Managing TDD-FDD Interference between Co-Sited Base Stations deployed in Adjacent Frequency Blocks

3rd November 2009

Executive Summary

The frequency assignments for broadband wireless applications within the 2500MHz~2690MHz range are being prepared for auction in many countries around the world. Regulators[1] and potential service providers are interested in minimizing inter-network interference challenges and one critical issue is the possibility for interference between TDD systems and FDD systems operating in adjacent spectrum blocks in the same geographical area. This paper provides guidance to supplement the regulations to assist potential service providers for the frequency usage of FDD/TDD applications in a common co-siting deployment scenario.

Adjacent TDD systems can be synchronized to reduce the impact of inter-network interference and this is reported in detail in a companion WiMAX Forum® white paper[2]. However this is not the case for mixed systems in adjacent spectrum blocks.

The interference cases between a TDD system and a FDD system consist of 4 scenarios according to the signal path between two systems summarised below;

1) Scenario 1:
   - DL→DL: BS of the adjacent system interferes with MS of the target system
2) Scenario 2:
   - UL→DL: MS of the adjacent system interferes with MS of the target system
3) Scenario 3:
   - DL→UL: BS of the adjacent system interferes with BS of the target system
4) Scenario 4:

[1] For Example European Commission Decision 2008/477 contains a specific annex detailing the technical regulatory conditions for minimizing inter network interference.
[2] WiMAX Forum® White paper: "TDD-TDD Interference Analysis involving Synchronized WiMAX systems" – 18 September 2009. http://www.wimaxforum.org/sites/wimaxforum.org/files/WiMAX_TDD-TDD_%20Interference_analysis_090918_0.pdf

- UL→UL: MS of the adjacent system interferes with BS of the target system

Many studies already conclude that scenario 3 presents the worst case, having the possibility to impact an entire cell or sector with no temporal mitigation. In this paper, this scenario 3 (the interference between BS's of two systems) is analyzed, and then the interference isolation to secure a certain performance of the system is derived.

Finally, the results of an antenna measurement campaign are provided which can add useful additional inter-system isolation allowing closer coexistence between systems in adjacent blocks. In particular the site sharing case is considered.

The studies conclude that through application of the European regulatory block edge mask, the baseline out of block emission levels and readily achievable additional antenna isolation, systems in adjacent frequency blocks can successfully site share (co-located base stations) with a minimal capacity loss due to adjacent channel interference.

This work builds upon previous analysis carried out on behalf of the WiMAX Forum® by the independent analysts Roke Manor Research titled "Practical Compatibility and Coexistence Measures Analysis"[3] which summarized a number of studies carried out within the ITU-R and other bodies from a WiMAX technology perspective.

[3] Downloadable from: http://www.wimaxforum.org/resources/documents/marketing/whitepapers

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List of Abbreviations

ACLR	*Adjacent Channel Leakage Ratio*
ACS	*Adjacent Channel Sensitivity*
ACIR	*Adjacent Channel Interference Ratio*
AMC	*Adaptive Modulation and Coding*
BEM	*Block Edge Mask*
BER	*Bit Error Rate*
BS	*Base Station*
DL	*Downlink*
EIRP	*Effective Isotropic Radiated Power*
ETSI	*European Telecommunications Standards Institute*
FDD	*Frequency Division Duplex*
FFT	*Fast Fourier Transform*
FRP	*Frequency Reuse Pattern*
ITU	*International Telecommunication Union*
MCS	*Modulation and Coding Scheme*
MS	*Mobile Station*
NF	*Noise Figure*
NLOS	*Non-Line Of Sight*
OOBE	*Out Of Band Emission*
PUSC	*Partial Used Sub-Carrier*
TDD	*Time Division Duplex*
UL	*Uplink*

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] "EC Decision on the harmonization of the 2500-2690MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community", 2008/477/EC June 24th, 2008

[3] WiMAX Forum®, WiMAX System Evaluation Methodology Version 2.1, July 7, 2008

[4] "Practical Compatibility and Coexistence Measures Analysis"; Roke Manor Research; August 2008. WiMAX Forum sponsored research.

1. Introduction

In Europe, the CEPT band plan designated for UMTS from ECC Decision(05)05 divides the band into 2x70MHz blocks for FDD use with 120MHz duplex spacing and a single block of 50MHz for TDD use as illustrated in Figure 1(a). Additionally, the EC Decision 2008/477 [2] provides a more flexible framework for countries who wish to provide more TDD bandwidth in 2500- 2690MHz, taking into account of local circumstances, whilst maintaining the 120MHz FDD duplex spacing as shown in Figure 1(b).

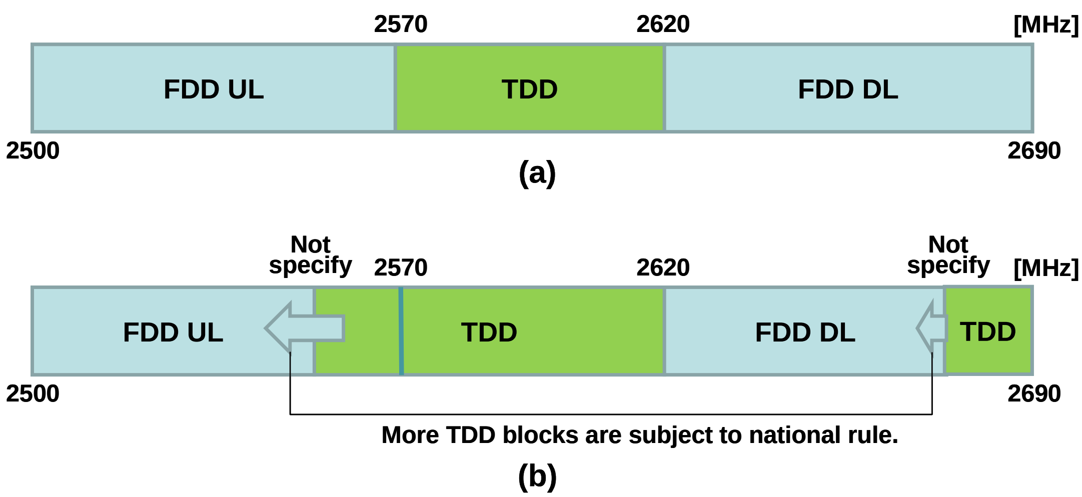

Figure 1. Frequency allocation for 2500-2690MHz

In either example, there is the potential for spectrum adjacencies between TDD systems and either FDD uplink or FDD downlink systems. To ensure the coexistence of TDD/FDD system in 2500~2690MHz, this paper considers the worst case interference scenario and investigates the acceptable ACI to meet a certain capacity degradation ratio. EC Decision 2008/477/EC [2] provides a technical annex detailing a BEM to limit out-of-block transmitter emissions into a neighbouring block. However the studies underpinning the derivation of this BEM are based upon a minimum BS to BS separation of 100m and an assumption that below this separation affected parties need to coordinate to avoid harmful interference.

In areas of dense deployment, suitable base station sites maybe limited, forcing competing service providers to share sites and co-locate. This can be attractive (or mandated) from the environmental aspect too.

This paper provides a method to mitigate interference in this situation based upon the derived acceptable ACI to build upon the technical licensing measures detailed in EC Decision 2008/477/EC [2].

2. Coexistence considerations between TDD and FDD systems

2.1. Interference scenarios between TDD and FDD systems

FDD and TDD indicate the duplex division method type for uplink and downlink. FDD is the duplex method to assign separate frequency bands for uplink transmission and for downlink transmission, thus FDD requires the paired band. A frequency separation between uplink and downlink transmissions is required due to the characteristic of FDD and known as 'Duplex spacing'. Generally, FDD downlink band is assigned as the upper band of the pair. TDD is the duplex method to assign alternate time slots for uplink and downlink transmission on the same frequency in an assigned band. This chapter defines the interference scenario for coexistence between FDD and TDD systems. When TDD and FDD systems are situated in the adjacent channel and in close proximity, four key interference scenarios can be identified.

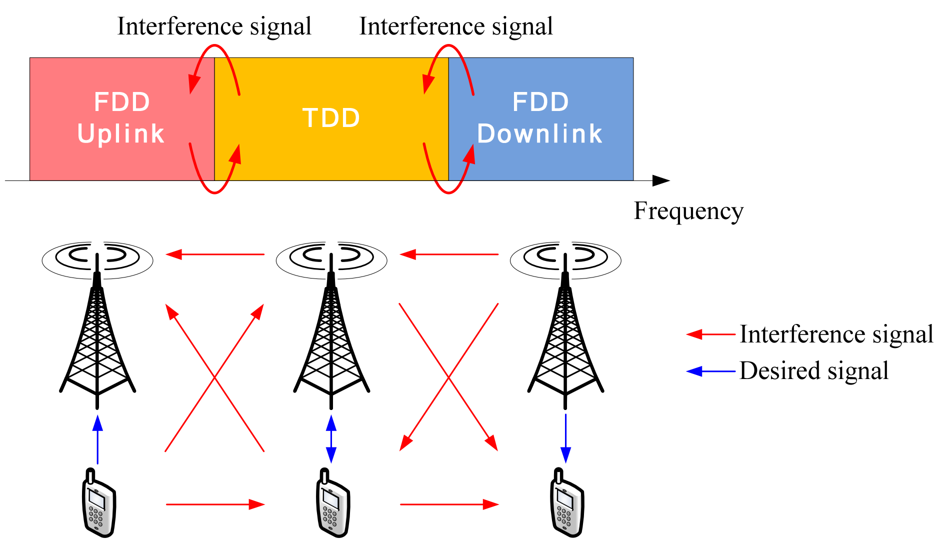

Figure 2. Interference paths between TDD and FDD systems

Figure 2 shows the band allocation and interference paths between TDD and FDD systems. Both edge channels of the TDD band can receive and create interference from the adjacent edge channel of the FDD uplink and downlink. In Figure 2, the red arrows indicate the interference signal and the blue arrows indicate the desired signal.

The four key interference scenarios between the TDD and FDD systems are identified in Table 1.

Table 1. Interference scenarios

Index	Interference Path	Scenario
1	BS to MS (DL → DL)	• BS of interferer system in adjacent channel to MS of victim system
2	MS to MS (UL → DL)	• MS of interferer system in adjacent channel to MS of victim system
3	**BS to BS (DL → UL)**	• **BS of interferer system in adjacent channel to BS of victim system**
4	MS to BS (UL → UL)	• MS of interferer system in adjacent channel to BS of victim system

The interference potential in each of the above scenarios depends upon the characteristics of BS and MS. In the first scenario, the effect of interference between interferer system and victim system is related with their respective locations. For example, if the BS of interferer system is located at cell edge of victim system, the MS at the cell edge can suffer significant interference from the BS of the interferer system. In the second scenario, when the MS in downlink is very close to the MS of interferer system in uplink, the MS of interferer system in uplink interferes with the MS of victim system. Because the transmitter power of the MS is smaller than that of the BS and the relative mobility of the MS can contribute to a transient nature to the interference, other studies have concluded that this interference level is negligible when considered across a network[4] . The worst case in these two scenarios occurs with a low probability.

On the other hand, the third and the fourth scenarios are more serious, because the BS or MS interferes with the fixed BS of the victim system with a relatively constant level. In this regard, the third scenario is the most severe. The reason is that BS's are generally located in high positions for coverage, leading to a high probability that the propagation loss between BS of victim system and BS of interferer system is low.

Therefore, **scenario 3 as the worst case** of four interference scenarios is analyzed in this paper.

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[4] ITU-R Report M.2113 or ECC Report 119

However, considering that a fixed MS of the interferer system uses an outdoor directional antenna, the location of the MS may be a critical factor in scenario 4 like the case of BS to BS.

2.2. Factors Affecting Interference

- ❑ Out of Block Emission

Out of block emission (OOBE) is the emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emission.

- ❑ Receiver selectivity

Receiver selectivity indicates the ability of receiver to not reject unwanted signals in adjacent channels. Ideally, the receiver filter passes just the signal in band but practical implementations preclude this. Receiver selectivity indicates the degree of attenuation of the signal 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 co-channel to the attenuation of the receiver filter in the adjacent channel.

- ❑ Transmitter Adjacent Channel Emissions

Imperfections in system implementation lead to low level unwanted transmitter emissions that fall outside the desired channel. These emissions can appear to a receiver in the adjacent channels as an in-band signal and create interference that can affect the ability of the receiver to de-modulate the wanted signal. ACLR is the ratio of the transmitter wanted channel power level to the adjacent channel unwanted power level based on a common evaluation bandwidth.

- ❑ Adjacent channel interference ratio

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 (beamwidth, Front-back-ratio) are the important factors to determine the interference level in the adjacent channel.

For example, EIRP level according to antenna gain is directly related to the level of interference. It is possible to isolate between BS's of two systems by the vertical pattern of BS's antenna. As the directivity of antenna is larger, generally, the isolation between BS's of two systems is larger. Providing that the directional antenna is applied, the interference in the adjacent channel decreases by the horizontal and vertical pattern of the antenna.

- ❑ Base station / Subscriber station location

The separation from victim system's BS to interferer system's BS is a critical factor to decide the level of interference in the adjacent channel. Providing that MS is in moving, the location of MS from BS is not important.

- ❑ Frequency Re-Use Pattern (FRP)

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.

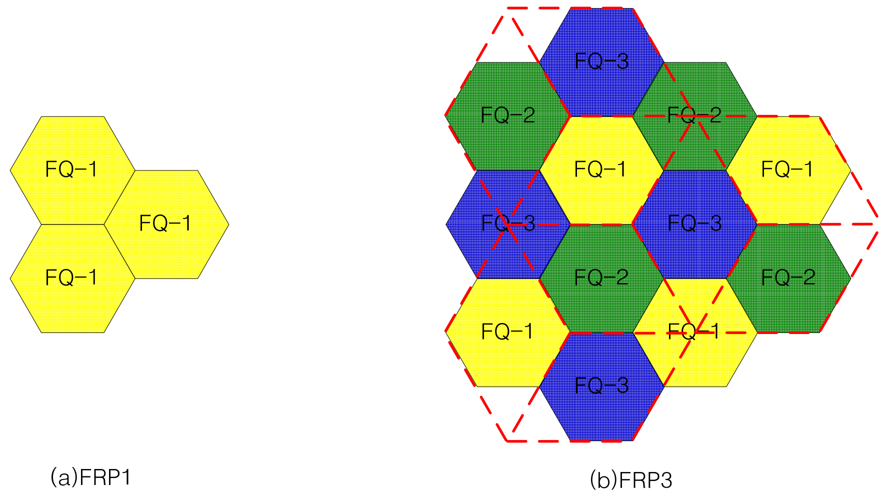


Figure 3. FRP1 and FRP3

2.3. Methods of mitigating interference for co-existence

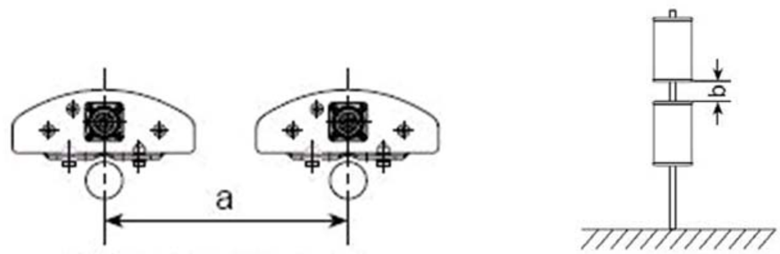
- Guard band and isolation improvement

One method to reduce the interference level between BS's in adjacent channels is to increase the frequency separation and assign a guard band between them.

Using the regulatory BEM in EC Decision 2008/477/EC [2] as an example, and assuming a system operating at the maximum EIRP (61dBm in a 5MHz channel corresponding to 54dBm/MHz), the implied ACLR in the adjacent channel (i.e.without a guard band - 1st ACLR) can be estimated to be 45.5dB, but the ACLR implied in the second adjacent channel (2nd ACLR) when the restricted channel effectively forms a 5MHz guard band, increases to 99dB. The difference between the two ACLR levels is 53.5dB which can be considered the isolation improvement obtained by inserting a 5MHz guard band in this case. The increased isolation through assignment of a guard band can be considered the interference mitigation.

- Site Design

The Antenna separation can be used to separate two BS antennas operating in adjacent channels, horizontally or vertically at site. The point is whether such antenna separation can provide useful additional isolation in addition to the isolation secured by a guard band. The installation for the antenna separation is illustrated as Figure 4. The detail information for the antenna separation is explained at Chapter 4.



(a) Horizontal separation (b) Vertical separation

Figure 4. Antenna separation

3. Simulation

A system level simulation (SLS) is used to evaluate the isolation required between two BS in adjacent systems for a given level of acceptable performance degradation. Based upon these results, this paper then proposes how antenna isolation can add additional mitigation. A measurement program was used to verify whether appropriate additional antenna isolation is achievable.

3.1. Simulation methodology

The simulation for the interference analysis has two steps:

First step is to characterise the uplink capacity loss as a result of increasing interference received at the victim BS from the adjacent channel through SLS. The inter-system interference received by the victim BS is assumed to be a constant power noise which adds to the UL thermal noise.

Second step is to determine the acceptable ACI level to secure a certain performance of the system and to calculate the additionally required isolation with the acceptable ACI level and out-of-band emission defined in EC regulation in 2008/477/EC.

RF characteristics and Antenna patterns are defined at Table 2.

Table 2. RF characteristics & Antenna pattern

Parameter	BS	MS
TX power	43dBm	23dBm
Antenna height	32m	1.5m
Antenna Gain	16dBi	0dBi
Cable loss	2dB	0dB
Antenna front-to-back ratio	25 dB	Omni
Antenna 3dB beamwidth	H: 70 º, V: 7 º	Omni
Noise Figure	5 dB	7dBm

The simulation parameters for system level simulation are drawn from [3] and summarized in Table 3.

Table 3. Simulation Parameters

Parameter	Value
Cell Layout	Ideal Hexagonal 2 tiers (19cell with 3sector)
BS to BS Distance	1000m
Bandwidth	10MHz (1024 FFT)
Center frequency	2600 MHz
Frequency Reuse Pattern	FRP1 / FRP3
MIMO	On
Log-normal shadowing	8.9dB
User mobility	Pedestrian B 3km/h : 60% Vehicular A 30km/h : 30% Vehicular A 120km/h : 10%
Propagation Environment for the BS-MS links	NLOS, Penetration Loss : 10dB

- ❑ Path loss model: COST231 HATA

The HATA model is used to model the BS to MS propagation

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 Cm and am 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[5]	MHz	1500 ~ 2000

- ❑ 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 on the basis of 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

[5] 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 [4].

- θ_{3dB}: 3dB beamwidth
- A_m: Maximum attenuation

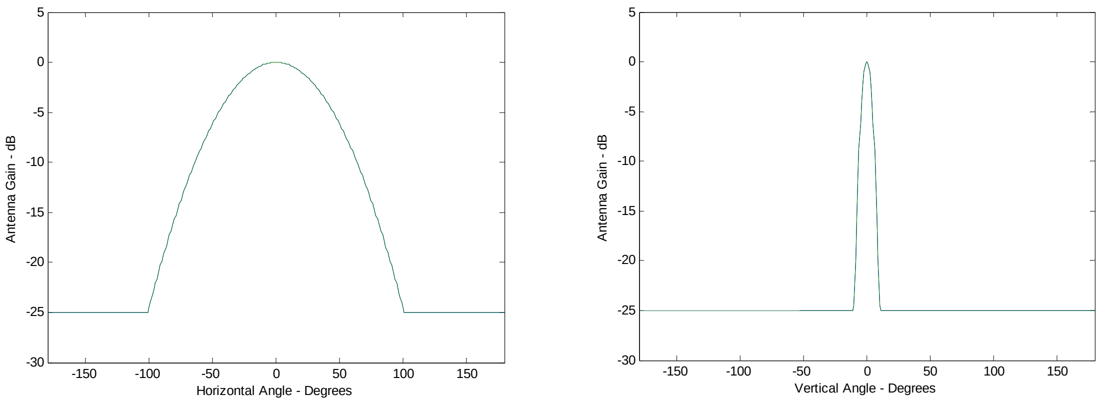


Figure 5. Horizontal(70º) & Vertical(7º) antenna pattern

❑ Simulation procedure

For obtaining the capacity degradation ratio according to the acceptable ACI, uplink system level simulation is based on Monte Carlo methodology. Power control of each MS is applied. Six clusters surround the center cluster using 19 cell wrap-around topology. To obtain the system performance in the edge cells, the wrap-around process are considered. This process is that six clusters[6] are wrapped around the center cluster virtually like Figure 6. 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 MS's in cells of the virtual cluster adjacent to the cell as well.

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

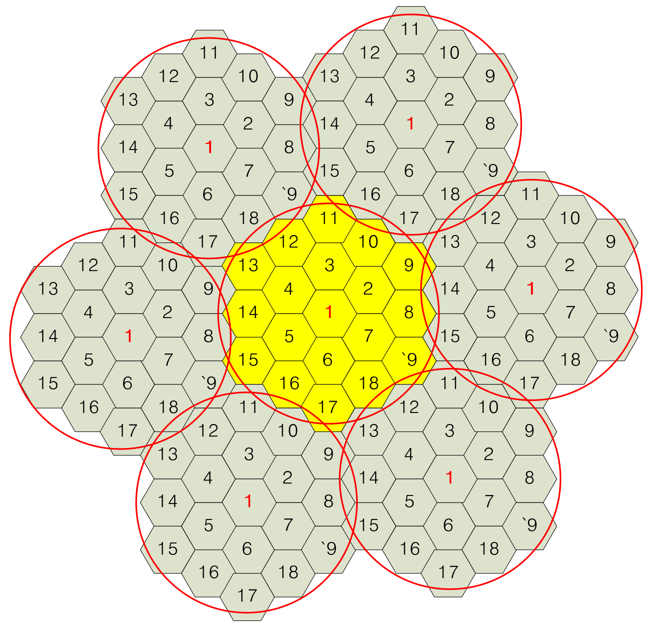


Figure 6. Wrap around cell type

The procedure of uplink system level simulation is following as

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. MS's are randomly dropped with uniform distribution 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 strengths are 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. The dropping MS's of six wrapping clusters complies with the same procedure with the center cluster.

D. Scheduling:

i. A scheduling function is run in every sector. Using the general proportional fairness algorithm, normalized headroom and MS throughput are the factors for determining priority. Afterwards the final MCS scheme is determined and the transmission format is defined.

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 a sufficient number of user performance measurements 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 all sectors of all cells.

The explained system level simulation procedure is expressed as flow chart like

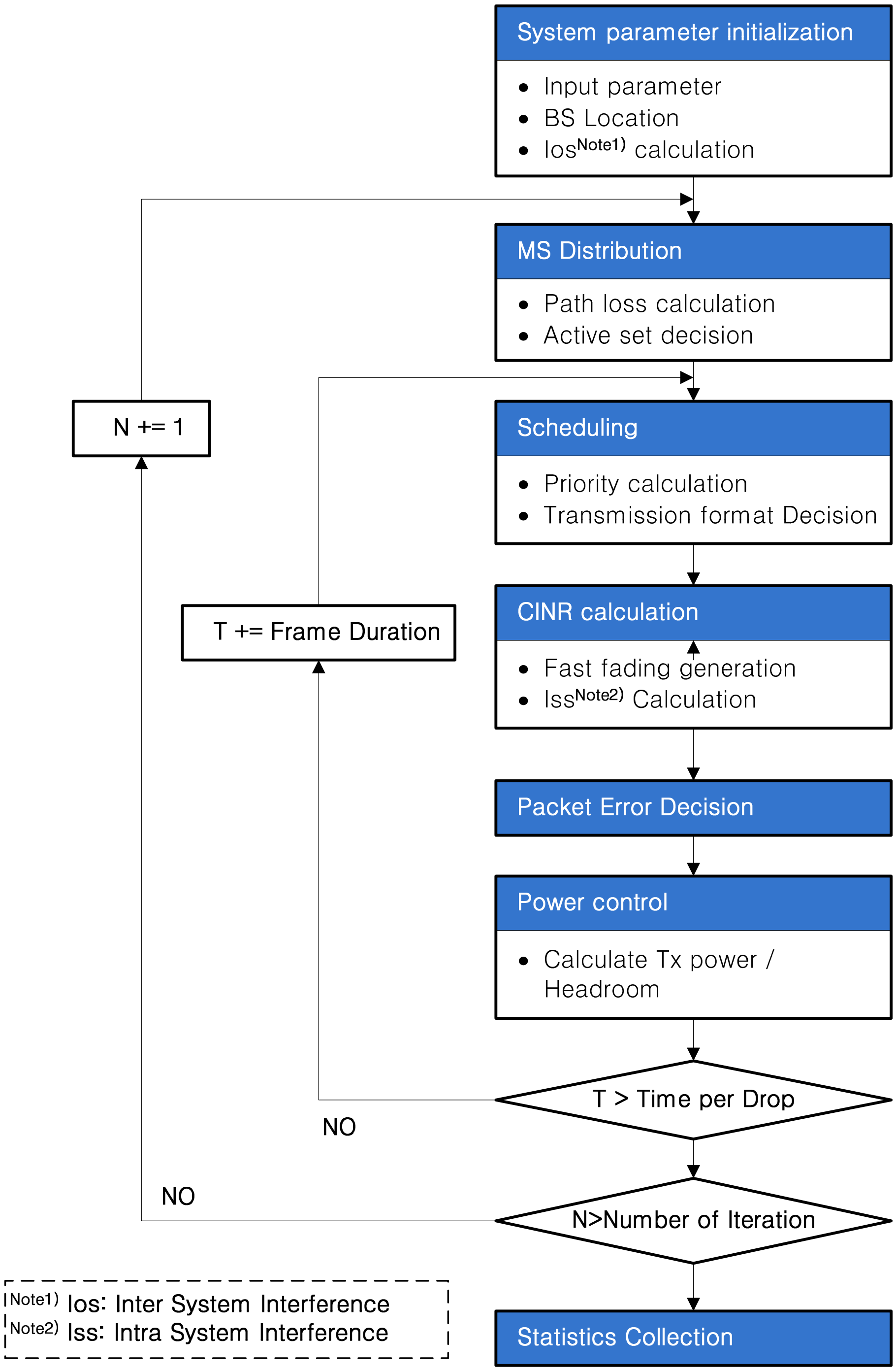


Figure 7. Uplink SLS procedure

3.2. Simulation Results & Analysis

3.2.1. Capacity Degradation and ACI

This chapter shows the capacity degradation ratio averaged across all sectors of all cells in uplink, according to interference from the adjacent channel through system level simulation. The simulation result is shown in Figure 8. The interference level to thermal noise ratio is denoted by I_{rx}/N_t with the assumption of -109dBm/MHz (including 5dB noise figure) as the value of N_t . The interference level, I_{rx}, becomes the multiplication of I_{rx}/N_t and N_t. The ACI to meet the certain capacity degradation can therefore be derived by using Figure 8 and the given N_t.

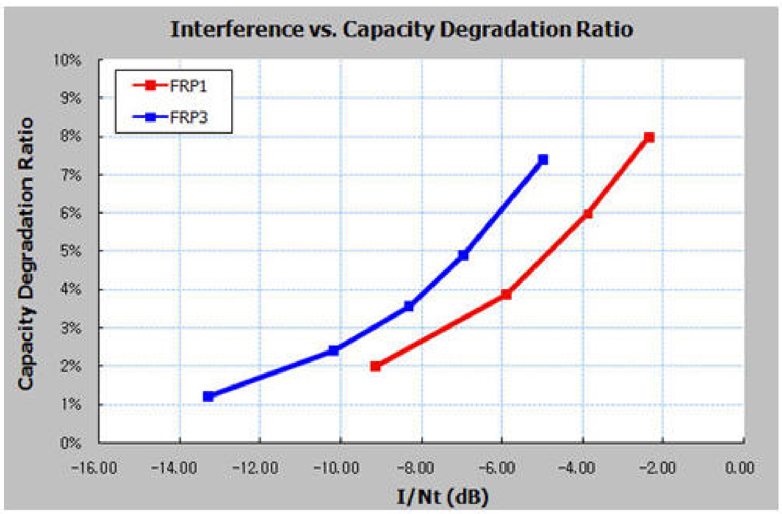


Figure 8. Uplink capacity degradation ratio vs. I_{rx}/N_t

The acceptable ACI levels for the given capacity degradations are summarized at Table 5. The first row in FRP1 case is I_{rx}/N_t for each given capacity degradation, which is drawn from Figure 8. The second row in FRP1 is the acceptable ACI level which is calculated with the drawn I_{rx}/N_t and the assumed Nt. The same method as FRP1 is used for filling the result of FRP3. As one of example, the acceptable interference level for 3% capacity degradation should be -116.4dBm/MHz in FRP1 and -118.2dBm/MHz in FRP3.

Table 5. Uplink capacity loss & Acceptable ACI level

Capacity degradation		2%	3%	5%
FRP1	I_{rx}/N_t	- 9.1dB	- 7.4dB	- 4.8dB
	Acceptable ACI level	-118.1 dBm/MHz	-116.4 dBm/MHz	-113.8 dBm/MHz
FRP3	I_{rx}/N_t	- 11.2dB	- 9.2dB	- 6.9dB
	Acceptable ACI level	-120.2 dBm/MHz	-118.2 dBm/MHz	-115.9 dBm/MHz

It is recognized that the acceptable ACI level in FRP3 is smaller than in FRP1. Because the thermal noise has greater influence on capacity degradation in FRP3 system than in FRP1 system, therefore the same interference from the adjacent channel in FRP3 system causes a larger capacity degradation than in the FRP1 system.

3.2.2. Deriving the Additional Isolation

In Table 6, the additional isolation is derived from:

a) the acceptable ACI level to meet 3% capacity degradation ratio from above result.
b) the OOBE levels derived from the EC Decision 2008/477/EC BEM which are represented in the second row of Table 6. Two guard band cases, 0MHz and 5MHz, are considered for the additional isolation. 1st ACLR is 45.58dB and 2nd ACLR is 99dB[7]. The difference between these two ACLRs is 53.42dB which is the isolation improvement obtained by inserting a 5MHz guard band and assuming the BEM characteristic.
c) the additional isolation is OOBE (the third row) minus the acceptable ACI (the fourth row).

[7] Based on maximum in band EIRP = 61dBm/5MHz.

Table 6. OOBE & Additional isolation

Item	No Guard Band	5MHz Guard Band
OOBE (TX Power)	-8.58 dBm/MHz	-62 dBm/MHz
Acceptable ACI (For 3% Capacity degradation)	-116.4 dBm/ MHz (FRP1) -118.2 dBm/ MHz (FRP3)	
Additional Isolation needed (OOBE–Acceptable ACI level)	107.82 dB (FRP1) 109.62 dB (FRP3)	54.4dB (FRP1) 56.2dB (FRP3)

3.2.3. Analysis

Based upon the OOBE = -62dBm/MHz (TX power), derived from the EC Decision 2008/477/EC [2] BEM characteristic, and assuming the implied 5MHz internal guard band between a TDD band adjacent to a FDD band, the additional isolation required is 56.2dB to meet -118.2dBm/MHz as the acceptable ACI in FRP3 system.

The BEM defined in the EC decision 2008/477/EC [2] is designed to allow coexistence for a minimum antenna separation of 100m. Lower antenna separation may be critical, but it is generally possible to avoid situations where the antennas of each system face each other.

When antennas are co-sited the far field conditions are not met, and specific measurements need to be performed to determine the decoupling or isolation (this is covered in section 4).

4. Antenna isolation mitigation

This chapter introduces antenna configuration as a means to achieve the target isolation between BS's based on results from the practical antenna measurements[8]. The installation for the measurement is described in Table 7.

Table 7. Installation for Measurement

Parameter	Value
Operating frequency	2.6GHz
Antenna gain	17.5dBi
Antenna beamwidth	65°
Network analyzer	E5071B, Agilent

The test scenarios for measurement are as follows

- Horizontal separation with boresight direction variation and electrical tilt
- Vertical separation with boresight direction variation and electrical tilt
- Mixed of horizontal and vertical separation

4.1. Horizontal Separation Results

- ❑ horizontal spacing vs. antenna isolation
  - ■ The antenna isolation between the antenna and the adjacent antenna is proportional to horizontal spacing
  - ■ Test result
    - More than 2m horizontal spacing is required for the isolation to exceed 55 dB.

[8] In this paper the antenna used in the test is AM-X-WM-17-65-00T-RB.

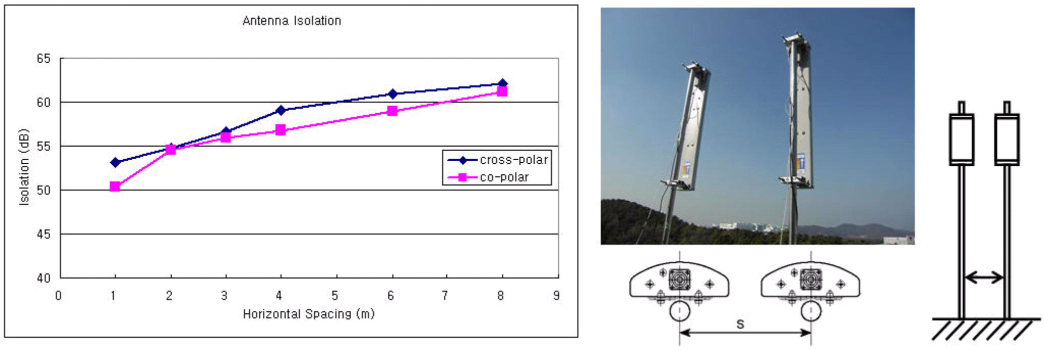


Figure 9. Antenna isolation vs. horizontal spacing

- ❑ Antenna boresight angle vs. antenna isolation
  - ■ Additional isolation can be secured over 0 degree in antenna installation.
  - ■ Test result
    - Positive rotation of boresight angle direction can improve the isolation by more than 10 dB.

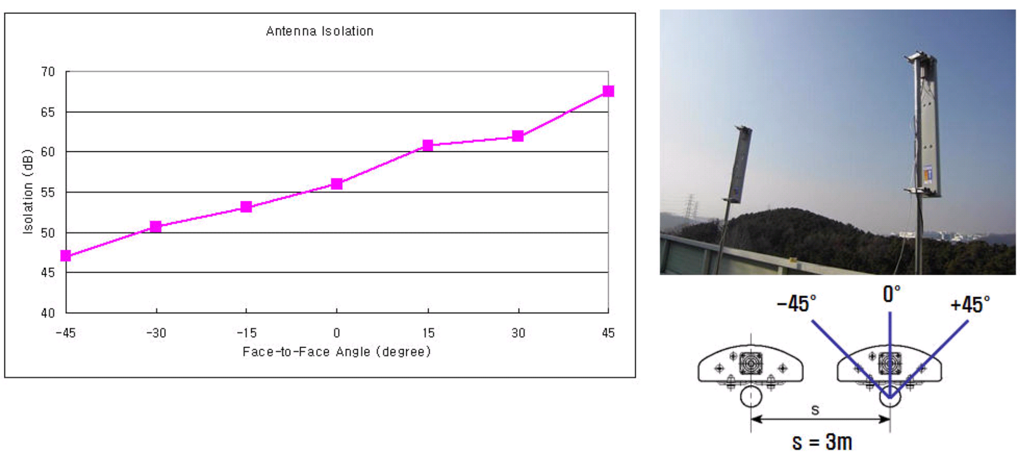


Figure 10. Boresight angle vs. antenna isolation

- ❑ Antenna tilt vs. antenna isolation
  - ■ It is considered that both antennas have the same electrical down-tilt
  - ■ Test result
    - Electrical tilt improves the isolation by 20 dB at 4°downward.

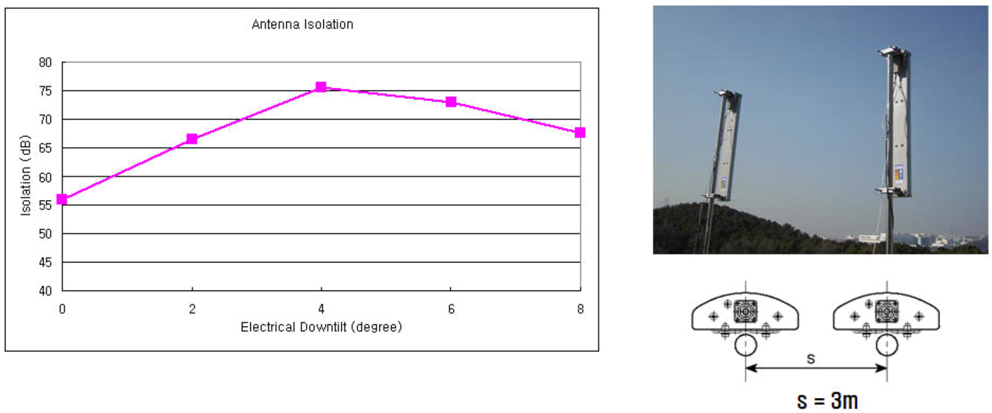


Figure 11. Electrical Down-tilt vs. antenna isolation

4.2. Vertical Separation Results

- ❑ Vertical spacing vs. antenna isolation
  - ■ The vertical spacing between the antenna and the adjacent antenna secures better isolation than horizontal spacing
  - ■ Test result
    - Vertical separation provides at least 70dB of isolation even in the case of 0m separation distance.

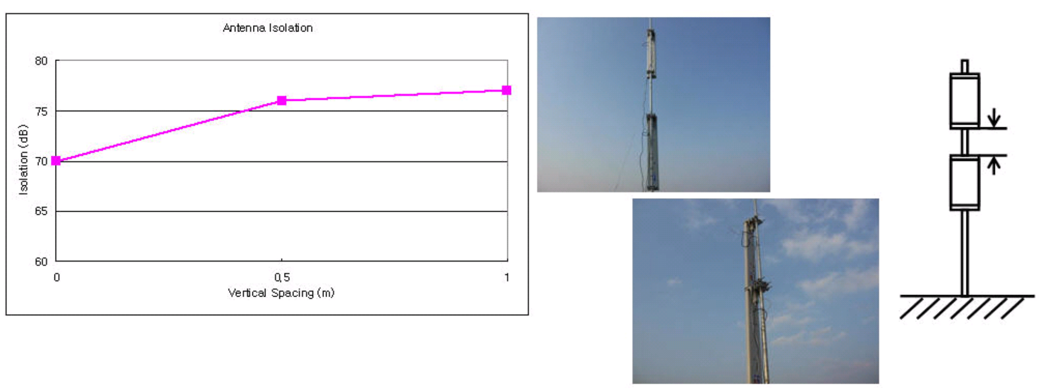


Figure 12. Vertical isolation vs. antenna isolation

- ❑ Boresight angle vs. antenna isolation
  - ■ Test result
    - Rotation of boresight angle is less effective below 90°
    - Rotation of boresight angle direction can improve the isolation by only 10 dB in 180° of boresight angle

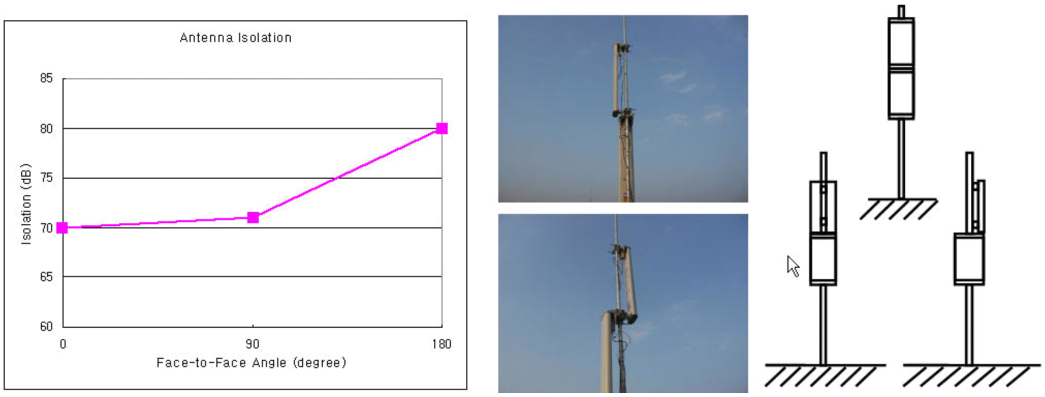


Figure 13. vertical angle vs. antenna isolation

- ❑ Antenna tilt vs. antenna isolation
  - ■ It is considered that both antennas have the same electrical down-tilt
  - ■ The upper antenna is used for transmitting, the lower antenna for receiving.
  - ■ Test result
    - Simultaneous electrical down-tilt of both antennas improves the isolation by more than 7dB at 4°downward.

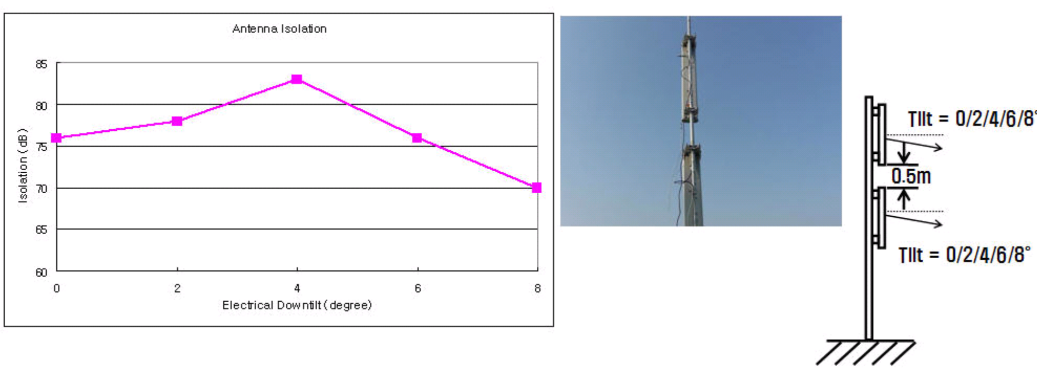


Figure 14. Electrical Down-tilt vs. antenna isolation

4.3. Horizontal and vertical separation

- Horizontal & vertical spacing vs. antenna isolation
  - Test result
    - The isolation for the mixed horizontal and vertical separation is decreasing with the increase in horizontal separation distance.
    - But this is better than that in simple horizontal isolation.
    - This concludes that the mixed of horizontal & vertical separation is more efficient in case that the use of same antenna pole for both BS's is not possible.

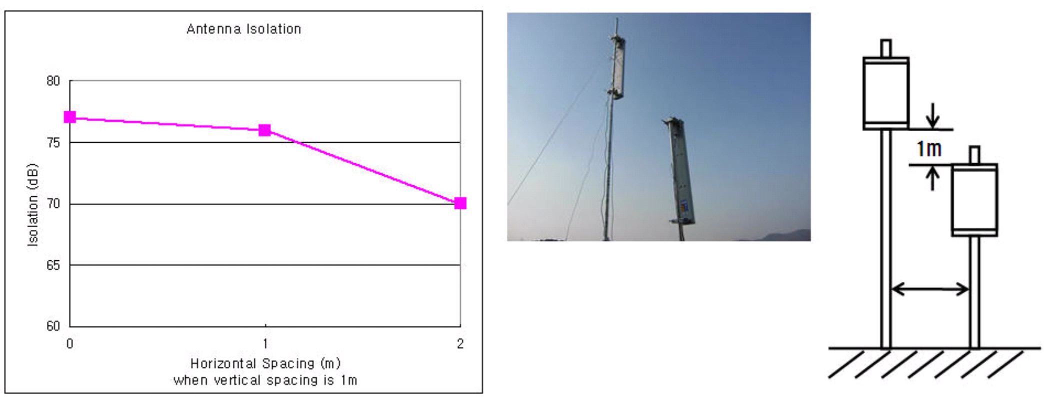


Figure 15. Horizontal & vertical spacing vs. antenna isolation

4.4. Result summary

The expected isolation for the antenna configuration is summarized at Table [9]. Up to 80dB isolation, either horizontal antenna configuration or vertical antenna configuration

[9] However, the isolation value may be different, depending on the antenna model and the test environment.

can be applied. Isolation of over 80dB is possible using a vertical antenna configuration.

Table 8. Summary of antenna configuration

Antenna Configuration	Expected Isolation
Horizontal separation 3m / 8m	56dB / 61dB
Horizontal separation 3m with 0°/ +15°boresight angle rotation	56dB / 60dB
Horizontal separation 3m with 0°/ 4°electrical down-tilt	56dB / 76dB
Vertical separation 0m	70dB
Vertical separation 1m with different antenna pole (horizontal separation 1m)	76dB
Vertical separation 0.5m with 0°/ 4°electrical down-tilt	76dB / 83dB

4.5. Result analysis

EC Decision 2008/477/EC [2] defines a 2.5GHz BEM and the associated co-existence condition between FDD and TDD systems in adjacent blocks. This BEM requires a baseline out of block emission level of -45dBm/MHz across BS receive parts of the band (See Annex A)

Our SLS demonstrates that the necessary inter-system isolation value is 107.82dB (FRP1) and 109.62dB (FRP3) which relate to allowable interference levels of -116.4dBm/MHz (FRP1, I/N = -7.4dB) and -118.2dBm/MHz (FRP3, I/N = -9.2dB) at a victim BS receiver to ensure uplink capacity loss less than 3% of capacity loss without ACI.

For co-sited BS's, the interference budget is as follows:

SLS derived maximum allowable interference density: -118.2 dBm/MHz

BEM derived out of band power density: -45-17 (antenna gain) = -62dBm /MHz

Measured isolation provided by antenna separation: at least 56dB

Worst case power density in victim band: -62-56dBm/MHz=118dBm/MHz

Resultant interference margin: 118-118.2=-0.2 dB.

This low margin illustrates that BS co-siting is possible, since horizontal/vertical antenna separation can provide at least 56dB of inter-BS isolation under reasonable conditions. Angle twist can be used to further reduce the received interference level and increase the margin even further.

5. Conclusion

This white paper analyses the potential to avoid interference between co-sited 2.6GHz TDD and FDD systems in the context of the European Decision 2008/477/EC [2]. The paper recognises that the BS to BS interference scenario presents the greatest challenge out of the possible inter-system interference scenarios.

The study and measurement campaign have confirmed that sufficient isolation can be achieved between co-sited FDD-TDD BS's that are operating in adjacent spectrum blocks and complying with the BEM baseline out of block emission requirements.

The implications of these results are particularly helpful to ease deployment challenges in dense areas where BS sites maybe at a premium or where environmental aspects lead to encouragement for site sharing amongst operators.

ANNEX A. Block Edge Mask identified in EC Decision (2008/477/EC)

The European Commission published Decision 2008/477/EC [1] to harmonize use of the band 2500~2690MHz under common 'least restrictive' technical conditions across the European Union member states.

.It adopts a Block Edge Mask to regulate emission requirements in the entire 2500~2690MHz band in the absence of bilateral or multilateral agreements between neighboring networks. The BEM consists of 'Baseline requirements' specified as out-of-block emission levels and 'Block specific requirements' specified as out-of-block emission levels within 5MHz frequency outside the assigned block edges. Finally, 'Restricted Block' usage (of the guard channel) is identified that requires further specific constraints that maybe applicable to BS's placed indoors or where the antenna height of BS is below a certain height.

In the unrestricted usage scenario for BS's, the baseline requirement is +4dBm/MHz in the frequency range which is allocated to FDD downlink ±5MHz. At all other frequencies in the band 2500~2690MHz not covered by the definition above, the baseline requirement is -45dBm/MHz. The baseline requirements for BS out-of-block emissions are illustrated in Figure A-1.

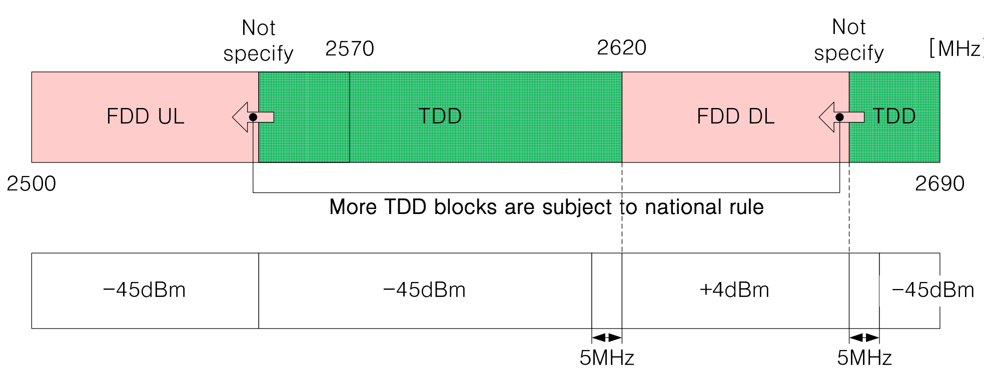


Figure A-1. Baseline requirements of the block edge mask

Block specific requirement for BS in-band is +61dBm/5MHz (in-block EIRP). Block specific requirements for BS just outside the assigned block are detailed in Table A-.

Table A-1. Block specific requirements for BS out-of-block in unrestricted band (Symmetric)

Frequencies (Upper Edge)	Maximum mean EIRP
0.0 to 0.2 MHz	+ 3 dBm/30kHz
0.2 to 1.0 MHz	+ 3 – 15(†Δf– 0.2) dBm/30kHz
1.0 to 5.0 MHz	+ 4 dBm/MHz
†Δf is the frequency offset from the relevant block edge (MHz)	

A 5MHz guard block needs to be identified between FDD operation and adjacent TDD operation which can alternatively be used in compliance with the requirements of the restricted block as detailed in Figure A-2. Therefore, interference from a TDD BS is restricted to below -45dBm/MHz in FDD UL band. Interference from FDD BS is restricted as below -45dBm/MHz in TDD band adjacent to FDD DL

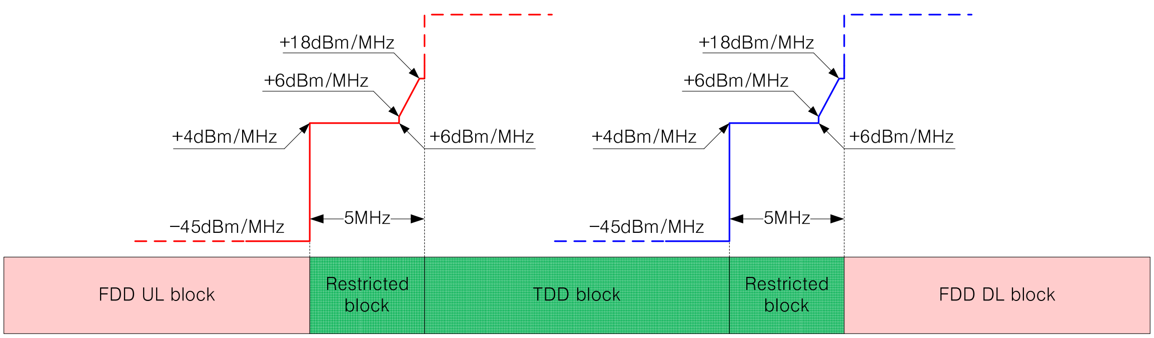


Figure A-2. Restricted block edge mask for BS

In the restricted block for BS's, block specific requirement for BS in-band is +25dBm/5MHz. Block specific requirement for BS out-of-band is limited like Table A-.

Table A-2. Block specific requirement for BS out-of-block emissions in the restricted band (Symmetric)

Frequencies (Upper Edge)	Maximum mean EIRP
0.0 to 0.2 MHz	– 19 dBm/30kHz
0.2 to 1.0 MHz	– 19 15(†Δf - 0.2) dBm/30kHz
1.0 to 5.0 MHz	– 18 dBm/MHz
5.0MHz(Upper edge) to end of band (2690MHz)	– 22 dBm/MHz
†Δf is the frequency offset from the relevant block edge (MHz)	

ACLR can be derived on the basis of the block edge mask of the EC Decision for 1st 5MHz channel and 2nd 5MHz adjacent channel. The calculated ACLR's in each case are presented in Table A- and Table A-. They are based on the assumption that TX power is 44dBm over 5MHz bandwidth. This BEM is also applied for the lower block BEM of TDD block.

Table A-3. ACLR calculation of unrestricted block

Frequency	Lower Block BEM	Upper Block BEM
1st 5MHz Adjacent Channel	45.58dB	55.58dB
2nd 5MHz Adjacent Channel	**99dB**	50dB

Table A-4. ACLR calculation of restricted block

Frequency	Lower Block BEM	Upper Block BEM
1st 5MHz Adjacent Channel	31.58dB	31.58dB
2nd 5MHz Adjacent Channel	**40dB**	**40dB**

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