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WiMax Interference and Coexistence Studies with Other Radio Systems

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1. Introduction

The first version of WiMax standard was focused merely on the fixed subscriber applications and the next generation mobile WiMax technologies are designed enabling both fixed and mobile subscribers with various form factors like: personal digital assistance, notebook PCs, handsets, and consumer electronics (WiMaxForum, 2005). The air interface of mobile standard is licensed for using 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands (IEEE, 2005). However, the allocation of these frequency bands are varying from one country to another or one geographical region to another for example the band 3.3 GHz and 3.5 GHz are reserved, for fixed and mobile version, in Europe as well as some other parts in the world except USA. Hence, the WiMax interference and coexistence scenario in those region will not be identical like in Europe where WiMax will necessary to coexist with Ultra-Wide Band (UWB), since in Feb 2002 FCC (FCC, 2002) approved an unlicensed frequency band from 3.1 to 10.6 GHz with maximum transmission power of -41.3 dBm/MHz for short range, high and low data rate applications on notebook PCs, headset and consumer electronics. Therefore, the usage models of both WiMax and UWB systems will be in very close proximity to desktop PC/laptop, handset, etc. Consequently, the interference from UWB radio can raise the Noise Floor (NF) by an amount sufficient to cause performance degradation at the WiMax subscriber receiver (Rahim, A. & Zeisberg, S. 2007), (Rahim et. al 2007). Therefore, the regulation authorities in Europe (ECC, 2006), Japan, Korea, etc had to define the UWB mask approximately 35~40 dB lower than the FCC limits over 3.1 to 3.8 GHz without applying mitigation technique. In addition, a mitigation technique called Detect and Avoid (DAA) have been well studied to increase the UWB power spectral density while protecting WiMax services; this mitigation technique is based on the detection of the WiMax signal and once the signal is detected then UWB devices require to give sufficient protection to the WiMax services (Mubaraq, 2007), (Rahim et. al 2008), (Kim et. al 2007). The coexistence studies among different systems are referred to (Indepen & Quotient, 2005), (Snow et. al, 2007), (Nader et. al 2007).

In line with the above descriptions, in this chapter the interference and coexistence issues between WiMax and UWB will be discussed. First, the WiMax receiver performance parameters like the noise floor, sensitivity level, antenna effect will be characterized and the maximum interference limits from UWB to WiMax receiver will be estimated. Depending on

the required protection level at the WiMax receiver, the maximum interference zone that a UWB can cause harmful interference to WiMax system will be identified. Since the interference from UWB devices may appear as an increase of the noise floor and sensitivity level of the WiMax terminal receiver, it can cause an impact on the WiMax system performance. Therefore, the UWB interference impact on WiMax cell coverage and an outage of active users will be studied considering different acceptable noise raise level at the WiMax receiver.

2. WiMax Receiver Characteristics and its Protection Limits

At the early stage of the coexistence studies, the victim receiver characteristics (e.g. noise floor, receiver sensitivity, bandwidth, acceptable interference criteria, etc) are necessary to discuss, since the interference impact from incumbent UWB devices entirely depends on those parameters. In generally, the receiver is designed by means of current market demands in developing a product being low cost, small size and low power consumption while compromising the system performance. A system contains two different kind of receivers namely Base Station Receiver (BSR) and Subscriber Station Receiver (SSR); the target quality and performance is fairly better in BSR compared to the SSR. It is true and well known for any product "Low cost trade-off low quality". In order to achieve such low cost several compromises are made on the receiver design, especially in the adjustment of high Noise Floor (NoF) as well as compensation of some losses. The design of low power and low size receiver is also strongly influenced by several factors like radio architecture, integrated circuit process technology, etc. They may encounter additional losses in the devices. Moreover the NF and losses within the SSR can not be replicated with the BSR.

2.1 Characterization of WiMax Noise Density

The Noise Floor (NoF) is the integration of noises, losses and errors present over the effective operating bandwidth at the WiMax receiver. Thermal Noise (TN) is the main part of the NoF and remaining noises like noise figure (LNA and mixer noises), synthesizer noise and several errors such as estimation error, tracking error etc has also a significant contribution in the NoF estimation. We define the Noise Density (ND) when the NoF is normalized with 1 MHz of channel bandwidth and given by

$$ND \left|_{dBm / MHz} \right. = TN \left|_{dBm / MHz} \right. + NF \left|_{dB} \right. + IL \left|_{dB} \right. \quad (1)$$

TN is computed base on, the kTBw formula, Boltzmann's constant ($k = 1.38 \times 10^{-23}$), the noise temperature T (in degree Kelvin $0^\circ C + 273$), and the effective channel bandwidth of the receiver, Bw (in MHz). For example, considering the temperature of $T = 290K$ results in a TN of -114 dBm/MHz (-174 dBm/Hz normalized with 1 Hz), which is in fact adopted in most applications. IL is the implementation loss including the non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors, and phase noise.

NF and IL are the critical parameters of the receiver performance in presence or in absence of any interference because the normalized TN is fairly constant. The increase of NF or IL obviously reduces the receiver activities which results in a higher level received signal requirement. In critical situations, a fraction of dB can make a huge difference of

interference impact to the receiver from incumbent systems and can play a big part in winning or losing contracts. Then predicting accurate NF and IL is of paramount importance. The (IEEE, 2004) standard limited these values with 7 dB of NF and 5 dB of IL but some vendors can reduce the values by means of some sophisticated techniques. The standard does not separate the BSR and SSR in terms of NF or IL, but in realistic applications both receivers may not be replicated. In addition, the worst case values are always recommended for performance evaluation. Hence, we have considered the NF of 5 dB and IL of 0 dB at the SSR. In this paper, we have investigated only the impact on the SSR but it is also possible to consider the NF of 3 dB and IL of 0 dB for BSR in further investigations.

2.2 WiMax OFDM Receiver Sensitivity

The sensitivity, R_{Sen} level of a receiver is an equivalent to the NoF plus the minimum acceptable Signal to Noise Ratio (SNR) at the receiver. The type of Modulation and Coding (MC) used in the system usually determines the SNR if the standard Bit Error Rate (BER) is met. The (IEEE, 2004) standard derives the R_{Sen} based on the SNR of an ideal receiver required to achieve a BER of 10^{-6} in Additive White Gaussian Noise (AWGN). But some other wireless standards may define the reduced BER of 10^{-6} in the system for the purpose to achieve the required system demands by accomplished better quality, reliability and robustness. One possibility to do this is to select a low data rate modulation and coding in the system which gives a lower SNR and robust link. WiMax systems use adaptive modulation and coding scheme and the corresponding SNR can be found in (IEEE, 2004) but this value has been corrected in (C802, 2005) and a new SNR ratio was proposed which is approximately 3.4 dB lower than the previous one.

Fig. 1. Relationship between WiMax receiver parameters

The receiver R_{Sen} in dBm is given by

$$R_{\text{Sen}} = ND + SNR + 10 \log_{10} (Bw) \quad (2)$$

Where Bw is the effective channel bandwidth of the receiver in MHz. OFDM scheme in IEEE 802.16 standard does not allocate the entire channel bandwidth for information transmission. There are some significant factors like FFT, sampling, DC and guard band, etc which partially reduces the effective channel bandwidth and it can be straightforwardly computed as follows (IEEE, 2004).

$$Bw = F_s N_{\text{used}} / RN_{\text{FFT}} \quad (3)$$

Finally, substituting (3) into (2), the receiver R_{Sen} for OFDM physical layer is give by

$$R_{\text{Sen}} = ND + SNR + 10 \log_{10} (F_s N_{\text{used}} / RN_{\text{FFT}}) \quad (4)$$

Whereas F_s is the sampling frequency, N_{used} is the number of subcarriers used, and N_{FFT} is the length of FFT in OFDM physical and R is the repetition rate. Figure 1 depicts the graphical relationship among TN , NoF and R_{Sen} .

2.3 WiMax Antenna Characterizations

The interference influences are also modelled and characterized by the antenna mounted in the victim receiver. The antenna parameters (e.g directivity, gain, radiation patterns, height, etc.) can lead to a significant interference mismatch on the victim receiver. The interference impact on MSR and SSR will differ in terms of these factors because the BSR in the WiMax system contains high gain directional antennas but the SSR may contain directional (FWA subscribers) or omni-direction (nomadic/mobility subscribers) antenna depending on the services. For an equal separation distance between fixed or nomadic victim SSR and UWB interferer, the fixed directional receiver will experience greater impact than nomadic one, if both antennas (UWB and SSR) are located in the boresight. Therefore, in order to investigate the impact on the high gain directional receiver, the antenna parameters need to be taken into account carefully. However, we have limited the evaluation within indoor nomadic SSR, i.e. the interference signal received by an omni-directional antenna is with 0 dB gain. In addition, the performances of BSR and SSR can not be replicated against interference because of the robust antenna used in the BSR. In generally, BSR gives better performance but it can also involve a feeder loss that is not being seen in SSR. Therefore the selection of antennas for SSRs is a mature of science and keeping the following characteristics in mind: i) small size ii) low cost iii) good gain characteristics and iv) a good omni-directional radiation patterns.

2.4 Estimation of Maximum Interference Limits

Maximum permissible noise raise at the WiMax receiver from a UWB transmitter is an important consideration. Starting from this limit the maximum allowable aggregate interference effects from that UWB terminal are computed. They strongly depend on the location of the WiMax terminal in the cell. In general, the maximum permissible noise limit

is a function of the distance between the WiMax client and the Base Station (BS). Therefore, the permissible level varies from one client to another client and those are located far from the cell edge can be operated with higher acceptable level of noise raise than clients close to the BS because of stronger desired received signal. Theoretically, the interference impact on the victim receiver is negligible when the received interference power is much below the NoF. For the terminals located near cell edge, the maximum interference power can be equal to the NoF, which corresponds to 3 dB noise raise limit at the victim receiver (Noise Floor, NoF (mW) + maximum UWB interference power, $I_{UWB} = \text{NoF(mW)} + \text{NoF(mW)} = 2\text{NoF(mW)} = \text{NoF(dBm)} + 3 \text{ dB}$. In (Giuliano, et. at 2005), UWB interference is considered to be harmful when the noise raise is more than 3 dB. However, we limited our interference analyse for not only 3 dB; it is assumed that the terminals can accept noise raise of 1-3 dB. For the generic WiMax victim receiver, the maximum permissible interference due to UWB interference can be accounted as follows (Sarfaraz, et. al, 2005):

$$I_{UWB} = ND + 10\log_{10} (10^{N_r/10} - 1) \tag{5}$$

Here N_r is the maximum allowable noise raise in the WiMax client receiver in dB.

Fig. 2. Noise raise vs. UWB permissible interference power

Figure 2 shows the maximum allowable interference input power corresponding to the permissible noise raise at the WiMax client. The results are computed by (1) with applied the NF of 5 dB and IL of 0 dB. One can see that at I_{UWB}/ND of -6 dB the corresponding noise raise limit is 1 dB. In similar way, when the I_{UWB}/ND is -2.35 dB the noise limit is 2 dB and at I_{UWB}/ND of 0 dB the maximum noise raise is 3 dB. Finally, at I_{UWB}/ND of 0 dB and the NF of 5 dB the maximum interference limit of -109 dBm/MHz is computed. The results are summarized in the table 1.

Noise Raise	1 dB	2 dB	3 dB
I_{UWB} / ND	- 6 dB	- 2.35 dB	0 dB
I_{UWB}	- 115 dBm/MHz	-111.35 dBm/MHz	-109 dBm/MHz

Table 1. Maximum UWB permissible interference power at SSR

3. SEMCAT Analysis of Maximum Possible UWB PSD at 3.5 GHz band

The analytical and simulation results for only one interfering signal by a UWB system have been taken into account to evaluate the impact of interference to a WiMax receiver. In the analytical part, we examined the results in the following order: assess a realistic interference scenario to find out the true separation distance between UWB transmitter and WiMax receiver, to determine the minimum coupling loss between the interferer and victim by using the minimum permissible interference power input, to translate the minimum coupling loss into a minimum interference range for a single UWB interferer by means of a free space propagation model, and to calculate the probability of UWB transmitter be located inside the interference range. In the simulation part, the Monte-Carlo based SEAMCAT® tool is used to implement the interference scenario and to evaluate the cumulative probability of interference. The most important parameters used for subsequent analysis are indicated in Table 2.

Parameters	Values
UWB Tx Power	-65 dBm/MHz to -85 dBm/MHz
UWB Tx Gain	0 dB
UWB RF Loss	1 dB
Channel Model	Free Space
Frequency	3.5 GHz
Channel BW	500 MHz (UWB)
Separation	0.35 m to 2 m
Victim Rx Gain	0 dBm
Channel BW	10 MHz (WiMax)
Noise Figure	5 dB to 7 dB
Imp: Loss	

Table 2. SEMCAT simulation parameters

3.1 Coexistence Scenario in SEMCAT

The scenario addressed the case when the UWB transmitter is "non co-located" with WiMax system (see Figure 3). Non collocated means UWB device is not included within the same hardware platform as the WiMax terminal. Hence, the scenario is considered where UWB will be operating in close vicinity to a WiMax terminal connected to the PC (TG3, 2006). Air interference exists between both UWB transmitter and WiMax terminal.

Fig. 3. Coexistence scenarios in the office desktop environment

The main idea behind the interference scenario analysis is to find out a realistic distance between the UWB transmitter and the victim receiver. We consider an office desk scenario where the UWB device is located together with a WiMax system on the same desk or in very close proximity. The separation distances between the UWB and WiMax receiver in the office desk are depending on the desk arrangement and desk size. Two types of layout are often observed; a long main desk and main desk with a small desk placed at the one corner of main desk. The small desk is mainly used to place PC, PDA, etc. The main desk will generally be 1.8 m to 2 m long. A WiMax terminal will be placed centrally or opposite corner of the desk, distance from the UWB to a WiMax terminal would be 0.5 m to 2 m (TG3, 2006). Alternative case, a WiMax terminal will often be placed at one of the back corners of the main desk and a wireless monitor placed centrally on the main desk, distances from the monitor to a WiMax terminal would be 0.35 m to 0.5 m. The UWB devices which are associated with a PC (such printers, remote hard drives, etc.) will be normally placed between 0.5 m to 2m. Therefore, the minimum separation between UWB and WiMax is assumed to be 0.35 m to 2 m.

3.2 Minimum Coupling Loss between UWB Tx and WiMax Rx

The Minimum Coupling Loss (MCL) characterizes the minimum protection distance required between the UWB transmitter and WiMax client to ensure that there is no such interference coming from interferer. In other words, it determines the interference zone surrounding of victim receiver and received interference signal if UWB transmitter appears in the zone. The MCL can be derived as follows:

$$MCL = P_t^{UWB} + G_t^{UWB} - L_{RF}^{UWB} + G_r^{WTS} - I \quad (6)$$

Where: P_t^{UWB} - UWB transmitter conducted power in dBm/MHz, G_t^{UWB} - UWB transmitter antenna gain in dB, L_{RF}^{UWB} - UWB transmitter RF Loss in dB, G_r^{WTS} - WiMax client antenna gain in dB, I - maximum permissible interference input at WiMax terminal in dBm/MHz. The above parameters are defined in the Table 2, except I . We assume RF loss in the UWB transmitter because it is commercialized as a low cost product. In order to achieve an

aggressive low cost goal several compromises are made particularly on fundamental receiver and transmitter parameters, which normally resulting in RF loss and high noise figure.

Fig. 4. Maximum interference zone radius vs. maximum N_r

3.3 Interference Zone Radius Center at WiMax Receiver

If we assume that the victim receiver has a certain noise figure and is within the line of sight of the UWB transmitter such that the free space path loss equation applied, then we can calculate the distance (interference zone radius, r_i) at which the received power will equal to the permissible interference input of the incumbent receiver, for a given UWB transmitter power.

$$PL (dB) = 20 \log_{10} \left(\frac{4\pi}{c} \right) + 20 \log_{10} \left(\frac{f}{10^{-6}} \right) + 20 \log_{10} (r_i) \quad (7)$$

Here, f is the center frequency in MHz, c is the light speed 3×10^8 m/s and r_i is the interference zone radius in meter.

Figure 4 depicts the radius of interference zone which is computed for noise figure of 5 dB and implementation loss of 2 dB. It is represented that the WiMax client receiver will not see the UWB interferer at any distance beyond 0.43 m, even assuming free space propagation when transmit power of -70 dBm/MHz and noise raise of 3 dB performed. This distance is independent of receiver bandwidth as long as the UWB system has a flat power spectral density across the incumbent's bandwidth.

P_t	Nr = 3 dB			Nr = 2 dB			Nr = 1 dB		
dBm/ MHz	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB
-65	0.76 m	0.68 m	0.60 m	1.0 m	0.89 m	0.79 m	1.50 m	1.34 m	1.19m
-70	0.43 m	0.38 m	0.34 m	0.56m	0.50 m	0.44 m	0.84 m	0.75 m	0.67m
-75	0.24 m	0.21 m	0.19 m	0.31m	0.28 m	0.25 m	0.47 m	0.42 m	0.37m
-80	0.13 m	0.12 m	0.10 m	0.17m	0.15 m	0.14 m	0.26 m	0.23 m	0.21m
-85	0.08 m	0.07 m	0.06 m	0.1 m	0.09 m	0.07 m	0.15 m	0.13 m	0.11m

Table 3. Interference zone radius

Table 3 represents the interference zone radius for different combinations of noise figure, transmit power and receiver noise raise. It is expected that the very weak interference signal may reach to the victim receiver if the interferer is located beyond the interference zone in case both systems agreed with the corresponding criteria. For example, a limited noise raise of 2 dB and noise figure of 6 dB, the WiMax receiver can operate without impact of UWB interference if the interferer is located beyond 0.15 m for -80 dBm/MHz transmit power and 0.5 m for -70 dBm/MHz.

Fig. 5. SEMCAT simulation scenario

3.4 Probability of Single UWB to be Inside Interference Zone

We assess the probability that a UWB transmitter is located inside the interference zone. The aggregation interference input to the victim receiver is negligible when the UWB device is placed outside of the interference zone. In Figure 5, the interference range is shown by the symbol of r_i . A WiMax victim receiver with omni-directional antenna is located in the origin of the circle. A UWB terminal is randomly distributed over a concentric ring, centred at the

victim receiver, with inner and outer radii r_{co} and r . Therefore, the area of distribution of $\pi(r^2-r_{co}^2)$ and area of collocated zone of πr_{co}^2 was computed. The cumulative probability of UWB device is located in $\pi(r^2-r_{co}^2)$ area can be expressed by the following equation:

$$p_i = \int_{r_{co}}^{r_i} P(r_i) dr_i$$

(8)

Where $P(r_i)$ is the probability density function of a UWB terminal that is inside the interference zone with radius of r_i . Since the terminal is distributed in the circle area of $\pi(r^2-r_{co}^2)$ then the $P(r_i)$ is given by

$$p(r_i) = \frac{2r_i}{r^2 - r_{co}^2} \quad r_{co} \leq r_i \leq r$$

(9)

The radius r_{co} and r are examined in the scenario section and these are 0.35 m and 2 m respectively.

P _t dBm/ MHz	Nr = 3 dB			Nr = 2 dB			Nr = 1 dB		
	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB
-65	0.117	0.087	0.061	0.226	0.172	0.129	0.548	0.431	0.333
-70	0.016	0.005	0	0.049	0.032	0.018	0.150	0.113	0.084
-75	0	0	0	0	0	0	0.025	0.013	0.003
-80	0	0	0	0	0	0	0	0	0

Table 4. Probability of UWB to be inside interference zone

Fig. 6. Probability vs. interference zone radius

Figure 6 shows the probability of UWB device is located inside the interference zone based upon the victim receiver and interferer parameters. When we take the interference zone radius from the Table 3 and set it to the Figure 6 it will give us the probability of interference power arrived to the victim receiver. For example, at UWB transmit power of -70 dBm/MHz, noise figure of 6 dB and noise raise limit of 3 dB interference zone radius of 0.38 m is determined. That means the interference impact on victim is negligible when the interferer is located outside of the zone. The probability of UWB devices being located inside this are is 0.5% . If the receiver noise raise is 1 dB then the probability reaches to 11%. However for transmit power of -80 dBm/MHz the examined probability is negligible for any distance even at the receiver limited noise raise of 1 dB. Table 4 represents this probability for various combinations of receiver and transmitter parameters.

3.5 Probability of Interference for Different UWB Power Emission Levels

We have performed a system level simulation using SEAMCAT® (Spectrum Engineering Advance Monte Carlo Analysis Tool) (SEMCAT) software tool in order to compute more precise result of probability of interference from UWB transmitter to WiMax victim client receiver. It is a tool developed by the group of CEPT administrations, ETSI members and international scientific bodies to study the coexistence problem between radio systems. It is an implementation of Monte Carlo methodology whose main principle is taking samples of random variables from their probability density functions defined by user and then using those samples to calculate the probability of interference. The parameters presented in the Table 2 are used to perform the simulation. A uniform polar distribution is carried out to distribute the UWB transmitter over the area between two circles with radius of 0.35 m and 2 m, respectively. In each trial, SEAMCAT® calculates the interference power from randomly distributed UWB devices over the distribution area. The resulting interference power is calculated by

$$iRSS = 10 \log_{10} \left(\sum_{j=1}^n 10^{\frac{iRSS_j}{10}} \right) \quad (10)$$

with $iRSS$ = interfering Received Signal Strength in dBm; n = number of trails.

The probabilities of interference for different UWB transmit power levels are depicted in the Figure 7, Figure 8 and Figure 9 for noise figure of 5 dB, 6 dB and 7 dB, respectively. The results are compared for three dissimilar maximum noise raise limit of 1 dB ($I/N = -6$), 2 dB ($I/N = -2.35$) and 3 dB ($I/N = 0$ dB) respectively. It is observed that for PSD of -80 dBm/MHz the probability of interference is zero even if low noise raise limit and high noise figure are taken into account. The maximum probability of interference of 15% is found when the PSD of -70 dBm/MHz and the receiver is satisfied with noise raise limit of 1 dB and noise figure of 5 dB. But it is negligible if the target noise raise limit is 2 dB or 3 dB. For a PSD of -65 dBm/MHz, the probability of interference mostly was found below of 20% if the noise raise limit of 2 dB or 3 dB is considered. The results show that the interference effects from a -70 dBm/MHz UWB transmitter to a WiMax client are negligible.

Fig. 7. Probability of interference for noise figure of 5 dB

Fig. 8. Probability of interference for noise figure of 6 dB

The presented simulation results agreed with the analytical results specified in Table 4. Hence, the probability of UWB device being located inside the interference zone is equal to the probability of interference.

Fig. 9. Probability of interference for noise figure of 7 dB

3.6 Interference Evaluation in presence of inter-cell interference

Due to the inter-cell interference, the permissible noise raise at the WiMax receiver will be increased if such interference itself becomes equal to or higher than nose floor. If we consider the inter-cell interference then we rewrite equation (5) as follows:

$$N_r = 10 \log_{10} \left(\frac{I_{inter} + I_{UWB} + N}{I_{inter} + N} \right)$$

(11)

Here, I_{inter} is the inter-cell interference.

P _t	Nr = 3 dB			Nr = 2 dB			Nr = 1 dB		
dBm/ MHz	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB
-65	0.098	0.0074	0.055	0.191	0.150	0.113	0.466	0.377	0.297
-70	0.009	0.001	0	0.038	0.025	0.013	0.125	0.098	0.074
-75	0	0	0	0	0	0	0.018	0.007	0.001
-80	0	0	0	0	0	0	0	0	0

Table 5. Probability of interference presence of inter-cell interference of -115 dBm/MHz

Table 5 presents the probability of interference when the inter-cell interference power of -115 dBm/MHz is considered. It is show that the probability of interference is reduced from 15% to 9.8% if noise raise limit of 1 dB and noise figure of 5 dB were assumed.

3.7 Interference Evaluation for Random path Loss Exponent

A free space path loss between the UWB transmitter and WiMax receiver has been used to evaluate the above interference results. Since the separation distance is about 2 meters, therefore, it is reasonable to consider the free space path loss. However, the path loss is not only depended on the separation distance rather on the environment conditions. The office desk may scatter with many small objects like books, files, monitor, etc which results of reflection, scattering of the signals. In addition, antennas might not be line-of-sight as it is integrated on the devices. It is assumed that due to multipath the path loss may decrease about 1 dB while the path loss exponent varying from 2 to 2.5. Therefore, the probability of free space path loss between these systems is low. In the following, we study the probability of interference considering the free space path loss is being 80% cases (see table 6).

P _t dBm/ MHz	Nr = 3 dB			Nr = 2 dB			Nr = 1 dB		
	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB	N _F 5dB	N _F 6dB	N _F 7dB
-65	0.078	0.059	0.044	0.153	0.120	0.090	0.373	0.302	0.238
-70	0.007	0.001	0	0.030	0.020	0.011	0.100	0.078	0.059
-75	0	0	0	0	0	0	0.014	0.006	0.001
-80	0	0	0	0	0	0	0	0	0

Table 6. Probability of Interference in presence of inter-cell interference of -115 dBm/MHz and 80% free space cases

4. Evaluation of UWB Interference Impact on WiMax System Performance

Since the interference from UWB devices may appear as an increasing of the NoF and R_{sen}, the tolerable interference levels at the receiver for the WiMax services required to be defined very carefully. Depending on its dimension, the link degradation may lead to decrease the quality of service in a certain degree. It will have a possible impact on the WiMax system in terms of loss of capacity, coverage reduction, outage of users, loss of link availability, etc. The remaining part of this chapter will investigate some of the feasible impact of the UWB emission on WiMax system, by means of loss of coverage and outage of the active users. In order to evaluate those impact, it is initially needed an estimation of cell radius using appropriate propagation model. The impacts have been studied when the receiver tolerable interference levels are limited with 1 dB, 2 dB and 3 dB of noise raise.

4.1 WiMax Cell Edge Reliability and Cell Radius

In the following, we present the relevant procedures and techniques to estimate the radius of a single cell. The initial approach is to select a proper channel model which is agreed with the geographical and environmental conditions on the planning areas. The IEEE 802.16 standard proposed to use Erceg propagation model for a WiMax system coverage prediction (Erceg, et. at, 1999). We used category B and category C of the Erceg path loss model with

the frequency and antenna height correction factors. The other two common factors which also indeed influence the cell radius evaluations are: CER and Fade Margin (FM). The CER refers to the probability that the RF signal strength on a circular contour at the cell edge will meet or exceed the quality threshold (e.g. -98 dBm for QPSK 1/2). However, the cell coverage reliability can be also used instead of CER, since for a given propagation environment, CER and cell area reliability are deterministically related and easily transformable.

A FM is calculated to ensure the desired CER and it is relied on the actual signal variation within each cell. If CER is increased the FM will be also increased relatively. The FM is computed on the basis of predetermined target CER figure and the said shadow fading, σ in dB. The σ is usually modelled as a lognormal distribution that describes the variation of the decibel value of the mean signal as a normal or Gaussian distribution. FM is usually given by (Bernardin, 1989)

$$F_M(\sigma, cov\%) = z\sigma$$

(12)

wherein z may be calculated from the defined cell edge reliability, then $CER(z)$ is calculated as follows

$$CER(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-(t^2/2)} dt$$

(13)

For example, a cell edge reliability, $CER(z)$ of 90% estimate the FM of 1.282σ . Similarly $CER(z)$ of 75% compute FM of 0.675σ .

Parameters	Values
Bandwidth, B_W	3.5 MHz
BS Power, P_t	35 dBm
BS Antenna Gain, G_{BS}	16 dB
Channel Model	Erceg Cat.B and Cat. C
Shadow, σ	9.6 dB (Cat. C) 8.2 dB (Cat.B)
Penetration Loss, L_{Wall}	12 dB
SS Antenna Gain, G_{SS}	0 dB
Frequency	3.5 GHz
BS Height	30 m
SS Height	6 m
Noise Figure, NF	5 dB
Implementation Loss, IL	0 dB
Sensitivity, R_{Sen}	-98 dBm (QPSK 1/2) -91 dBm (16QAM 1/2) -85 dBm (64QAM 2/3)

Table 7. WiMax system parameters for simulation

A calculation of path loss is an essential case in the cell planning and in determining the cell radius. The maximum path loss, L_{path} (path attenuation) between BS and Subscriber Station (SS) can be found using a practical power budget. It is based on the computed FM, both

antennas characteristics, BS transmit power (P_t), SS receiver R_{sen} level, and outdoor to indoor penetration losses L_{wall} . Then L_{path} can be expressed by the following equation,

$$L_{path} = P_t + G_{BS} - FM - L_{wall} + G_{SS} - R_{Sen}$$

(14)

Where, G_{BS} and G_{TS} are antennas gains at BS and at SS respectively. The assumed values of those parameters except FM can be taken from the table 7. Finally, the L_{path} is applied in the Erceg path loss equation in order to extract the cell radius R . The Erceg path loss model can be given by (Erceg, et. at, 1999)

$$L_{path} = A + 10 \gamma \log_{10} \left(\frac{R}{d_0} \right) + X_f + X_h + \sigma$$

(15)

Where A is the free space path loss at a reference distance of $d_0=100$ m, R is the distance from BS to the cell edge point and X_f , X_h are the correction factors of the operating frequency and the receiver antenna respectively. σ is the path loss exponent, which is computed according to the considered terrain type. σ is omitted in this equation because this term is already included in the FM.

CER	FM	Cell Radius Cat. B (km)			Cell Radius Cat. C (km)		
		QPSK 1/2	16QAM 1/2	64QAM 2/3	QPSK 1/2	16QAM 1/2	64QAM 2/3
75%	0.675σ	1.456	1.007	0.735	2.322	1.570	1.122
80%	0.841σ	1.338	0.926	0.675	2.151	1.454	1.039
85%	1.036σ	1.213	0.839	0.612	1.967	1.330	0.951
90%	1.282σ	1.072	0.741	0.541	1.758	1.188	0.850
95%	1.645σ	0.892	0.617	0.450	1.488	1.006	0.719
99%	2.327σ	0.632	0.437	0.319	1.089	0.736	0.526

Table 8. Estimated cell radius for Cat. B and Cat. C in km

Table 8 shows the calculated FM and cell radius for the corresponding CER. The radius is calculated for the category B and category C of the Erceg model. Type C is associated with the minimum path loss for flat terrain with light tree densities. On the other hand type B is mostly for flat terrains with moderate to heavy tree densities or hilly terrains with light tree density. For more details please refer to (Erceg, et. at, 1999). The WiMax system adopted adaptive modulation and the upper boundary of the cell coverage is determined by the robustness QPSK $\frac{1}{2}$ modulation scheme. Since, it gives lowest R_{sen} level, the low power signal can be feasible to receive. The cell radius is represented in the table 8 and seems slightly smaller than other literatures. The reason is the SSR antenna gain and the penetration loss. Most of the studies have taken into account the SSR antenna gain of 16 dB and penetration loss 0 dB. That means 28 dB (12 dB + 16 dB) additional path attenuation is considered in our study which results in a smaller cell radius in comparison to the previous one.

Fig. 10. Subscriber station height vs. cell radius

4.2 UWB Impact on the WiMax Cell Coverage

The potential UWB interference impact on WiMax cell coverage in terms of coverage reduction or cell radius reduction is estimated in the following part. The network provider may be affected economically because the reduction of cell coverage can increase the instalments cost and reduce the net profit. The provider will need to expand the number of BS or cell to cover the same area. The process to compute the reduction of cell radius can be conveniently considered in two steps:

i) The first step is to define the tolerable noise raise limits which will present a given level of UWB signal at the WiMax SSR.

ii) The second step is to compute the reduction of cell radius with introducing the noise raise limits. The decreased of the NoF will need a compensation of the R_{sen} level in order to meet the minimum signal level. It must be received with a certain acceptable BER or necessary SNR for a particular modulation and coding scheme in order to decode correct the data stream. Since the cell radius is computed with respect to the R_{sen} level, it will reduce with reduction level of the R_{sen} . At the end the percentage of cell radius reduction is calculated.

Noise Rise	1 dB	2 dB	3 dB
I_{UWB}/ND	-6 dB	-2.35 dB	0 dB
Cat. B	5.12%	9.98%	14.61%
Cat. C	5.44%	10.58%	15.44%

Table 9. Estimated reduction of cell radius

Table 9 shows the cell radius reduction with respect to the noise raise limits of 1 dB, 2 dB and 3 dB for the category B and category C channel model. It is found that the percentage of reduction slightly depended on the channel model. The reduction seems unacceptable when the tolerable link degradation of 3 dB is applied at SSR. For example it is about 15% when the noise raise limit is of 3 dB. On the other hand around 5% of cell radius reduction is observed if the noise increased of 1 dB is considered. In principle the 10% of cell reduction is well acceptable.

4.3 Interference Impact of the Active Users (Outage of Users)

WiMax SSR will be suffered by UWB interference that results of outage if it is located near the cell edge. The receiver can experience on outage when it does not meet the required SNR. Those terminals are operating very close to cell edge can goes to outage because they are running with few dB of SNR margin. The users are situated far from the cell edge will be effected on the capacity not on the outage because they usually run with enough SNR margin. Our investigation following two categories: one is to determine the percentage of the devices are situated in the 1 dB, 2 dB and 3 dB zone and other is to find out the total number of outage corresponding to the noise raise limits.

Fig. 11. 1 dB, 2 dB and 3 dB zones in the cell planning

The representation of three zones is shown in the Figure 11. The possible number of devices are located in the zone is expressed by the following equation,

$$P(x) = N \cdot \left(\frac{r_i^2 - r_{i+1}^2}{r_i^2} \right) CER(z) \quad (16)$$

where N is the total number of active users distributed uniformly in the cell, r_i and $r_{(i+1)}$ are the inner and outer radius of the zone and $i=0,1,2$.

	Cat.B			Cat.C		
CER	3dB Zone	2dB Zone	1dB Zone	3dB Zone	2dB Zone	1dB Zone
75%	6.07%	6.74%	7.49%	6.35%	7.10%	7.94%
80%	6.47%	7.19%	7.99%	6.77%	7.57%	8.50%
85%	6.90%	7.64%	8.50%	7.19%	8.04%	9.00%
90%	7.28%	8.09%	9.00%	7.62%	8.51%	9.52%
95%	7.69%	8.54%	9.50%	8.04%	9.00%	10.05%
99%	8.00%	8.90%	9.91%	8.38%	9.37%	10.48%

Table 10. Victim users located in the zones at QPSK 1/2

Table 10 represents the percentage of users being located in the noise raise limits of 1 dB, 2 dB and 3 dB zone. It is obvious that the percentage of users in 3 dB zones will be less compared to 1 dB zone because of the less area. It is also shown that around 7.28% of victims are placed in the 3 dB zones if CER of 90% is considered.

	Cat.B			Cat.C		
CER	3dB Zone	2dB Zone	1dB Zone	3dB Zone	2dB Zone	1dB Zone
75%	20.3%	14.2%	7.49%	21.3%	15.0%	7.94%
80%	21.6%	15.2%	7.99%	22.8%	16.1%	8.50%
85%	23.0%	16.1%	8.50%	24.2%	17.0%	9.00%
90%	24.4%	17.1%	9.00%	25.6%	18.0%	9.52%
95%	25.7%	18%	9.50%	27.1%	19.00%	10.05%
99%	26.8%	18.8%	9.91%	28.2%	19.8%	10.48%

Table 11. Outage users for noise raise of 1 dB, 2 dB and 3 dB at QPSK 1/2

Table 11 shows the computed number of active devices which are suffered by outage if the corresponding noise raise limits is allowed in the SSR. It is found that for 3 dB of noise raise limits above 20% of active devices are experienced outage. If it was assumed the total numbers of active devices are 30 then about 5-6 devices will be gone on outage in the case of 3 dB noise raise. Similarly about 2-3 users for 2 dB and about 1-2 users for 1 dB of noise raise limits.

5. Conclusion

In this chapter, the interference effect and coexistence of UWB system with WiMax has been analysed. Results have been investigated by the analytical and simulation studies. A SEAMCAT tool based on Monte-Carlo simulation methodology is used to determine the maximum possible power spectral density at the 3.5 GHz band by limiting the maximum acceptable interference level at the WiMax receiver. Also SEMCAT is used to evaluate the probability of interference by implementing a realistic interference scenario where UWB and WiMax are operating in linking with desktop PC. It is found that UWB interference impact on WiMax is harmful if UWB conducted transmit power is of more than -70 dBm/MHz.

Then, the possible UWB interference impact on the WiMax cell coverage and on outage of users has computed by considering the maximum allowable noise raise level at the receiver or vice versa. This evaluation was important to investigate how severe is UWB interference for WiMax system. At prior, the realistic cell radius by considering cell edge reliability and the practical WiMax system parameters have been calculated. It is found that cause of interference the nose raise of 1 dB, 2 dB and 3 dB at the WiMax receiver, the cell radius can be reduced about 5%, 10% and 15%, respectively.

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WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband access network named by industry group called the WiMAX forum formed in June 2001. It is Wireless MAN with IEEE 802.16 family standards. Loosely, WiMAX is a standardized wireless version of Ethernet that enables the last mile, intended primarily as an alternative to wire technologies (such as Cable Modems, DSL and T1/E1 links) to provide broadband access to customer premises. Mission of the WiMAX forum is to promote and certify compatibility and interoperability of broadband wireless products. This book touches most of the above issues in form of 22 individuals' papers containing research work in WiMAX domain in particular. WiMAX has two important standards/usage models: a fixed usage model IEEE 802.16-2004 for Fixed Wireless Broadband Access (FWBA) and a portable usage model IEEE 802.16e-2005, which is mainly concentrated on Mobile Wireless Broadband Access (MWBA). Both are released as standards and amendments are available in form of drafts. Higher data rate transmissions (@ 100 Mbps) are achieved in IEEE 802.16-2004 WiMAX through LOS communications which incorporate a stationary transmitter and receiver but IEEE 802.16e supporting NLOS communication is much complicated and little less bit rate is achieved. 2-11 GHz licensed band is the range of frequencies with TDD and FDD supports. The book will provide a wide horizon to visualize the WiMAX technology and its developments leading towards 4G systems. It will provide a good platform to the researchers with clues to the innovative ideas in WiMAX domain. I wish all the best to the authors and readers of this book in their successful research of WiMAX technology.

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