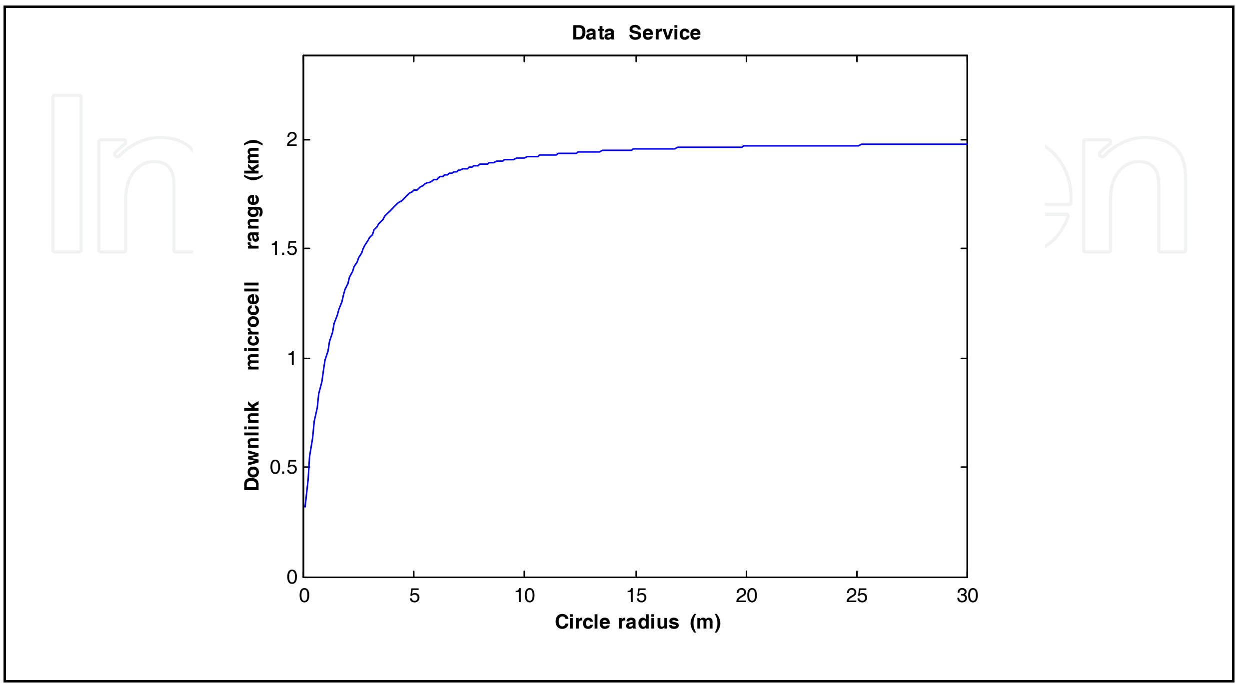

Fig. 8. Effect of the UWB interference on the UMTS microcell range as a function of the circle radius (N = 6, P_{UWB} = -55dBm/MHz).

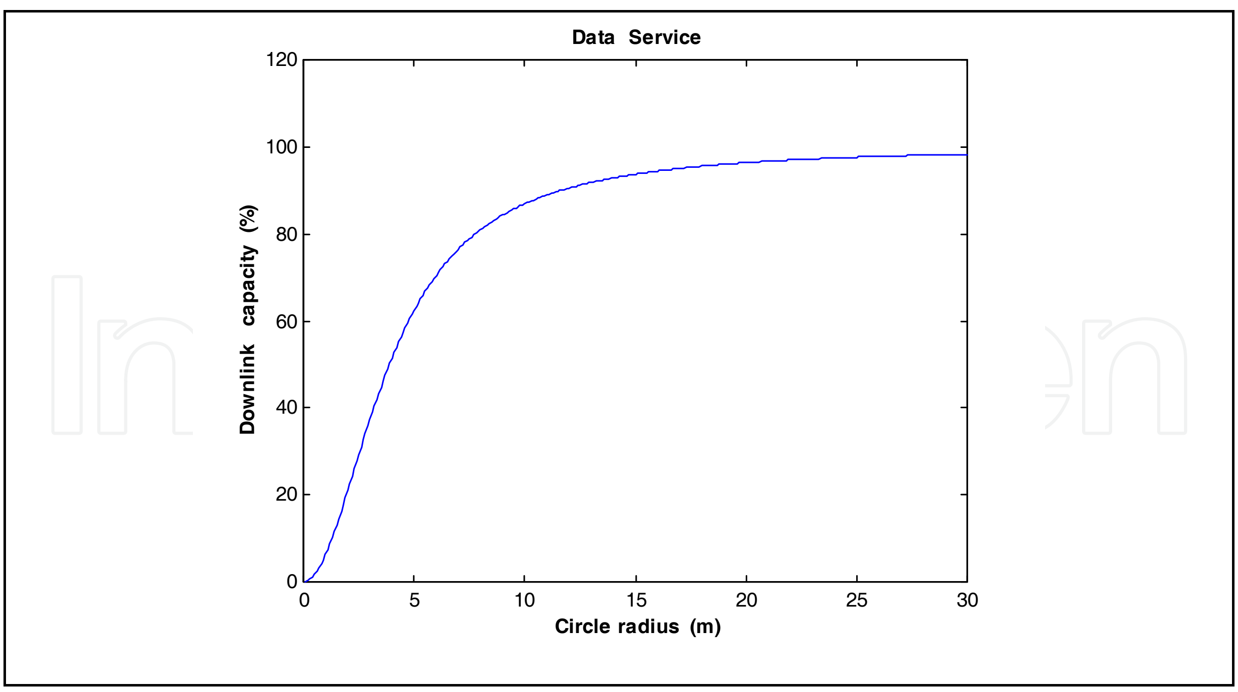

Fig. 9. Effect of the UWB interference on the UMTS microcell capacity as a function of the circle radius (N = 6, P_{UWB} = -55 dBm/MHz).

Now we study the case of UWB multi transmitters when the UWB power density is -87 dBm/MHz and N = 6. Fig. 10 shows the downlink microcell range as a function of the circle radius. It can be noticed that the UWB signal creates a very low interference (which reflects in a microcell range reduction of less than 1%) when the circle radius is 0.5 m or more.

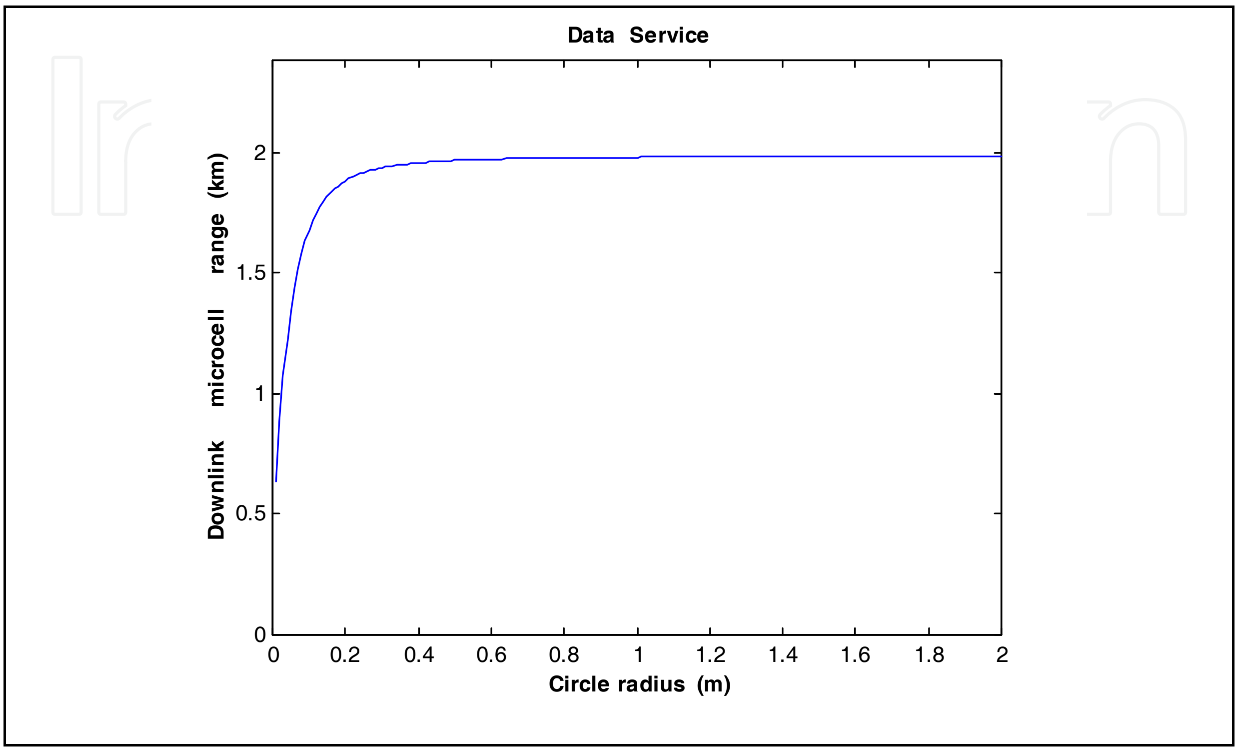

Fig. 10. Effect of the UWB interference on the UMTS microcell range as a function of the circle radius (N = 6, P_{UWB} = -87 dBm/MHz).

Fig. 11 shows the downlink microcell normalized capacity as a function of the circle radius. It can be noticed that the microcell capacity reduction is low (1%) when the circle radius is 1 m.

Table 5 shows the distance d_C at which the microcell capacity is 99% of its original value and the distance d_R at which the microcell range is 99% of original value for the case of multi UWB transmitters (N = 6).

Next we study the case of the GSM1800 system. Fig. 12 shows the GSM1800 downlink microcell range as a function of the separation between the GSM1800 mobile and the UWB transmitter when the UWB power density is – 80 dBm/MHz. It can be noticed that the UWB signal creates a high interference (which reflects a microcell range reduction) when the separation is less than 0.2 m. For larger separation, the interference is lower. At a distance higher than 1 m, the effect of the interference is quasi null (less than 1% range reduction). The GSM1800 microcell downlink original range is 3.43 km.

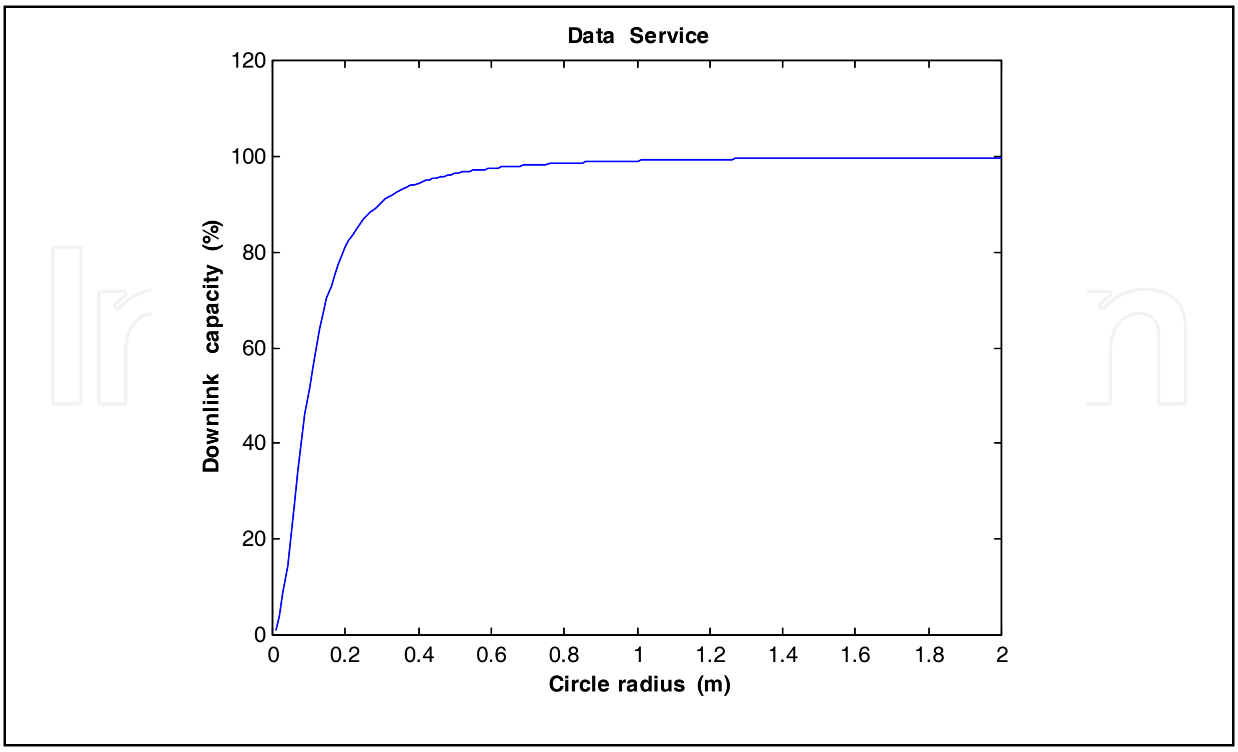

Fig. 11. Effect of the UWB interference on the UMTS microcell capacity as a function of the circle radius (N = 6, PUWB = -87 dBm/MHz).

UWB Power density (dBm/MHz)	$d_{R\ 99\%}$ (m)	$d_{c\ 99\%}$ (m)
-65	5.9	12.2
-70	3.3	6.9
-75	1.9	3.9
-80	1.1	2.2
-85	0.6	1.3
-90	0.34	0.7

Table 5. Distance d_C at which the microcell capacity is 99% of its value without the UWB interference and the distance d_R at which the microcell range is 99% of its value without the UWB interference for the UWB multi transmitter case.

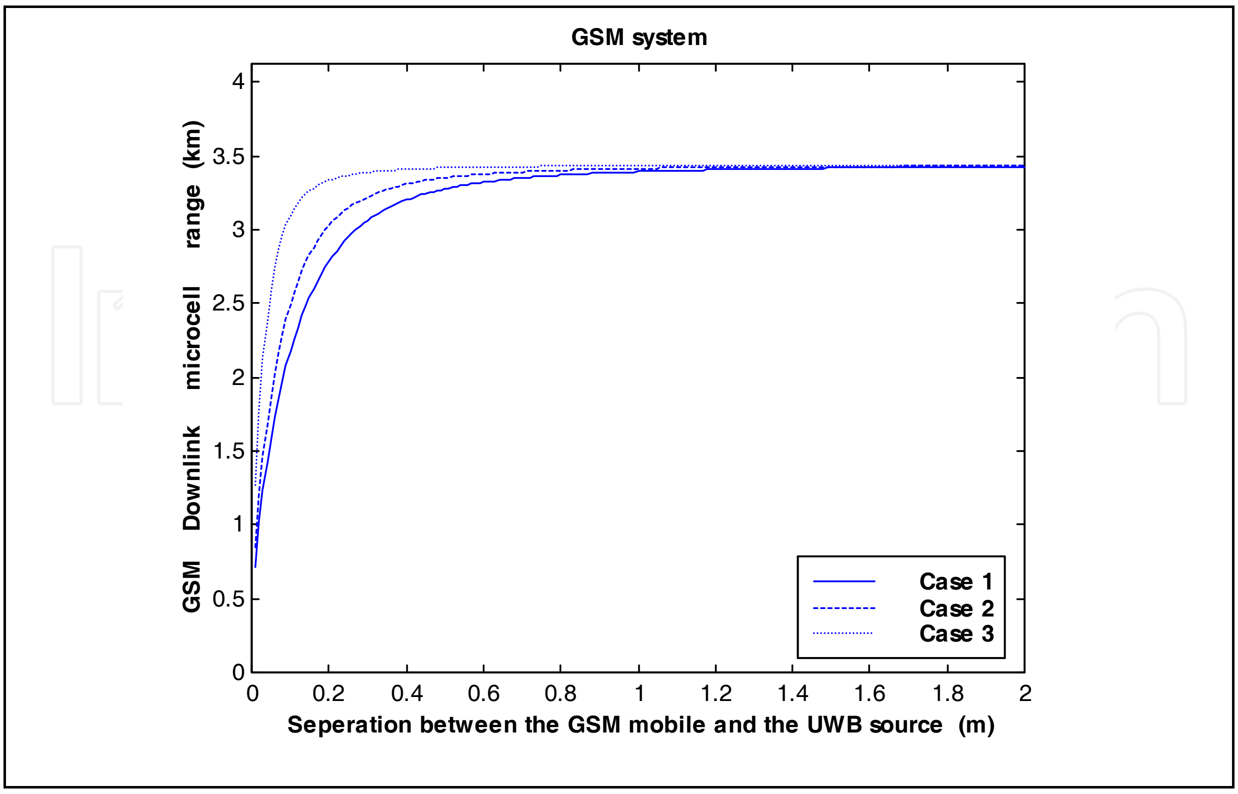

Fig. 12. Effect of the UWB interference on the GSM1800 microcell range as a function of the separation between the UWB transmitter and the GSM1800 mobile (P_{UWB} = -80 dBm/MHz).

Fig. 13 shows the GSM1800 downlink microcell range as a function of the separation between the GSM1800 mobile and the UWB transmitter when the UWB power density is –86 dBm/MHz. It can be noticed that the UWB signal creates a high interference (which reflects a microcell range reduction) when the separation is less than 0.1 m. For larger separation, the interference is lower. At a distance equal to or higher than 0.5 m, the effect of the interference is quasi null (less than 1% range reduction).

Finally we study the case of the GSM900 system. Fig. 14 shows the GSM900 downlink microcell range as a function of the separation between the GSM900 mobile and the UWB transmitter when the UWB power density is – 87 dBm/MHz. It can be noticed that the UWB signal creates a high interference (which reflects a microcell range reduction) when the separation is less than 0.2 m. For larger separation, the interference is lower. At a distance equal to or higher than 1 m, the effect of the interference is quasi null (less than 1% range reduction). The GSM900 microcell downlink original range is 6.696 km.

Fig. 15 shows the GSM900 downlink microcell range as a function of the separation between the GSM900 mobile and the UWB transmitter when the UWB power density is –93 dBm/MHz. It can be noticed that the UWB signal creates a high interference (which reflects a microcell range reduction) when the separation is less than 0.1 m. For larger separation, the interference is lower. At a distance equal to or higher than 0.5 m, the effect of the interference is quasi null (less than 1% range reduction).

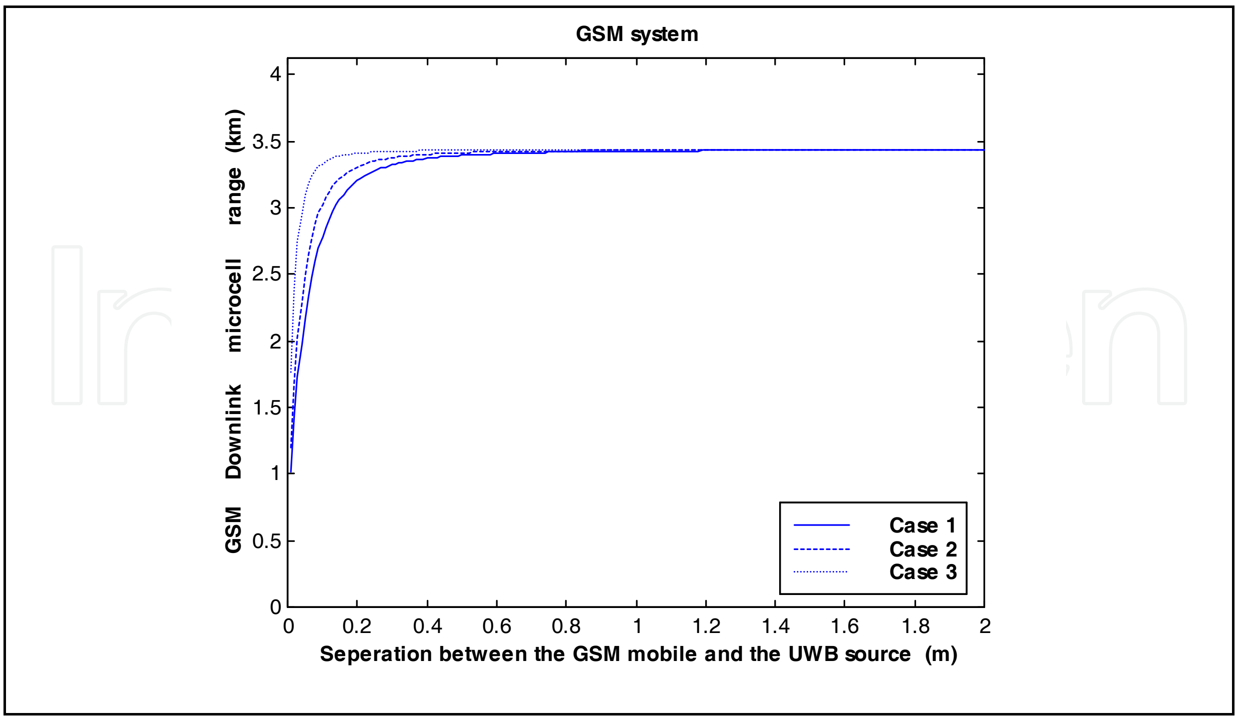

Fig. 13. Effect of the UWB interference on the GSM1800 microcell range as a function of the separation between the UWB transmitter and the GSM1800 mobile (P_{UWB} = -86 dBm/MHz).

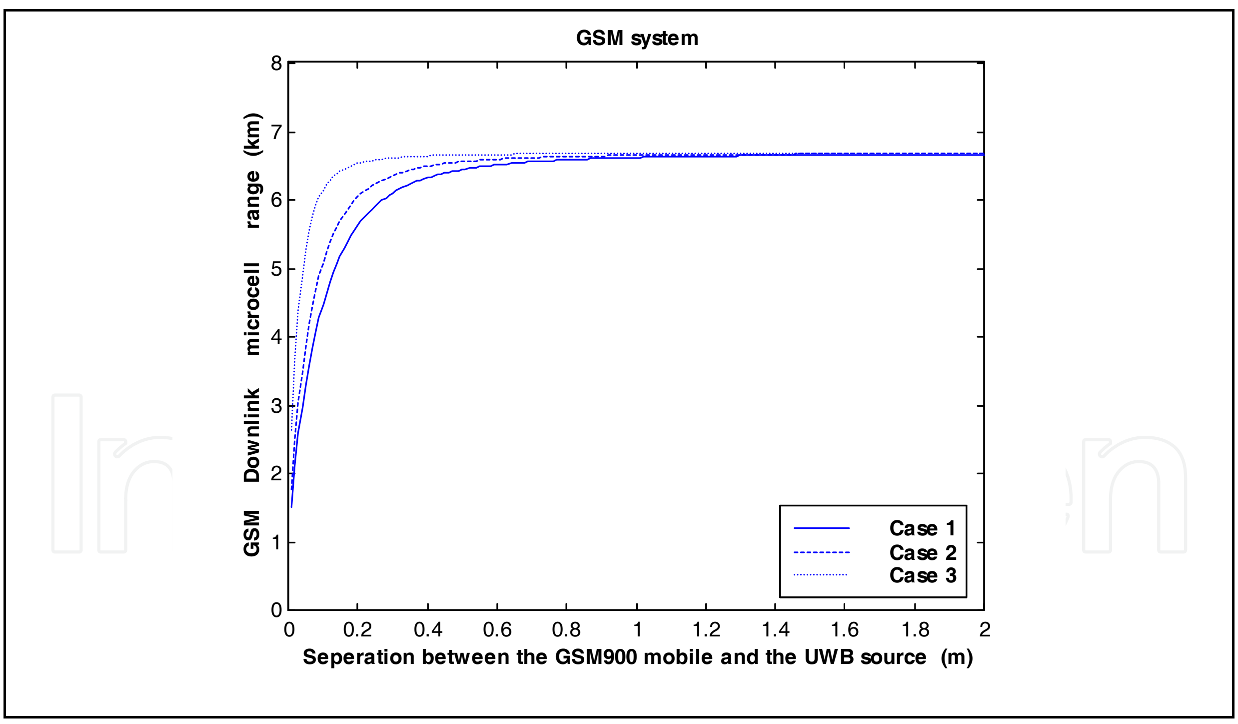

Fig. 14. Effect of the UWB interference on the GSM900 microcell range as a function of the separation between the UWB transmitter and the GSM900 mobile (P_{UWB} = -87 dBm/MHz).

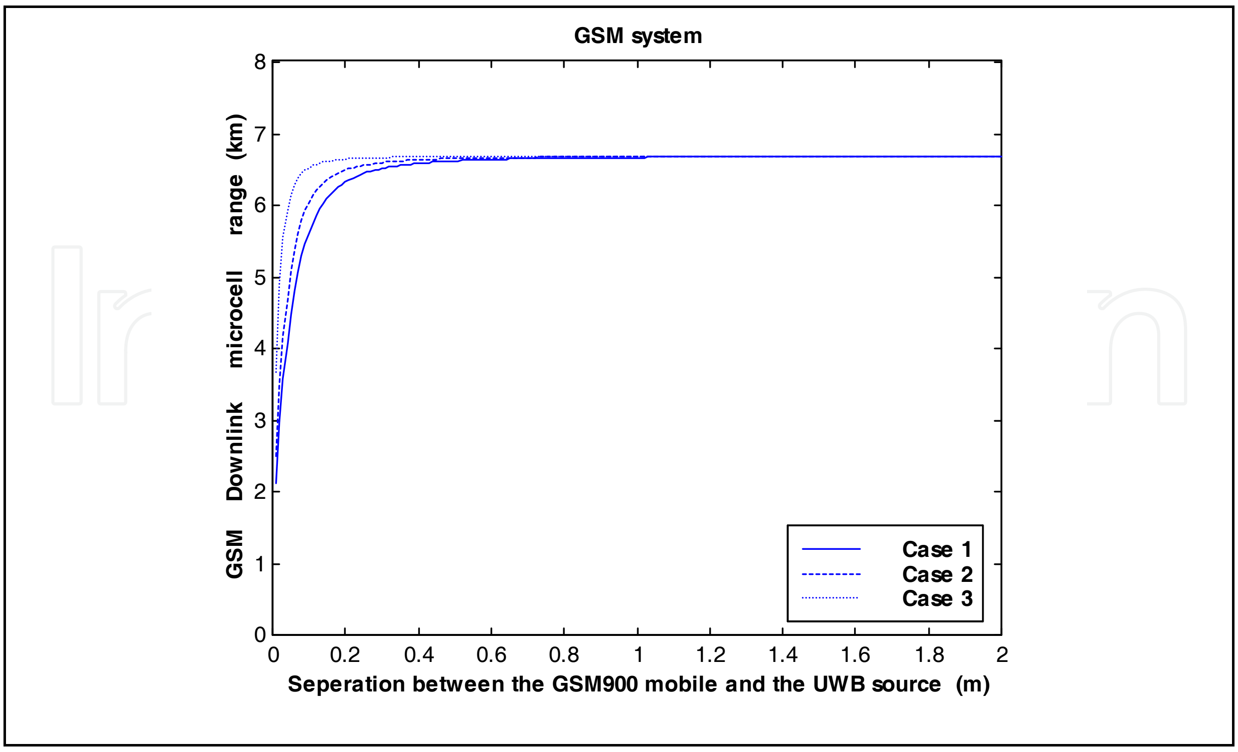

Fig. 15. Effect of the UWB interference on the GSM900 microcell range as a function of the separation between the UWB transmitter and the GSM900 mobile (P_{UWB} = -93 dBm/MHz).

5. Conclusions

The effect of the UWB transmitters on the UMTS microcell downlink has been presented for different configuration and environments. For the case of single UWB transmitters, the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the UMTS receiver is 1 m or more and the UWB power density is -80 dBm/MHz or less. For the case of multi UWB transmitters, the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the UMTS receiver is 1 m or more and the UWB power density is -87 dBm/MHz or less.

For the case of single UWB transmitters, the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the GSM1800 receiver is 1 m or more and the UWB power density is -80 dBm/MHz or less. For the case of multi UWB transmitters , the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the GSM1800 receiver is 1 m or more and the UWB power density is -86 dBm/MHz or less.

For the case of single UWB transmitters, the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the GSM900 receiver is 1 m or more and the UWB power density is -87 dBm/MHz or less. For the case of multi UWB transmitters, the effect of the UWB signals is quasi null when the distance between the UWB transmitter and the GSM900 receiver is 1 m or more and the UWB power density is -93 dBm/MHz or less.

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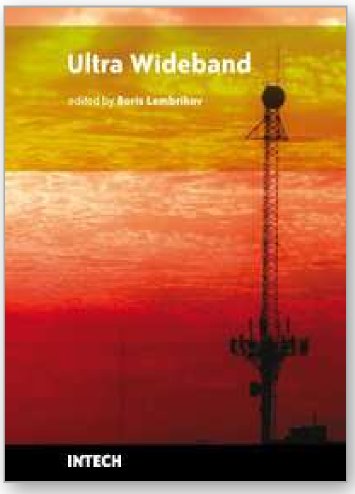

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Ultra wideband technology is one of the most promising directions in the rapidly developing modern communications. Ultra wideband communication system applications include radars, wireless personal area networks, sensor networks, imaging systems and high precision positioning systems. Ultra wideband transmission is characterized by high data rate, availability of low-cost transceivers, low transmit power and low interference. The proposed book consisting of 19 chapters presents both the state-of-the-art and the latest achievements in ultra wideband communication system performance, design and components. The book is addressed to engineers and researchers who are interested in the wide range of topics related to ultra wideband communications.