TDD-TDD Interference Analysis Involving Synchronized WiMAX Systems

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Executive Summary

The purpose of this white paper is to provide guidance on the deployment of adjacent synchronized[1] WiMAX TDD systems in the same geographical area. The target adjacent channel interference rejection figures are assessed based on simulation assuming the same cell characteristics and a consequential frequency separation (guard frequency) is estimated in order to reduce the interference impact between the two systems to a certain acceptable level.

In the case of synchronized TDD systems, the BS to BS and the MS to MS interference scenarios are not relevant therefore two simulation scenarios between two adjacent TDD systems are considered:

- Scenario 1: (downlink), BS to MS interference scenario.
- Scenario 2: (uplink), MS to BS interference scenario.

Capacity degradation in the victim cell caused by interference from the adjacent channel is used as the evaluation metric and 3% capacity degradation ratio is assumed as an acceptable figure. In these scenarios, the system level simulation (SLS) assumed a 2 tier and 19 cell configuration. The required ACIR value and the consequential guard band are analyzed to meet the acceptable capacity degradation criteria, against a range of distances between the BSs of two systems.

Results of the SLS are as follows:

- In scenario 1(Downlink case), the required ACIR is 27.5dB and 28.5dB in Frequency Reuse Pattern 1 (FRP1) and Frequency Reuse Pattern 3 (FRP3) system respectively, to meet the 3% capacity degradation criteria. Based on the spectrum masks defined by the WiMAX Forum and ETSI, the required guard band is 0~1MHz to achieve these ACIR figures and maintain ≤3% capacity loss.
- In scenario 2(Uplink case), the required ACIR is 28.5dB and 24.5dB in FRP1 and

[1] synchronized UL:DL ratio, synchronized frame length and starting point

FRP3 system respectively, to meet the 3% capacity degradation criteria. Based on the WiMAX Forum spectrum mask, the required guard band is 0.5~1MHz to achieve these ACIR figures and maintain ≤3% capacity loss.

It can be concluded that based upon the most likely emission mask characteristics and taking into account additional specifications for ACLR performance, it is entirely possible for synchronized TDD systems to operate satisfactorily in adjacent frequency blocks with zero guard frequency.

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List of Abbreviations

ACLR	*Adjacent Channel Leakage Ratio*
ACIR	*Adjacent Channel Interference Ratio*
ACS	*Adjacent Channel Sensitivity*
AMC	*Adaptive Modulation and Coding*
BER	*Bit Error Rate*
BS	*Base Station*
CINR	*Carrier to Interference+ Noise Ratio*
DL	*Downlink*
FFT	*Fast Fourier Transform*
FRP	*Frequency Reuse Pattern*
MCS	*Modulation and Coding Scheme*
MS	*Mobile Station*
OOB	*Out Of Band Emission*
NLOS	*Non-Line Of Sight*
PUSC	*Partial Used Sub-Carrier*
SLS	*System Level Simulation*
TDD	*Time Division Duplex*
UL	*Uplink*
WiMAX	*Worldwide Interoperability for Microwave Access*

References

[1] 3GPP, “Universal Mobile Telecommunications System (UMTS); Radio Frequency (RF) System Scenarios (3GPP TR 25.942 version 6.4.0 Release 6)”, 3GPP TR 25.942, March 2005

[2] ITU-R Administrative Circular Letter 279

[3] ETSI, Fixed Radio Systems; Multipoint Equipment and Antennas, EN 302 326, 2008.02

[4] ETSI, Broadband Data Transmitting Systems operating in the 2 500 MHz to 2 690 MHz frequency band; Part 1: TDD Base Stations, EN 302 544-1, 2008.12

[5] WiMAX Forum, "Spectrum Mask WiMAX Profile: Mobile Band Class 1B 2300-2400 MHz with 5/10 MHz channel", November 2008.

[6] WiMAX Forum, "WiMAX™ System Evaluation Methodology", V2.1, July 2008.

1. Introduction

Many countries consider WiMAX technology for BWA system deployment. WiMAX technology is a standardized broadband wireless technology that defines the physical and medium access control layers.

The BWA licenses are normally assigned to several operators in blocks within the same frequency bands (e.g. 2300-2400MHz, 2500-2690MHz) with or without a guard band between operators. Managing interference across the boundaries of adjacent blocks due to transmitter and receiver out of band performance is a challenge in any radio system.

This report describes guidance to manage the interference impact between two different synchronized TDD systems when deployed in adjacent frequency blocks in the same geographical area. Through SLS, the capacity degradation ratio in the victim cell is derived according to ACIR which quantifies the interference rejection accounting for the adjacent channel characteristics of both the transmitter and receiver. Considering the simulation result, the size of guard band for mitigating the interference is estimated based on the known spectrum mask.

This report is divided into 5 chapters.

- Chapter 1: Introduction
- Chapter 2: Coexistence consideration of TDD-TDD systems: This chapter presents the considerations for coexistence between TDD-TDD systems such as interference scenarios and factors affecting interference susceptibility.
- Chapter 3: Simulation methodology: This chapter defines the required system parameters, assumptions and simulation procedure for interference analysis and the cell layout configurations including the path model and antenna modeling.
- Chapter 4: Simulation result & Analysis: Based on the scenarios and simulation methodology definition in chapter 3, the results of simulations are derived and analyzed at this chapter.
- Chapter 5: Conclusion: Interference analysis impact between synchronized WiMAX TDD systems is concluded in this chapter. To help more understanding the analysis, the spectrum related specifications are explained in ANNEX A.

2. Coexistence considerations between TDD systems

2.1. Interference scenarios

With the assumption of synchronization (synchronized UL:DL ratio, synchronized frame length and starting point) between two adjacent TDD systems only two interference scenarios are relevant and need to be considered to investigate the coexistence conditions between the two systems.

1) Scenario 1(Downlink case) : Figure 1
   - BS to MS (DL to DL): BS of B system as an interferer causes interference to MS of A system as a victim

   .

2) Scenario 2(Uplink case) : Figure 2
   - MS to BS (UL to UL): MS of B system as an interferer causes interference to BS of A system as a victim.

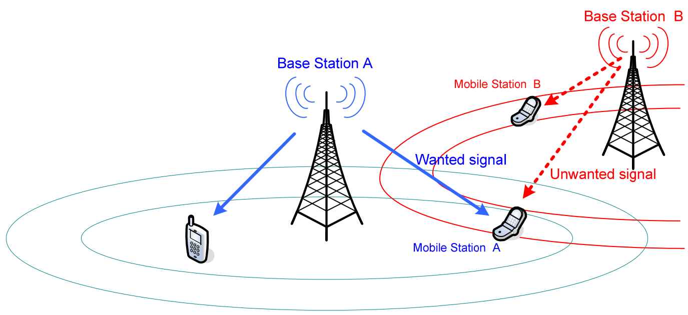


Figure 1. Scenario 1: Downlink [BS] interfere to Downlink [MS]

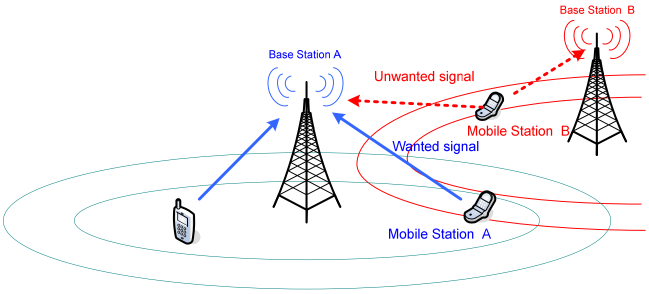


Figure 2. Scenario 2: Uplink [MS] interfere to Uplink [BS]

2.2. Factors Affecting Interference

- Out of Band Emission

Out of band emission (OOB) is the emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emission. To evaluate OOB, ACLR (Adjacent Channel Leakage Ratio) is used as the ratio between the power of in-band channel and the power of adjacent channel.

- Receiver selectivity

Receiver selectivity indicates the performance of receiver. Ideally, the receiver filter passes just the signal in band but practical implementations preclude this. Receiver selectivity indicates the degree of signal attenuation in the adjacent channel. The scale of the receiver selectivity is represented as ACS which is the ratio of the attenuation of the receiver filter in its own channel to the attenuation of the receiver filter in the adjacent channel.

- Adjacent channel interference ratio (ACIR)

The resultant interference impact to the adjacent channel due to the combination of ACLR and ACS is represented by ACIR, and is given by

$$ACIR_{linear} = \frac{1}{\frac{1}{ACLR_{linear}} + \frac{1}{ACS_{linear}}}$$

(Eq 1)

As described in the (Eq 1), ACIR is one over the sum of the inverse of ACLR and ACS. Note that ACLR and ACS are presented in the linear scale in the equation above **[1**].

- ❑ Antenna characteristic

In the BS case, the antenna characteristics such as the antenna gain, the radiation pattern (beam width, Front-back-ratio) are the important factors to determine the interference level in the adjacent channel.

- ❑ Frequency Reuse Pattern

Two frequency reuse schemes are employed, FRP = 1 and FRP = 3. In FRP = 1 all the available spectrum resource is assumed to be deployed across all the sectors of a cell. Therefore, all sectors in the cell can be considered co-channel. In FRP = 3, the available spectrum resource is assumed to be divided into three separate blocks one of which is deployed in each sector of the cell. In this case not all sectors in adjacent cells will be immediately adjacent (or co-channel). In both cases three blocks of spectrum resource are assumed.

3. Simulation methodology

This chapter suggests the simulation methodology for analyzing the interference between two TDD systems and assessing the capacity degradation in the victim cell. The system parameters used in the simulation are defined in section 3.1 and the cell layout for simulation is configured in sections 3.2 to 3.4. Finally, the procedure for simulation is explained in section 3.5.

3.1. System characteristics & assumption

It is assumed that two adjacent TDD systems have the same characteristics and are completely synchronized. The system parameters for the analysis are presented in Table 1 and Table 2.

Table 1. The system parameters for the Base Station

Parameter	Value
TX power	43dBm
Height	32m
Antenna Gain	16dBi
Antenna front-to-back ratio	25 dB
Antenna 3dB beam width (H)	70 º
Antenna 3dB beam width (V)	7 º
Number of transmit antennas	2
Number of receive antennas	2
Noise Figure	5 dB
Cable loss	2 dB

Table 2. The system parameters for the Mobile Station

Parameter	Value
TX power	23dBm
Height	1.5m
Antenna Gain	0 dBi
Antenna Pattern	Omni
Number of transmit antennas	1
Number of receive antennas	2
Noise Figure	7
Cable loss	0

3.2. Cell configuration

The parameters used for configuring the cell layout are defined in Table 3.
The cell layout is composed of 19 cells and each cell has three sectors. The distance between one BS and the next adjacent BS is fixed at 1000m. 20 users are randomly placed with uniform distribution over the whole cell for every an iteration.

Table 3. Cell parameters for simulation

Parameter	Value
Cell Layout	Ideal Hexagonal 2 tier (19cell with 3sector)
BS to BS distance	1000m
User placement	20 user / sector (Uniform distribution)
Operating frequency	2.3 GHz
Bandwidth	10MHz (1024 FFT)
Frequency Reuse Pattern	FRP1 / FRP3
Pathloss model	Cost 231 HATA BS Height : 32m MS Height : 1.5m
Propagation environment	NLOS, Penetration Loss : 10dB
Thermal noise density	-174dBm / Hz

Log-normal shadowing	8.9dB (BS shadowing correlation: 0.5)
Fast fading generation	JTC fader
Channel model	• Pedestrian B 3km/h : 60% • Vehicular A 30km/h : 30% • Vehicular A 120km/h : 10%
Traffic model	Best effort(Full buffer)
MIMO	On (DL:STC/SM, UL:CSM)
Hybrid ARQ	On
Scheduler type	PF scheduler (Fairness exponent factor : 1.0)
Power control	Open loop power control(Uplink)

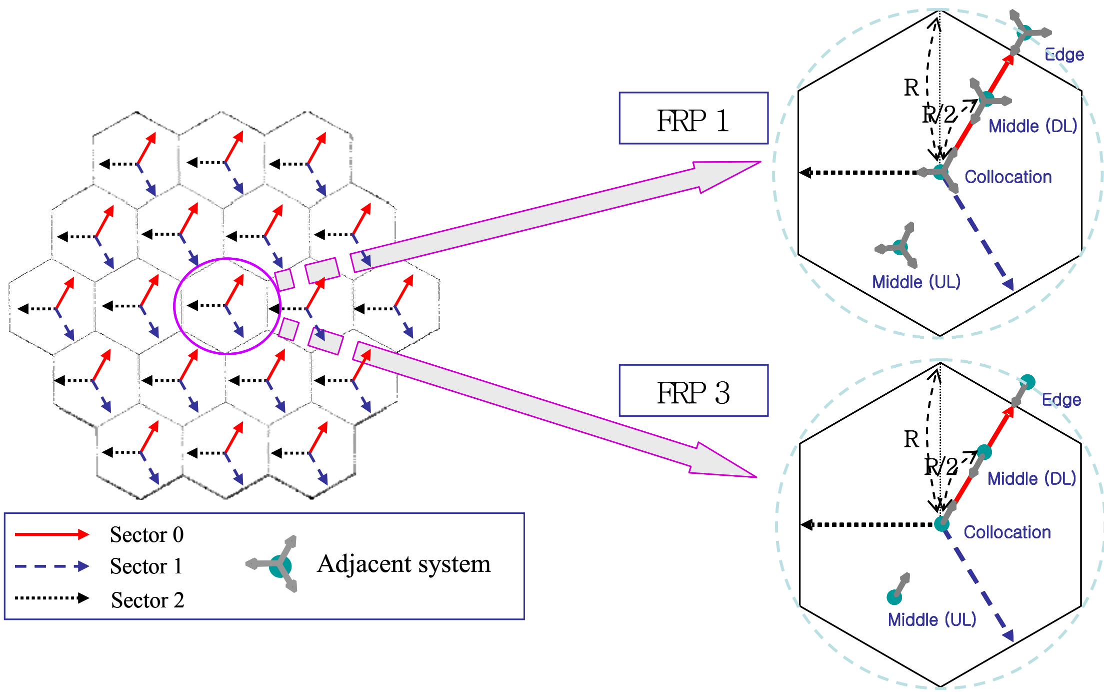


Figure 3. Cell layout with two TDD systems

ACIR is the main factor to determine the level of interference between the two systems. In this analysis, the capacity degradation in the victim cell due to interference for the downlink and the uplink are investigated in accordance with changing the values of ACIR.

The required ACIR derived from the simulation result for the target degradation criteria is used to estimate the appropriate guard band, by consideration of the defined spectrum mask (WiMAX Forum, or ETSI) to calculate an ACLR value and with the assumption of a fixed ACS value in the MS of 31dB at any frequency point. In uplink, generally, ACS of BS is much more stringent than the ACLR of the MS, so MS ACLR becomes dominant in UL interference. The spectrum mask specifications used for the analysis are explained in ANNEX A.

The relative cell layouts between the two systems for the interference analysis are classified into three cases based on the distance between BS of victim system and BS of interferer system as follows:

- Collocation case (Figure 4): Two BSs are collocated. The sector antenna directions of two systems are same.
- Middle case (Figure 5) BS of interferer system is located at the middle of BS victim system between the center and the cell edge. The sector antenna directions of two systems are configured differently on the downlink SLS and uplink SLS. In the downlink SLS, the sector antenna direction of the interferer system in sector 0 faces to that of victim system in sector 0 like Figure 5(a). In the uplink SLS, the direction of the interferer system is the same as the direction of the victim system like Figure 5(b).
- Edge case (Figure 6): BS of interferer system is located at the cell edge of victim the sector antenna direction of the interferer system in the sector 0 faces that of victim system in the sector 0.

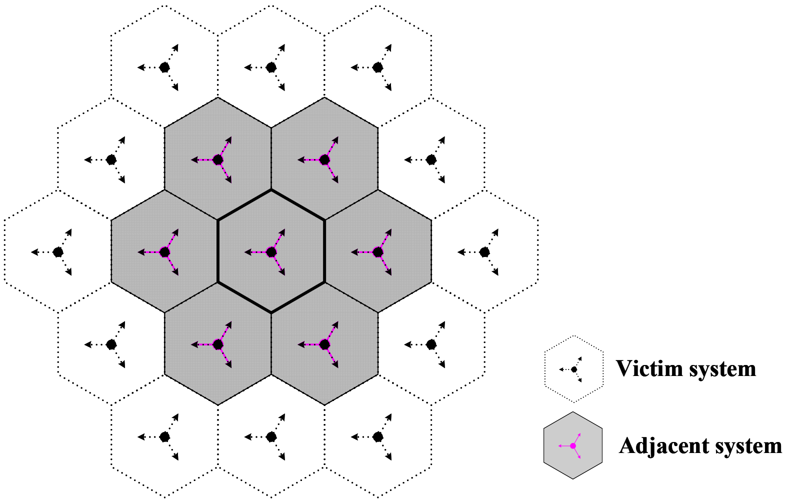
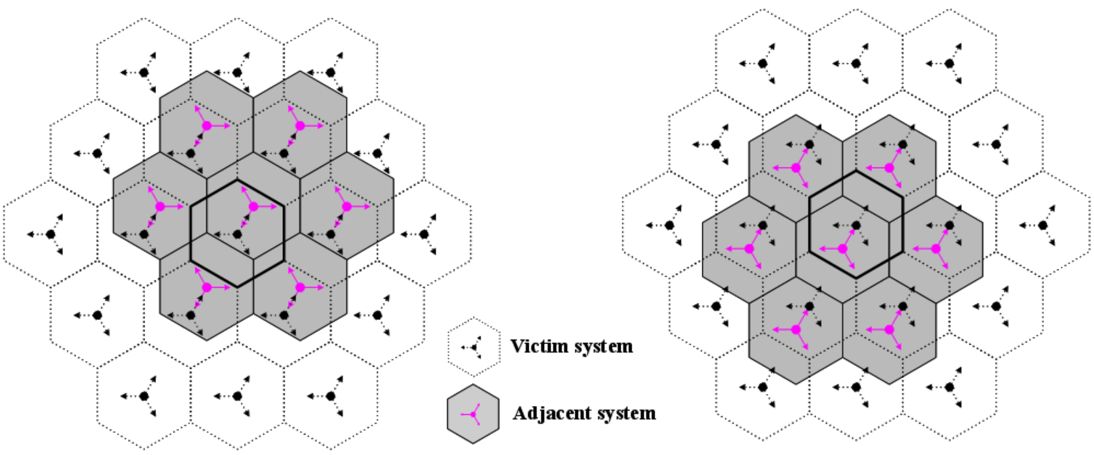


Figure 4. Victim system and interferer system in the collocation case



(a) Downlink (b) Uplink

Figure 5. Victim system and interferer system in the middle case

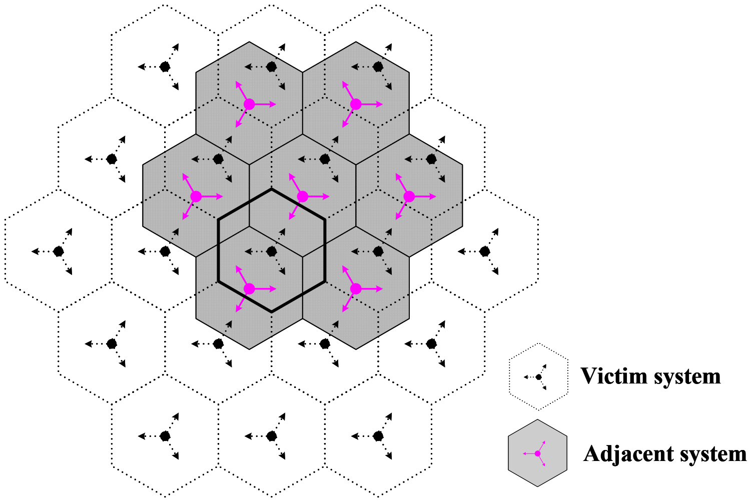


Figure 6. Victim system and interferer system in the edge case

The cell radius of interferer system and victim system are equal. The cell structures of downlink SLS the uplink SLS are implemented differently. In scenario 1(downlink case), the cell structure of interferer system is composed of 7 cells and one cell is surrounded by other six cells. Based on this cell structure, the simulation result is acquired by accumulating the values in only the sector 0 of cell 0.

In scenario 2(uplink case), the cell structure has two tiers by wrap-around process like the victim system. To obtain the system performance in the edge cells, the wrap-around process are considered. This process is that six clusters[2] are wrapped around the center cluster virtually like Figure 7. Then, MS locations of six clusters are the same as that of the center cluster. Accordingly, the system performance of the edge cells of the center cluster is calculated with MSs in cells of virtual cluster adjacent to cell as well.

[2] A cluster means the cell configuration which is composed of two tiers

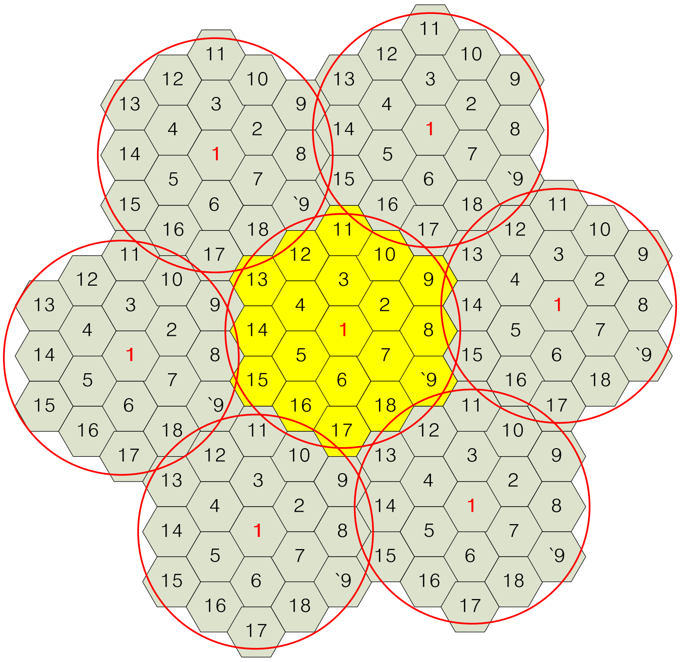


Figure 7. Wrap around cell type

The simulation result is acquired by accumulating the values in only the sector 0 of each cell.

3.3. Path loss model: COST231 HATA

The equation of COST231 HATA model is defined as (Eq 2)

$$L_{ch}[dB] = 46.3 + 33.9\log(f_c) - 13.82\log(h_b) + (44.9 - 6.55\log(h_b)\log(d) + a_m(h_s) + C_m \quad \text{(Eq 2)}$$

where C_m and a_m are defined below

$$C_m = \begin{cases} 0\,dB & \text{(for medium sized city and suburban centers with medium tree density)} \\ 3\,dB & \text{(for metropolitan centers)} \end{cases}$$

$$a_m(h_s) = (0.7 - 1.1\log(f_c))h_s + 1.56\log(f_c) - 0.8$$

Other parameters in (Eq 2) are defined in Table 4.

Table 4. Parameters for COST231 HATA model

Parameters	Definition	Unit	Range
L_{ch}	COST HATA model Propagation Loss	dB	
h_b	BS antenna height	m	30 ~ 200
h_s	MS antenna height	m	1 ~ 10
d	Distance	km	1 ~ 20
f_c	Carrier frequency[3]	MHz	1500 ~ 2000

3.4. Antenna modeling

The antenna model for BS has all the vertical and horizontal characteristics. The antenna pattern of the BS is the combination of vertical pattern and horizontal pattern which are designed with their antenna 3dB beamwidth based on the directional antenna pattern.
The equation for directional antenna pattern is below

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$$

(Eq 3)

Where the parameters in (Eq 3) are explained below:

- $-180 \le \theta \le 180$: Angle from the antenna pointing direction
- θ_{3dB}: 3dB beam width
- A_m: Maximum attenuation

[3] There is the difference of the operating center frequency between the COST231 HATA and the simulation, but the effect of result due to this difference is very minor. In the evaluation methodology of WiMAX forum, COST231 HATA model is recommended as well **[6]**.

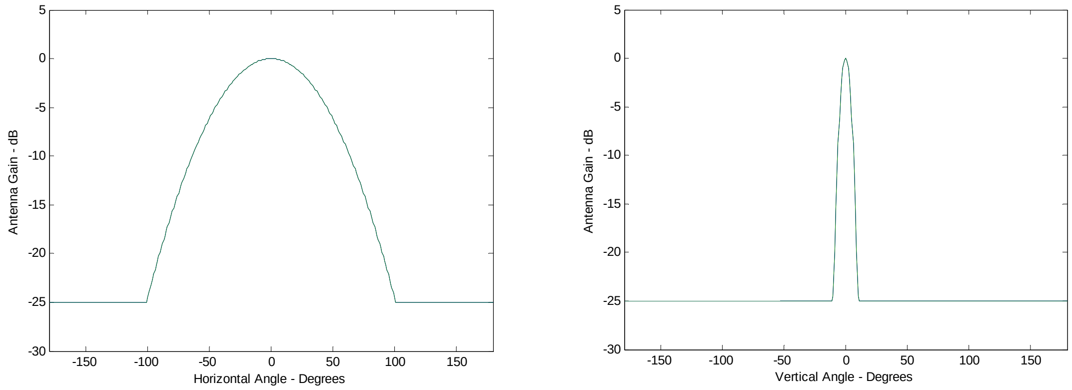


Figure 8. Horizontal (70º) & Vertical (7º) antenna pattern

3.5. Simulation procedure

For each ACIR assumption the following procedures are followed for each scenario.

The Scenario 1 (Downlink) SLS is performed with the following procedure described in the flow chart in Figure 9.

A. Parameter set up:

  i. Parameters for Cell radius, RF configuration (Tx power, antenna, path loss model, shadowing, penetration loss, channel model) are set up.

B. BS Location:

  i. Cell layout configures 19 cells of 2 tiers as the ideal type. Each cell is composed of 3 sectors. Operating frequency is assigned into each sector according to FRP.

C. MS distribution:

  i. The MSs are randomly placed with uniform distribution over the whole cell for every an iteration.

  ii. The necessary parameters are calculated between the BS in all sectors and each MS such as path loss, shadowing, penetration loss, and antenna gain. The best server (sector) for each MS is determined with the long-term CINR derived from the calculated parameters.

D. CINR calculation:

i. Preamble CINR of each MS in every frame is calculated in fast fading environment.

ii. CINR of each MS data is calculated

E. Packet error decision:

i. Whether Packet error occurs or not is determined by comparing the calculated CINR with the result of each link level simulation.

F. Scheduling:

i. MCS level is selected from preamble CINR. According to the proportional fairness algorithm, the priority of MSs is updated and the slot for each MS is assigned.

G. Iteration:

i. An iteration process is followed such that a sufficient number of frames are considered to obtain the mean value of user performance.

ii. A second iteration process is followed such that user performance failures are considered appropriately to obtain the mean value of system performance.

H. Statistics collection:

i. For the performance statistics, only the results of a single set of MSs in the sector 0 of cell 0 are considered.

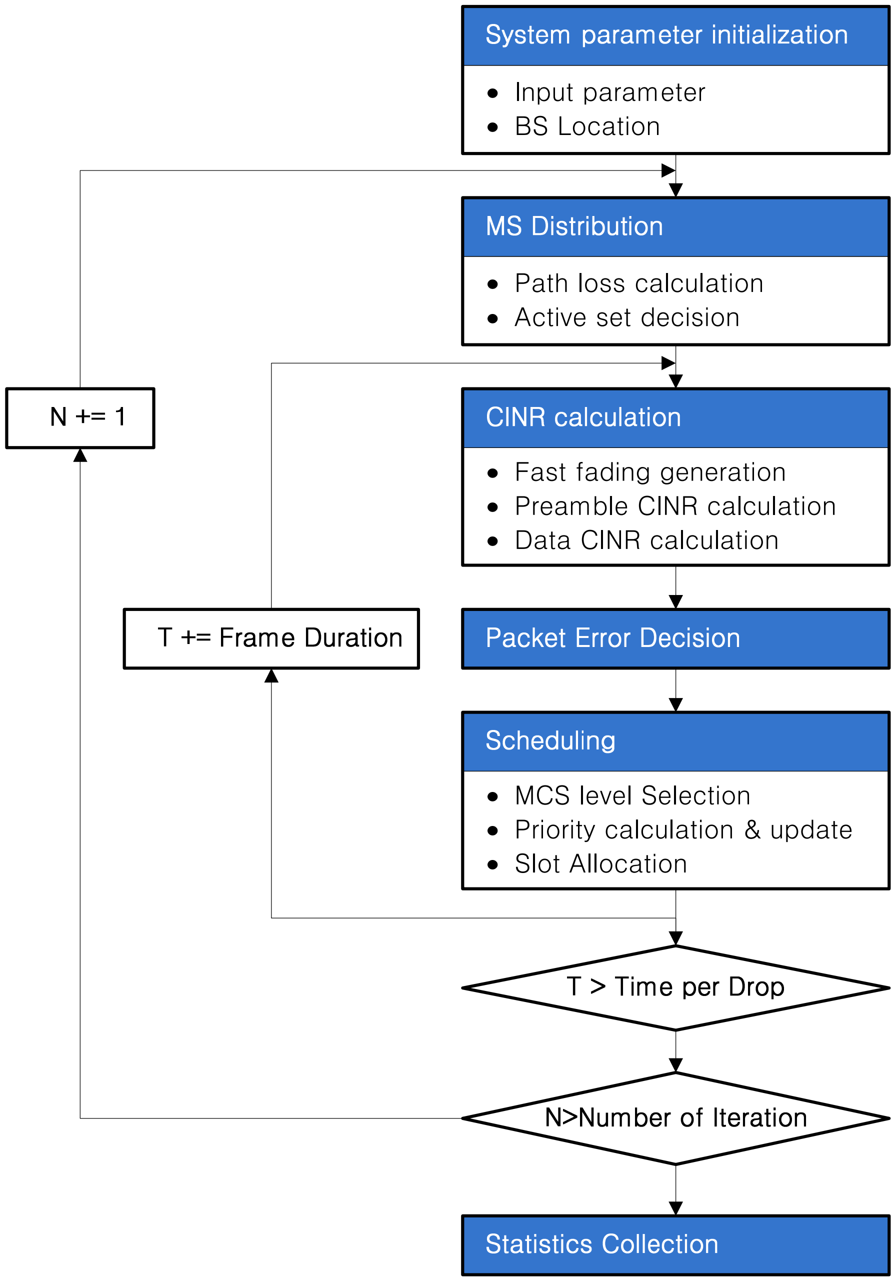


Figure 9. Scenario 1(Downlink) SLS Procedure

Scenario 2 (Uplink) SLS is based on Monte Carlo methodology. Power control is applied to each MS. The 6 clusters surround the center cluster using 19 cell wrap-around topology.

The Scenario 2 procedure for uplink SLS is following the procedure below and described in the flow chart in Figure 10:

A. Parameter set up:

   i. Cell radius, RF configuration (TX power, antenna, path loss model, shadowing, penetration loss, channel model)

B. BS location:

   i. The system is designed with 7 clusters in the wrap-around method. A cluster is composed of the center cell and 18 cells surrounding the center cell. Each cell is configured as a hexagonal type with the defined BS cell radius and is composed of 3 sectors

C. MS distribution:

   i. MSs uniformly drop into 57 sectors of 19 cells. MS of sectors belonging to the center cluster are chosen with a possible received signal path from all possible serving sectors. The received signal strength is calculated considering path loss, shadowing, penetration loss, and antenna gain. The sector with the best path between the MS and the BS becomes the serving sector for the MS. MS's continue to be randomly dropped into the sector and assessed as above until the number of MS's in one sector meets the required number of MS's per sector. Additionally, MS's that fall within 35m around sector antenna are re-dropped. Six wrapping clusters have the same MS location with the center cluster.

D. Scheduling:

   i. A scheduling function is run in every sector. Using the general proportional fairness algorithm **[6]**, normalized headroom and MS throughput are the factors for determining priority. After MCS level and code rate are determined by applying AMC (Adaptive Modulation and Coding), transmission format is defined by assigning the slot into the MS.

E. CINR calculation:

   i. CINR is calculated with intra system interference and inter system interference on the fading channel.

F. Packet error decision:

   i. Whether Packet error occurs or not is determined by comparing the calculated CINR with the result of each link level simulation.

G. Power control:

   i. Transmitter power of MS in next frame is determined based on the open loop power control method in 802.16e

H. Iteration:

   i. An iteration process is followed such that a sufficient number of frames are considered to obtain the mean value of user performance.

   ii. A second iteration process is followed such that user performance failures are considered appropriately to obtain the mean value of system performance..

I. Statistics Collection:

   i. Performance statistics are collected with the results of all MS's in sector 0 of all cells.

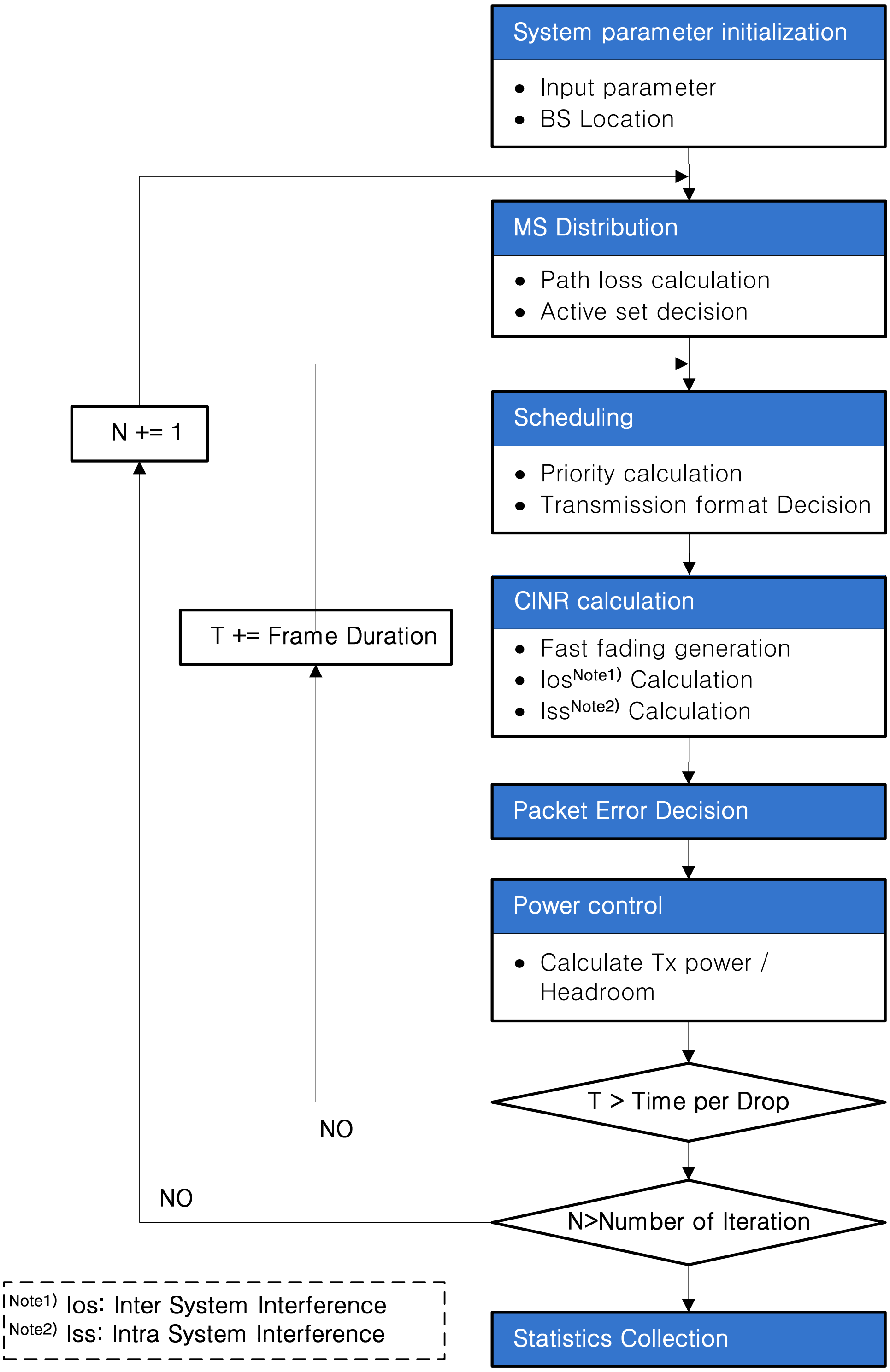


Figure 10. Scenario 2 (Uplink) SLS procedure

4. Simulation results & Analysis

4.1. Scenario 1(Downlink): BS to MS interference (DL to DL)

Figure 11 for FRP1 system and Figure 12 for FRP3 system show the simulation result of the downlink capacity degradation ratio in the victim cell due to the interference (BS to MS) from the adjacent channel in accordance with the variation of ACIR value.

In Figure 11 (FRP1 system), the middle case marked with a red line hits the highest capacity degradation ratio among the three cases. When the ACIR value in the middle case drops to 22dB, the capacity degradation is about 8%.

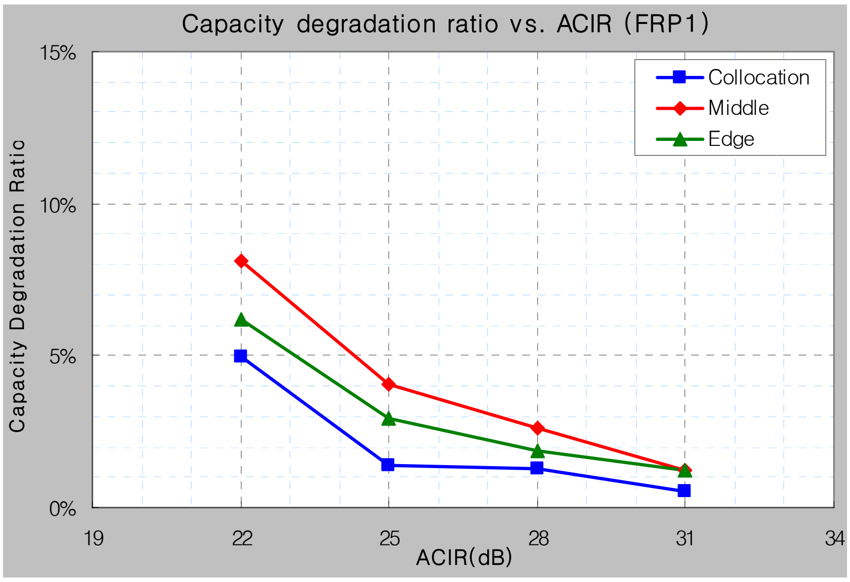


Figure 11. Downlink capacity degradation ratio vs. ACIR (FRP1)

In Figure 12 (FRP3 system), the collocation case shows the highest capacity degradation ratio. When the ACIR value in the collocation case is 22dB, about 6.3% capacity degradation results.

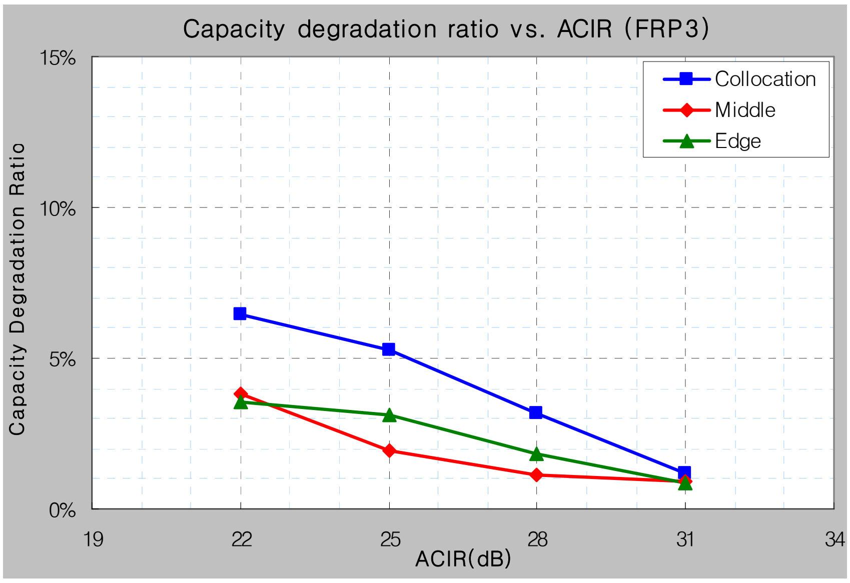


Figure 12. Downlink capacity degradation ratio vs. ACIR (FRP3)

In the middle case and the edge case, the capacity degradation ratio of the FRP3 system is less than that of the FRP1 system. This is because the number of sectors in the adjacent channel causing dominant interference decreases from three sectors (in FRP1) to one sector (in FRP3).

In the collocation case, the FRP3 system shows higher capacity degradation ratio than the FRP1system. The reason is that the FRP3 system causes less intra system interference than the FRP1 system. In other words, the FRP3 system capacity degradation is more affected by adjacent inter-system interference than the FRP1 system, where intra-system interference is dominant Therefore, the required ACIR should be over 28.5dB to meet less than 3% capacity degradation ratio.

In FRP1 system, the required ACIR should be over 27.5dB to meet less than 3% capacity degradation ratio. The required ACIR for the downlink capacity loss is summarised in Table 5.

Table 5. Required ACIR for downlink capacity loss

Frequency reuse pattern	Capacity loss		
	3%	5%	10%
FRP1	27.5 dB	24.5 dB	< 22 dB
FRP3	28.5 dB	25.5 dB	< 22 dB

4.2. Relating ACIR to Guard Frequency

The ACIR between two systems can be increased by inserting frequency separation between the aggressor transmitter and the victim receiver as the relative overlap between the transmitter out of band emissions and the receiver adjacent channel performance are varied. The frequency separation can be identified as a guard frequency which maybe set by consideration of the transmitter emission mask characteristics.

From the simulation ACIR result, the implied guard band can be estimated by considering published ETSI or WiMAX spectrum masks. Spectrum masks used for the analysis are referred to ETSI EN302 326, ETSI EN302 544, and the WiMAX Forum. These masks are explained in ANNEX A. The relation of the implied guard band and the capacity degradation ratio is based on the defined spectrum mask. In detail, since ACIR at the given frequency offset from channel edge is derived from the defined spectrum mask, the implied guard band corresponding to ACIR is equal to the frequency offset. With the consideration of the spectrum masks, Table 6 shows the capacity degradation ratio without guard band in the worst case of FRP1 and FRP3. Based on the spectrum masks of ETSI EN 302 544 or the WiMAX Forum, the capacity degradation is not critical. On the other hand, applying the less stringent spectrum mask defined by ETSI EN 302 326 compared with the above two spectrum masks, the decrease in capacity is about 8% in FRP1 system. .

Table 6. Capacity degradation ratio without guard band

Frequency reuse pattern / Defined Spectrum mask	FRP1	FRP3
	Middle case	Collocation case
ETSI EN302 326 Mask	8.1 %	6.5 %
ETSI EN302 544 Mask	< 2%	< 2%
WiMAX Forum Mask	< 2%	< 2%

The implied guard band is dependent on ACLR estimated from the BS transmitter spectrum mask in the adjacent channel. The results are described in Table 7 for the FRP1 systems and Table 8 for the FRP3 system. These results show the guard bands to meet the capacity degradation ratios such as 3%, 5%, and 10% in each spectrum mask. The SLS results indicate that the capacity loss is <3% when the required ACIR is 27.5dB for FRP1 and 28.5dB for FRP3. When the MS ACS is 31dB, the resultant ACLR becomes 30.1dB for FRP1 and 32.1dB for FRP3.

When the ETSI EN 302.236 spectrum mask is assumed, the guard band for 3% capacity loss should be 1MHz both in FRP1 and FRP3. In the case of the ETSI EN302.544 or the WiMAX Forum spectrum mask, the guard band can be reduced to zero.

Table 7. Implied guard band for specific capacity loss (FRP1)

Capacity loss		3%	5%	10%
Required ACIR (dB)		27.5 dB (ACLR 30.1)	24.5 dB (ACLR 25.6)	< 22dB
Implied guard band	ETSI EN302 326 Mask	1 MHz	0.5 MHz	0 MHz
	ETSI EN302 544 Mask	0 MHz	0 MHz	0 MHz
	WiMAX Forum Mask	0 MHz	0 MHz	0 MHz

Table 8. Implied guard band for specific capacity loss (FRP3)

Capacity loss		3%	5%	10%
Required ACIR (dB)		28.5 dB (ACLR 32.1)	25.5 dB (ACLR 27.0)	< 22dB
Implied guard band	ETSI EN302 326 Mask	1 MHz	0.5 MHz	0 MHz
	ETSI EN302 544 Mask	0 MHz	0 MHz	0 MHz
	WiMAX Forum Mask	0 MHz	0 MHz	0 MHz

4.3. Scenario 2 (Uplink): MS to BS interference (UL to UL)

Figure 13 for FRP1 system and Figure 14 for FRP3 system show the simulation results of the uplink capacity degradation ratio in the victim cell due to the interference (MS to BS) from the adjacent channel in accordance with the variation of ACIR value..

The capacity degradation ratios are simulated for three distance cases and two frequency reuse pattern. The capacity loss is the largest in the edge cases in FRP1 and FRP3. In the FRP1 system, ACIR should be 28.5dB to meet 3% capacity loss and 25.5dB for 5% capacity loss. In the FRP3 system, ACIR should be 24.5dB to meet 3% capacity loss.

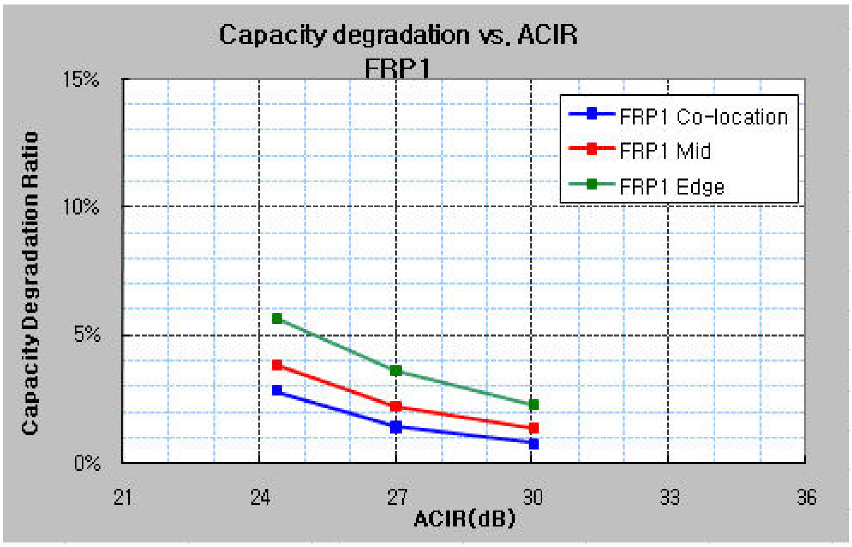


Figure 13. Uplink capacity degradation ratio vs. ACIR in FRP1

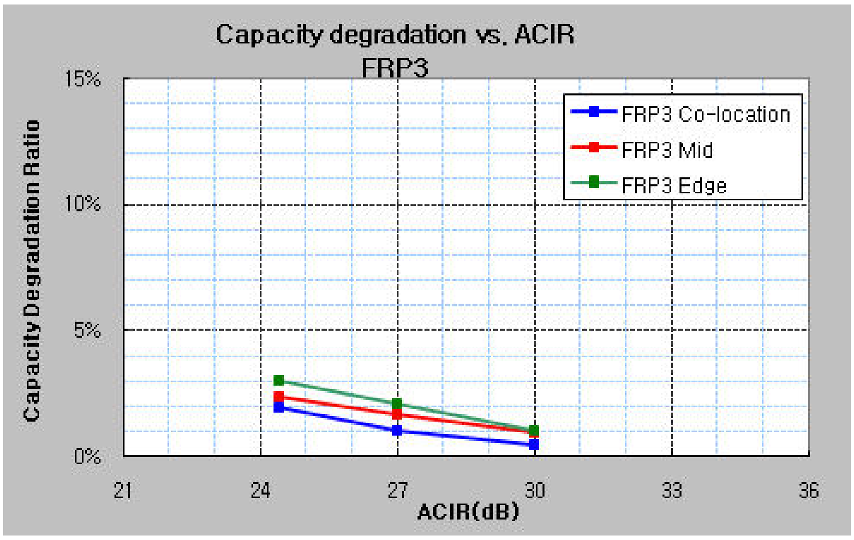


Figure 14. Uplink capacity degradation ratio vs. ACIR in FRP3

When the capacity degradation ratios are 3%, 5%, and 10%, the required ACIR is summarized at Table 9. The capacity loss of the FRP1 system is larger than that of the FRP3 system in all cases. Although thermal noise gives more influence to the FRP3 system than to the FRP1 system, the adjacent interference is relatively smaller to the FRP3 system than to the FRP1 system unlike the downlink case. This is because the FRP1 system has a greater number of MS's using higher TX power which dominantly interferes with the BS victim system compared with FRP3.

Table 9. Required ACIR for uplink capacity loss

Frequency reuse pattern	Capacity loss		
	3%	5%	10%
FRP1	28.5 dB	25.5 dB	< 24.4 dB
FRP3	24.5 dB	< 24.4 dB	< 24.4 dB

4.4. Relating ACIR to Guard Frequency

For the MS analysis only the spectrum mask that is used for WiMAX Forum certification ("WiMAX Forum Certification Mask") is considered. Uplink capacity degradation ratio without guard band is 5.6% for FRP1 and 3% for FRP 3 based on the WiMAX Forum Certification Mask.

Table 10. Uplink capacity loss without guard band

Defined spectrum mask	FRP1	FRP3
WiMAX Forum Certification Mask	5.6 %	3.0 %

However, ACIR can be increased by adding frequency separation between the adjacent operating frequencies in different networks, introducing a small guard band. The size of this can be related to the emission mask so that a guard band can be implied from the target ACIR.

The implied guard bands for specific capacity loss figures drawn from the simulation results are detailed in Table 11.The implied guard band for the FRP1 system should be 1MHz for 3% capacity loss and 0.5MHz for 5% capacity loss. In FRP3, the implied guard band is only 0.5MHz for 3% capacity loss. In this analysis, 0.5MHz unit is assumed for guard band assignment.

Table 11. Implied guard band against capacity loss

Capacity loss		3%	5%	10%
FRP1	Required ACIR (dB)	28.5 dB	25.5 dB	< 24.4 dB
	Implied guard band based on the WiMAX Forum Certification Mask	1 MHz	0.5 MHz	0 MHz
FRP3	Required ACIR (dB)	24.5 dB	< 24.4 dB	< 24.4 dB
	Implied guard band based on the WiMAX Forum Certification Mask	0.5 MHz	0 MHz	0 MHz

5. Simulation Outcome

The simulation result implies that TDD-TDD interference is negligible in downlink case, and minor in uplink case. On the worst estimation basis, the guard band is required to be about 1MHz in order to maintain capacity loss less than 3% in synchronized TDD case. However, it is noted that a trade-off between guard band and implementation burden needs to be considered in order to manage a certain level of capacity degradation. In addition there is another trade off between the introduction of guard bands and the overall impact on the spectrum utility of a spectrum block assigned to an operator.

6. Conclusions

The study results show that for synchronized TDD systems assigned spectrum in adjacent blocks the guard frequency requirements are minimal based on adjacent channel performance estimated from the emission masks considered and assuming the same adjacent cell characteristics.

However it must be noted that in most cases the emission mask specifications for BS and MS are supplemented by ACLR requirements that tend to be more stringent than the estimates based upon the emission masks:

Table 12. Specific BS ACLR Requirement

Standard	Estimated ACLR (dB)	Specific ACLR Requirement (dB)
EN 302 544-1	39.1	45

Table 13. Specific MS ACLR Requirement

Standard	Estimated ACLR (dB)	Specific ACLR Requirement (dB)
WiMAX Forum MS	24.4	30[4]

Therefore based upon the most likely emission mask specifications and the ACLR requirements it can be concluded that in fact the zero guard band scenario can prevail and that this situation may still include additional margins.

The results are based upon a simulation carried out at 2300 MHz but can be readily applicable to the 2.6GHz band since the effect of such a small shift in frequency is negligible and the system parameter values are unchanged.

[4] ITU-R Recommendation M.1581-2; Annex 6

ANNEX A. Spectrum Mask Specifications

A.1. BS transmitter spectrum mask

The following emission masks were assumed or the purposes of this study. At the time of simulation, the ETSI specifications applicable to the mobile WiMAX BS and MS masks for the 2300-2400 MHz band remained under development but are expected to largely follow those in the close-by 2.6GHz band. Therefore the EN 302 544-1 mask was considered a good candidate for the studies along with the WiMAX Forum mask identified for the 2300-2400MHz band[5] . It should be pointed out that the mask from EN 302 326 is not specifically designed for mobile WiMAX systems but provides a good example of a less stringent mask.

A.1.1. WiMAX Forum (ITU-R M.1580-2 Annex 6 update)

The spectrum emission mask of base stations applies to frequency offsets between 2.5 MHz and 12.5 MHz away from the base station centre frequency for the 5 MHz carrier and between 5 MHz and 25 MHz away from the base station centre frequency for the 10 MHz carrier. Δf is defined as the frequency offset in MHz from the channel centre frequency.

Table A-1. Spectrum emission mask for 5 MHz carrier

Frequency offset from centre	Allowed emission level	Measurement bandwidth
$2.5 \leq \Delta f < 3.5$ MHz	−13 dBm	50 kHz
$3.5 \leq \Delta f < 12.5$ MHz	−13 dBm	1 MHz

[5] The WiMAX Forum has contributed emission masks to the development of ITU-R Recommendations M.1580-2 and M.1581-2. These updates are currently (July 2009) undergoing approval by correspondence through ITU-R Administrative Circular Letter 279 [2].

Table A-2. Spectrum emission mask for 10 MHz carrier

Frequency offset from centre	Allowed emission level	Measurement bandwidth
$5 \le \Delta f < 6$ MHz	−13 dBm	100 kHz
$6 \le \Delta f < 25$ MHz	−13 dBm	1 MHz

Therefore, the spectrum mask based on TX power 43dBm is illustrated at Figure A-1. Then, the resolution bandwidth is 1MHz.

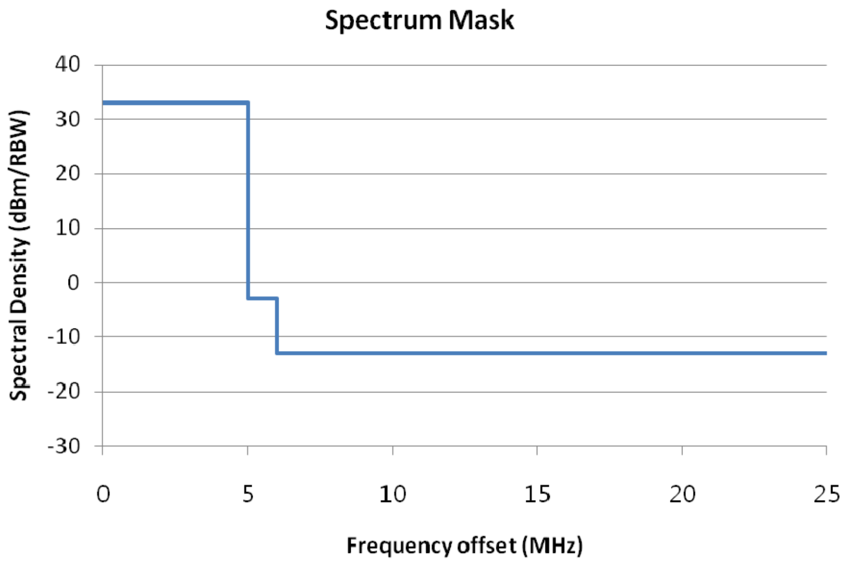


Figure A-1. BS Spectrum mask by WiMAX Forum

A.1.2. ETSI EN 302 326

Transmitter spectrum mask depends on the equipment classification in ETSI EN 302 326.**[3]** The standards of the equipment classification are primary equipment type (Eqc-PET), equipment modulation order, secondary equipment type (Eqc-SET), and frequency range (Eqc-FR).

Eqc-PET value is defined according to the access methods as Table A-3. Eqc-EMO value is related of the modulation order which is expressed as Log_2(number of discrete states which may be assigned to each symbol). Therefore, 4-state modulation, 16-state modulation, and 64-state modulation become EMO 2, EMO 4, and EMO 6, respectively.

Table A-3. Historic meanings of Primary and Secondary Equipment Type

Primary Equipment Types	Historic Meaning (Access Method)	Secondary Equipment Type	Historic Meaning
T	TDMA	HC	High compatibility
		LC	Lower complexity System Type C, only applicable for FR 3GHz to 11 GHz
		QP	QPSK, only applicable for FR below 1GHz
		GM	GMSK, only applicable for FR below 1GHz
		DQ	DQPSK, only applicable for FR below 1GHz
		Null	No special attributes
F	FDMA	FA	Type A
		FB	Type B
D	DS-CDMA	OR	Orthogonal coding
		PR	Pseudo random coding
O	TDMA/OFDMA	DM	OFDM
		MA	OFDMA
H	FH-CDMA	Non applicable	
M	MC-TDMA	Non applicable	

Eqc-PET becomes 'O' in WiMAX systems, then, the point of the spectrum mask according to Eqc-EMO is presented at Table A-4.

Table A-4. Point of the spectrum mask

Eqc-EMO	F/ChS						
	0	0.5	0.5	0.71	1.06	2	2.5
2	0dB	0dB	-8dB	-25dB	-27dB	-50dB	-50dB
4	0dB	0dB	-8dB	-27dB	-32dB	-50dB	-50dB
6	0dB	0dB	-8dB	-32dB	-38dB	-50dB	-50dB

Based on Table A-4, the spectrum mask for EMO6 and 43dBm tx power is illustrated as Figure A-2.

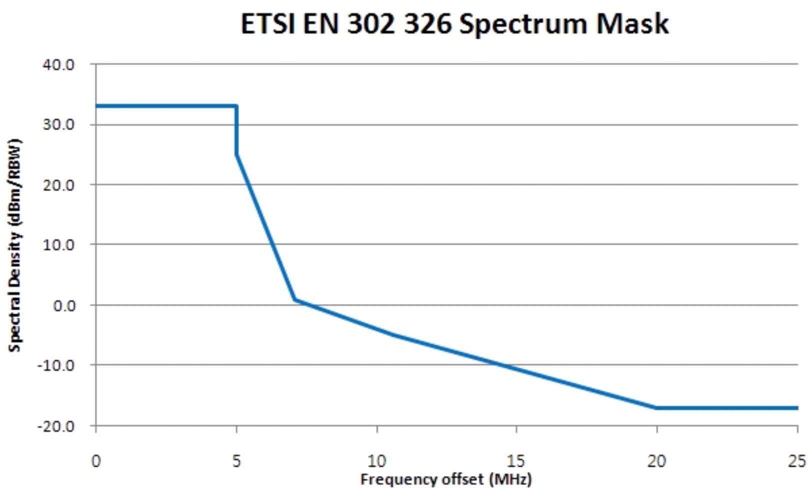


Figure A-2. BS Spectrum mask by ETSI EN 302 326

A.1.3. ETSI EN 302 544-1

Spectrum emission mask reflects the condition of out-of-band emission in transmitter. The modulation procedure and the nonlinearity of transmitter cause out-of-band emission. In ETSI EN 302 544-1 **[4]**, spectrum emission mask is dependent on the bandwidth. The value of spectrum emission mask is defined from 0.015MHz to 20MHz of edge. Tx power is 43dBm. f_{offset} is the frequency offset from edge. Requirement for spectrum emission mask is described at Table A-5.

Table A-5. Requirements for spectrum emission mask value, P ≥ 43 dBm

Frequency offset from channel edge of the measurement filter centre frequency, f_{offset} (MHz)	Maximum level (dBm)	Measurement bandwidth
$0.015 \leq f_{offset} < 0.43$	-15.5	30 kHz
$0.43 \leq f_{offset} < 2.03$	$-15.5-7.5(f_{offset} -0.43)$	30 kHz
$2.03 \leq f_{offset} < 3.0$	-27.5	30 kHz
$3.0 \leq f_{offset} < 11.0$	-14.5	1MHz, by aggregation of 30kHz measurements
$11.0 \leq f_{offset} < 20.0$	-14.5	1MHz, by aggregation of 30kHz measurements

Based on Table A-5, the spectrum emission mask is illustrated at Figure A-3

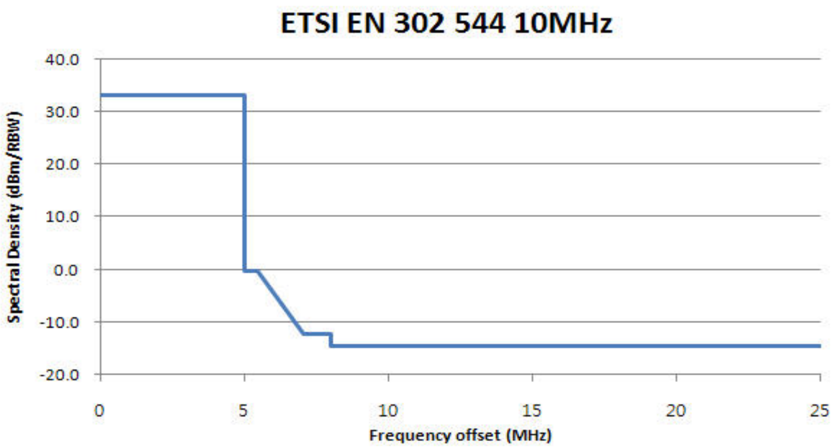


Figure A-3. BS Spectrum emission mask by ETSI EN 302 544-1

A.1.4. ACLR Estimation

For each of the three masks considered above, the adjacent channel (i.e. zero guard band) ACLR can be estimated with the following results in Table A-6:

Table A-6. ACLR Estimation

Mask	ACLR – Zero Guard Band (dB)
ETSI EN302 326 Mask	22.1
ETSI EN302 544-1 Mask	39.1
WiMAX Forum Mask	43.7

A.2. Mobile station

A.2.1. WiMAX Forum

Spectrum mask by WiMAX Forum is designed by considering the minimum requirement which satisfies most regulation conditions in WiMAX market **[5]**. Channel mask for 10MHz bandwidth in 2.3GHz~2.4GHz is described at Table A-7. Δf is the frequency offset from channel centre. The spurious emission requirement is defined for the protection over 25MHz

Table A-7. Channel Mask

Segment number	Offset from channel centre (MHz)	Integration bandwidth (kHz)	Allowable Emission level as measured at the antenna port (dBm/Integration Bandwidth)
1	5 to <6	100	-13
2	6 to <10	1000	-13
3	10 to <11	1000	-13-12*(Δf-10)
4	11 to <15	1000	-25
5	15 to <20	1000	-25
6	20 ~ 25	1000	-25

Therefore, based on Table A-7, the channel mask with 23dBm Tx power and 1MHz resolution bandwidth is illustrated as Figure A-4.

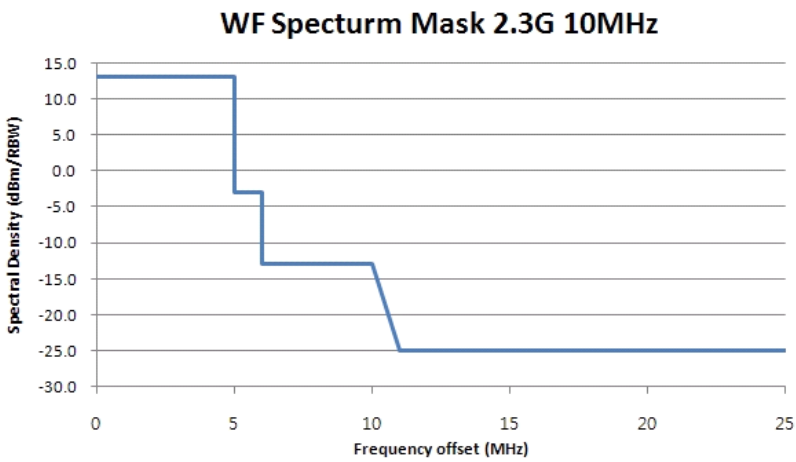


Figure A-4. MS Spectrum mask by WiMAX Forum

A.2.2. ACLR Estimation

For the mask considered above, the adjacent channel (i.e. zero guard band) ACLR can be estimated with the following result in Table A-8:

Table A-8. ACLR Estimation

Mask	ACLR–Zero Guard Band
WiMAX Forum	24.4dB

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