# 2.6 GHz 대역에서 M-WiMAX OFDMA/TDD 시스템과 WCDMA FDD 시스템간의 상호 간섭 분석

## Part II : Adjacent Interference Analysis with Smart Antenna in M-WiMAX System

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# Adjacent Interference Analysis between M-WiMAX OFDMA/TDD and WCDMA FDD System in the 2.6 GHz Band

## Part II : Adjacent Interference Analysis with Smart Antenna in M-WiMAX System

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## ABSTRACT

This paper presents the coexistence issues between M-WiMAX TDD and WCDMA FDD systems. To improve the M-WiMAX system performance and to reduce the adjacent channel interference to WCDMA FDD system, transmit and receive beamforming techniques are applied in the base stations of M-WiMAX system. Furthermore, we propose an adjacent channel interference modeling methodology, which captures the effect of transmit beamforiming on the adjacent channel interference. Besides, we verify the performance improvement in the uplink of WCDMA system due to the transmit beamforming in M-WiMAX downlink based on the proposed adjacent channel interference modeling methodology. We also verify the performance enhancement due to the receive beamforming in the uplink of M-WiMAX system through system level Monte Carlo simulations, considering random user position, the effect of shadowing and multi-path fading channel. Discussions on the gain of applying transmit and receive beamforming in M-WiMAX system comparing the case of SISO system are also included. Furthermore, we present the performance of cosited M-WiMAX and WCDMA systems, considering commercial deployment, additional channel filter at base stations and the effects of TxBF and RxBF.

**Key Words** : ACI, M-WiMAX, WCDMA, Smart Antenna, Transmit Beamforming, Receive Beamforming

## Ⅰ. Introduction

The 2500 - 2690 MHz band has been identified as an additional spectrum band that administrations may choose to make available for IMT-2000[1]. Due to the fact that M-WiMAX TDD system operates in the adjacent band of WCDMA FDD system, the interference between M-WiMAX TDD and WCDMA FDD system should be mitigated without resulting in performance degradation in the both systems.

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In [2-5], some studies are drawn on the mutual interference analysis between M-WiMAX TDD and WCDMA FDD systems.

Smart antenna is well-known technique to mitigate interference and to increase the received signal power and is usually categorized as TxBF (Tranmist Beamforming) and RxBF (Receive Beamforming). In [6] and [7], some research is made to apply TxBF in base stations to reduce co-channel interference for improving system performance. But little work is made on how to model adjacent channel interference when the interfering system is equipped with TxBF. Some adaptive algorithms about RxBF are introduced in [8] and [9].In this paper, we proposed a novel methodology to model the ACI (Adjacent Channel Interference) from M-WiMAX TDD to WCDMA FDD system, when TxBF is applied in the M-WiMAX base station. The performance enhancement due to the application of TxBF and RxBF in the BSs (base stations) of M-WiMAX TDD system is verified through system level Monte Carlo simulation. Furthermore, analysis on the gain of TxBF and RxBF are also presented.

The remainder of this paper is organized as follows. In section II, the proposed methodology to model ACI from M-WiMAX with TxBF to WCDMA system and the RxBF algorithm for the M-WiMAX uplink (UL) are described. In section III, the environment of system level simulation is analyzed. Results and analysis of our interference investigation are shown in section IV. The coexistence performance of M-WiMAX and WCDMA systems under more practical environment are shown in section V. Finally, conclusions are drawn in section VI.

## Ⅱ. Proposed Methodology to Apply Transmit Beamforming and Receive Beamforming in the M-WiMAX Base Station

### 2.1 Proposed Adjacent Channel Interference Modeling Methodology Capturing the Effect of Transmit Beamforming in M-WiMAX Downlink

In this paper, we utilize the conventional eigenvector transmit beamforming algorithm as transmit beamforming scheme in WiMAX DL (Downlink). Eigenvector transmit beamforming algorithm adaptively adjusts the antenna steering vector to make the antenna main lobe towards the desired UE, which can increase the received signal power and reduce the interference to other UEs.

Some work is done considering the usage of TxBF to enhance the system performance through increasing the received signal power and reducing the interference in a single system. But little research is made on the issues of adjacent channel interference from a system with TxBF. Therefore, in our adjacent channel interference investigation, we proposed a methodology to model the ACI from M-WiMAX system with TxBF in DL. In our investigation, TxBF can reduce ACI from M-WiMAX to the victim WCDMA system by steering the M-WiMAX base station antenna towards the desired M-WiMAX UE. Therefore, directivity gain is obtained in the victim WCDMA system and depends on the location of M-WiMAX UEs.

According to the eigenvector transmit beamforming algorithm, we can calculate the beamforming weight on the $i^{th}$ subcarrier of the $k^{th}$ user in the following three steps:

1. Calculate the channel spatial covariance matrix $\mathbf{H}_{i,k}$ of the desired M-WiMAX UE on subcarrier $i$.
2. Find the normalized eigenvector $\lambda_{\max,i,k}$, which corresponds to the largest eigenvalue.
3. Select $\lambda_{\max,i,k}$ as the transmit weight factor $w_{i,k}$ of the desired M-WiMAX UE on subcarrier $i$.

Based on the calculated transmit weight of each M-WiMAX UE, we model the directivity obtained by the victim WCDMA system as in (1) and (2)

$$\text{Temp\_DG}(\theta)=\frac{1}{NN_u}\sum_{i=0}^{N}\sum_{k=0}^{N_u} w_{i,k}^{H}a(\theta) \tag{1}$$

And

$$\text{Dirvty\_Gain}(\theta)=10\log\left(\frac{\text{Temp\_DG}(\theta)}{\underset{\beta\,:\,0\sim 360\text{ deg}}{\arg\max}\ \text{Temp\_DG}\,(\beta)}\right) \tag{2}$$

where $N$ is the number of data subcarriers of M-WiMAX system $N_u$ is the number of users per M-WiMAX sector; $w_{i,k}$ is the transmit weight factor on the $i^{th}$ subcarrier for the user $k$ in M-WiMAX BS and $a(\theta)$ is the array factors of the antenna array in the M-WiMAX base station, corresponding to the angle $\theta$.

The ACI received by the WCDMA base station can be calculated as

$$\begin{aligned}\mathrm{ACI}_{\mathrm{WCDMA\_UL}}\ (\mathrm{dBm}) = {} & \mathrm{P}_{\mathrm{WiMAX\_Inter}}\ (\mathrm{dBm}) + \mathrm{ACIR}\ (\mathrm{dB}) - \mathrm{Path\ Loss}\ (\mathrm{dB}) \\ & - \mathrm{Shadowing}\ (\mathrm{dB}) + \mathrm{Antenna\ Gain}(\theta)\ (\mathrm{dB}) \\ & + \mathrm{Direc\_Gain}(\theta)\ (\mathrm{dB})\end{aligned} \tag{3}$$

where $\mathrm{P}_{\mathrm{WiMAX\_Inter}}$ means the interfering power in M-WiMAX DL, ACIR value can be taken from Table 1 with corresponding guard band bandwidth[1]. Antenna gain should be calculated according to the antenna pattern with the corresponding angle $\theta$.

### 2.2 Receive Beamforming in the Uplink of M-WiMAX

In the receive beamforming of M-WiMAX UL (Uplink), DSMI (direct-sample-matrix-inverse) based on the above MMSE criterion is applied.

In the MMSE criterion, the weights are chosen to minimize the mean-square error (MSE) between the beamformer output and the reference signal. The error signal $e^2(t)$ can be represented as

$$e^2(t) = [d^*(t) - \mathbf{w}^H x(t)]^2 \tag{4}$$

where $d^*(t)$ is the conjugate of the reference signal and $\mathbf{w}$ is the beamforming weight vector. Opetaror $H$ means the complex conjugate transpose.

The optimal weight vector $\mathbf{W}_{\mathrm{opt}}$ can be calculated as

$$\mathbf{w}_{opt} = \mathbf{R}^{-1}\mathbf{r} \tag{5}$$

which is referred to as the Wiener-Hopf equation or the optimum Wiener solution. If $s(t)=d^*(t)$, $\mathbf{r} = E\{d^2(t)\}\mathbf{v}$, let us further express $\mathbf{R} = E\{d^2(t)\}\mathbf{v}\mathbf{v}^H + \mathbf{R}_i$, where $\mathbf{R}_i = E\{\mathbf{u}\mathbf{u}^H\}$ and apply Woodbury's identity to $\mathrm{R}^{-1}$ and we have

$$\mathbf{R}^{-1} = [\frac{1}{1 + E\{d^2(t)\}\mathbf{v}^H \mathbf{R}_i^{-1}\mathbf{v}}]\mathbf{R}_i^{-1} \tag{6}$$

The idea of direct sample matrix inversion (DSMI) algorithm [10] is to estimate the correlation matrix $\mathbf{R}$ and the cross-correlation vector $\mathbf{p}$ based on the samples of the array sensor input in an observation interval, i.e.,

$$\hat{\mathbf{R}} = \sum_{n=N_1}^{N_2} \mathbf{x}(n)\mathbf{x}^H(n) \tag{7}$$

$$\hat{\mathbf{p}} = \sum_{n=N_1}^{N_2} d^*(n)\mathbf{x}^H(n) \tag{8}$$

where $N_1$ and $N_2$ are the lower and upper limits of the observation interval, respectively. $d(n)$ is the reference signal and $\mathbf{x}(n)$ is the received desired signal.

The weight vector then calculated using the optimum wiener solution

$$\hat{\mathbf{w}} = \hat{\mathbf{R}}^{-1}\hat{\mathbf{p}} \tag{9}$$

which is then applied to the samples of array sensor input that are received within the same observation interval. In order to allow the array to adapt as the signal environment changes, the correlation sample matrix $\hat{\mathbf{R}}$ and the cross-correlation sample vector $\hat{\mathbf{p}}$ are re-estimated for each observation interval.

In M-WiMAX system, the weights are calculated on each data subcarrier. On subcarrier $n$, the singular value decomposition of channel matrix is as in (10)

$$\mathbf{H}(n) = \mathbf{U}_H(n)\mathbf{S}_H(n)\mathbf{Z}^H{}_H(n) \tag{10}$$

Table 1. ACIR values between M-WiMAX BS and WCDMA BS.

| Interference Source | Victim Receiver | 1st Adjacent Channel | 2nd Adjacent Channel |
|---|---|---|---|
| M-WiMAX BS | WCDMA BS | 45.3 | 57.4 |
| WCDMA BS | M-WiMAX BS | 42.2 | 46 |

The receiver weight vector $\mathbf{W}(n)$ can be chosen as in

$$\mathbf{W}(n)=\frac{\mathbf{H}(n)\mathbf{V}(n)}{\mathbf{V}^H(n)\mathbf{H}^H(n)\mathbf{H}(n)\mathbf{V}(n)+{\sigma_n}^2/{\sigma_s}^2}\times\mathbf{a}(\theta) \qquad (11)$$

where $\sigma_n^2$ is the receiver noise variance; ${\sigma_s}^2$ is the power of the transmitted signal; $\mathbf{a}(\theta)$ is the array factor with the desired signal DoA (Direction of Arrival); and $\mathbf{V}(n)$ is the first column of $\mathbf{Z}_H(n)$ .

Thus, the received SINR on subcarrier *n*, can be calculated as

$$SINR_n=\frac{\sigma_s^2\mathbf{w}^H(n)\mathbf{a}(\theta)\mathbf{a}(\theta)'\mathbf{w}(n)}{E\{\mathrm{P}_{\mathrm{int}}\}\sum\mathbf{w}^H(n)\mathbf{a}(\theta_i)\mathbf{a}(\theta_i)'\mathbf{w}(n)+\sigma^2_{n+ACI}\mathbf{w}^H(n)\mathbf{w}(n)} \qquad (12)$$

where $\mathrm{P}_{\mathrm{int}}$ is the interference signal power from the interfering M-WiMAX UE; $\sigma^2_{n+ACI}$ is the background additional noise power including ACI and AWGN; $\theta$ is the DoA of the desired signal; $\theta_i$ is the DoA of the i-th interfering signal of M-WiMAX UE; and $\mathbf{W}(n)$ is the weight vector on subcarrier *n* of the desired UE corresponding to the DoA of the desired UE.

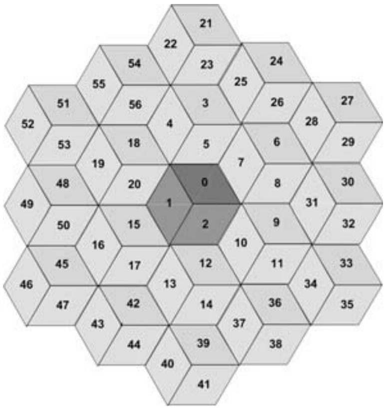

Fig. 1. Two-tier cell layout.

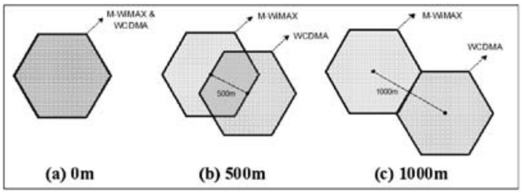

Fig. 2. Three deployment scenarios of target M-WiMAX and WCDMA cells.

## Ⅲ. Simulation Environment and Parameter Setting

In this paper, we consider 2- tier deployment layout for both WCDMA system and M-WiMAX systems as shown in Fig. 1. And there are total 57 sectors in 19 hexagonal cells[11]. Besides, we consider three scenarios that the WCDMA BS and the M-WiMAX BS are deployed with the distance of 0m, 500m, and 1000m, which is illustrated in Fig. 2.

The antenna pattern used in this paper is defined as

$$A(\theta)=-\min[12(\frac{\theta}{\theta_{3dB}}),A_m] \qquad (13)$$

where $-180\le\theta\le180$ is the angle from the antenna pointing direction; $\theta_{3dB}$ corresponds to 60 degrees, and $A_m=30\,dB$ is the maximum attenuation.

Due to our preliminary work shown in Part I paper [12], we found that the worst interfering scenarios between M-WiMAX and WCDMA system are M-WiMAX DL interfering to WCDMA UL and WCDMA DL interfering to M-WiMAX UL. Therefore, in this paper we only consider the effects of TxBF and RxBF equipped in M-WiMAX base station under the above two worst scenarios, that is, the scenarios of M-WiMAX DL interfering to WCDMA UL where TxBF is applied, and WCDMA DL interfering to M-WiMAX UL where RxBF is applied.

Here, power control is applied in WCDMA UL and AMC (Adaptive Modulation and Coding) technique is used in M-WiMAX UL. Besides, both of the data and voice service are considered in WCDM UL. We show the explicit parameters setting for M-WiMAX and WCDMA systems in Tables 2 and 3, respectively.

## Ⅳ. Coexistence between M-WiMAX and WCDMA Systems

In this section, we show the performance evaluation criterion of WCDMA and WiMAX systems to analyze the performance degradation due to the ACI, which is same as that in Part I paper. Furthermore, we present the performance gain in WCDMA UL and WiMAX UL, when TxBF and RxBF are utilized in the M-WiMAX BSs. Besides, discussions on the gain of TxBF and RxBF are also made in this section.

### 4.1 WCDMA UL Performance Evaluation Criterions

To evaluate the UL performance of WCDMA system, the following requirements should be met.

- Uplink loading in a single system case is evaluated according to a 6 dB noise rise over the thermal noise.
- A simulation is run with a predefined number of users per sector.
- The average noise rise is measured at the end of power control.
- A link is outage if its *Eb/No* is less than (target *Eb/No* – 0.5 dB) at the end of power control

The throughput and capacity loss of the victim WCDMA system can be calculated as in (14) and (15), respectively.

$$Throughput\_Loss = 1 - \frac{Throughput\_ul\_ACI}{Throughput\_ul\_NoACI} \qquad (14)$$

And

$$Capacity\_Loss = 1 - \frac{N\_ul\_ACI}{N\_ul\_NoACI} \qquad (15)$$

where *Throughput_ul_ACI* means the WCDMA system throughput in UL where there is adjacent channel interference coming from M-WiMAX sys-

Table 2. Parameter setting for M-WiMAX system.

| Item | Parameter | Value |
|---|---|---|
| Freq. Band | Carrier Freq. | 2.6 GHz |
| | Effective B.W | 8.75 MHz |
| BS Side | Max Tx Power | 36 dBm |
| | Antenna Gain | 18 dBi |
| | Antenna Height | 30 m |
| | Antenna Array | 4 uniform linear antenna elements with 0.5 λ separation / per sector |
| | Thermal Noise | -174.0 dBm / Hz |
| | Noise Figure | 3 dB |
| | Max Interference Limit | -110 dB |
| MS Side | Max Tx Power | 20 dBm |
| | Antenna Gain | 0.0 dBi |
| | Antenna Height | 1.5m |
| Channel Model | ITU-R M.1225 Veh-A 60 km/h Independent fading for each antenna element | |
| | Path Loss Model | ITU-R M.1225 Vehicular Model between MS and BS<br>Dual Slope LOS Model between BSs |
| | Shadowing | Std. 10 dB |
| Cell Site | Nr. of Cells | 19 |
| | Cell Configuration | Hexagonal |
| | Cell Radius | 1 km |
| UE | Nr. of Users | 5 |
| | Position | Uniform |
| Resource Loading | | 75% |
| Target PER | | 1% |
| Downlink / Uplink Ratio | | 2:1 |

Table 3. Parameter setting for WCDMA system.

| Item | Parameter | Value |
|---|---|---|
| Freq. Band | Carrier Freq. | 2.6 GHz |
| | Effective B.W | 3.84 MHz |
| BS Side | Max Tx Power | 43 dBm |
| | Antenna Gain | 17 dBi |
| | Antenna Height | 30 m |
| | Thermal Noise | -174.0 dBm / Hz |
| | Noise Figure | 5 dB |
| | Max Interference Limit | -109 dB |
| MS Side | Max Tx Power | 21 dBm |
| | Antenna Gain | 0.0 dBi |
| | Antenna Height | 1.5 m |
| Channel Model | Voice : ITU-R M.1225 Veh-A 30 km/h | |
| | Data : ITU-R M.1225 Ped-A 3 km/h | |
| | Path Loss Model | ITU-R M.1225 Vehicular Model between MS and BS<br>Dual Slope LOS Model between BSs |
| | Shadowing | Std. 10 dB |
| Cell Site | Nr. of Cells | 19 |
| | Cell Configuration | Hexagonal |
| | Cell Radius | 1 km |
| | Nr. of Users | UL Voice : 3 |
| | | UL Data : 3 |
| | Position | Uniform |
| Resource Loading | | 100% |
| Downlink / Uplink Ratio | | 2:1 |
| Target PER | | Voice : 1% |
| | | Data : 0.1 % |
| Spreading Factor | UL | Voice : 64 |
| | | Data : 16 |
| Data Rate | UL | Voice : 12.2 kbps |
| | | Data : 64 kbps |

tem; *Throughput_ul_NoACI* is the WCDMA system throughput in UL without ACI; *N_ul_ACI* is the number of WCDMA links in UL which meet the required Eb/N0 when ACI exists; and *N_ul_NoACI* is the number of WCDMA links in UL which meet the required *Eb/N0* without ACI[1].

Table 4. Target CINR and modulation efficiency values for each MCS in M-WiMAX UL.

| Link | MCS | Target CINR | ME |
|---|---|---|---|
| WiMAX UL | QPSK 1/2 | 6.32 | 1 |
| | QPSK 3/4 | 10.86 | 1.5 |
| | 16QAM 1/2 | 12.44 | 2 |
| | 16QAM 3/4 | 17.83 | 3 |

### 4.2 M-WiMAX UL Performance Evaluation Criterions

The evaluation on the performance of M-WiMAX UL is based on the following considerations:

- M-WiMAX system is 75% loaded, i.e., at any given time, 75% of sub-carriers are occupied.
- ARQ (Automatic Repeat Request) gain is not included.

The average modulation efficiency in M-WiMAX UL is calculated based on each link's instantaneous SINR and the target SNR values in the above Table 4, assuming that the interference is noise-like. It is given by

$$\overline{SE} = \frac{\sum_{i=1}^{N} SE_i}{N} \qquad (16)$$

where $SE_i$ is modulation efficiency of the $i^{th}$ link and $N$ is the number of links which are not in outage.

The loss in the modulation efficiency is calculated by

$$SE\_loss = 1 - \frac{\overline{SEmulti}}{\overline{SEsingle}} \qquad (17)$$

where $\overline{SEsingle}$ is the average modulation efficiency of the M-WiMAX system without WCDMA interference and $\overline{SEmulti}$ is the average modulation efficiency of the M-WiMAX system when coexisting with a WCDMA system [1].

### 4.3 Analysis on the Performance Improvement induced by TxBF and RxBF in M-WiMAX System

To evaluate the gain of TxBF and RxBF in M-WiMAX system, we show the UL performance of WCDMA and M-WiMAX systems under two worst scenarios of M-WiMAX DL interfering to WCDMA UL and WCDMA DL interfering to M-WiMAX UL with applying TxBF and RxBF in the M-WiMAX DL and UL, respectively. And we compare the simulation results to that of SISO system as in [12]. In our simulation, we use 5 MHz guard band as the default guard bandwidth and the case of "with GB" means that we use 10 MHz guard band instead of 5 MHz one.

Tables 5 and 6 show the WCDMA UL performance with voice and data services, respectively. In these tables, we consider that WCDMA UL suffers ACI coming from M-WiMAX DL and TxBF with 4 antenna elements is applied in M-WiMAX DL to reduce ACI to WCDMA system.

From the results, we find that GB can provide 20% gain at most and TxBF in M-WiMAX DL can provide another 8% and 9% gain on the throughput and outage loss for voice and data, respectively. But the gain provided by TxBF is not constant, as the distance between the two systems base stations increases, the gain is decreased for both cases of voice and data services. In the case of 1000m base station to base station distance with GB, TxBF gain is only around 4.1% for voice and 1.9% for data, respectively. We develop a simple analysis in (18)-(20) which is independent of service type in WCDMA UL and shows that as the deployment distance between the two systems increases (which means ACI decreases), TxBF gain in WCDMA UL is decreased.

$$SINR_{SISO} = \frac{P}{ACI + N_{AWGN+I_{inter}}} \qquad (18)$$

$$SINR_{TxBF} = \frac{P}{(1-G)ACI + N_{AWGN+I_{inter}}} \qquad (19)$$

$$\begin{aligned} SINR_{Increase\_ratio} &= (SINR_{TxBF} - SINR_{SISO}) / SINR_{SISO} \\ &= \frac{G \bullet ACI}{(1-G)ACI + N_{AWGN+I_{inter}}} \\ &= \frac{1}{\frac{1}{G} - 1 + \frac{N_{AWGN+I_{inter}}}{G \bullet ACI}} \end{aligned} \qquad (20)$$

where $SINR_{SISO}$ means the received SINR in WCDMA UL when the interfering M-WiMAX DL uses a single antenna; $SINR_{SISO}$ represents the received SINR in WCDMA UL when TxBF is applied in the M-WiMAX DL; $SINR_{Increase\_ratio}$ is the ratio of increased SINR in WCDMA UL; $G$ is the ACI reduction ratio provided by the directivity gain of TxBF in M-WiMAX DL; and $N_{AWGN+I_{inter}}$ is the total noise from thermo noise and inter-cell interference of WCDMA UL. Statistically, $G$ and $N_{AWGN+I_{inter}}$ are independent of the deployment distance between M-WiMAX and WCDMA systems and only depends on the desired WCDMA UE position. Therefore, $G$ and $N_{AWGN+I_{inter}}$ are constant for all the scenarios of deployment distance. From (20), we can see that $SINR_{Increase\_rati}$ increases as ACI increases. That is, smaller deployment distance between the two systems will have larger TxBF gain. But in the case

Table 5. Victim WCDMA UL performance of voice traffic in the cases of Interfering M-WiMAX DL with and without TxBF.

| | Item | Distance between WCDMA BS and M-WiMAX BS | | | |
|---|---|---|---|---|---|
| | | 0m | | 500m | 1000m |
| | | 50 dB | 70 dB | | |
| No ACI | Throughput (kbps) | 34.62 | 34.62 | 34.62 | 34.62 |
| | Outage | 5.2% | 5.2% | 5.2% | 5.2% |
| w. GB SISO | Throughput | 7.75 | 20.54 | 29.83 | 31.44 |
| | Throughput Loss | 77.6% | 40.7% | 13.8% | 9.2% |
| | Outage | 78.8% | 43.7% | 18.1% | 13.8% |
| | Capacity Loss | 77.6% | 40.6% | 13.6% | 9.1% |
| w. GB Tx BF | Throughput | 10.71 | 22.65 | 31.66 | 32.87 |
| | Throughput Loss | 69.1% | 34.6% | 8.6% | 5.1% |
| | Outage | 70.7% | 38% | 13.3% | 10% |
| | Capacity Loss | 69.0% | 34.6% | 8.6% | 5.0% |
| w.o. GB SISO | Throughput | 2.96 | 12.97 | 26.08 | 27.45 |
| | Throughput Loss | 91.5% | 62.5% | 24.7% | 20.7% |
| | Outage | 91.9% | 64.3% | 28.8% | 24.8% |
| | Capacity Loss | 91.4% | 62.4% | 24.9% | 20.7% |
| w.o. GB Tx BF | Throughput | 3.77 | 15.19 | 28.13 | 29.34 |
| | Throughput Loss | 89.1% | 56.1% | 18.7% | 15.2% |
| | Outage | 90.1% | 59.1% | 23% | 19.7% |
| | Capacity Loss | 89.6% | 56.9% | 18.8% | 15.2% |

Table 6. Victim WCDMA UL performance of data traffic in the cases of Interfering M-WiMAX DL with and without TxBF.

| | Item | Distance between WCDMA BS and M-WiMAX BS | | | |
|---|---|---|---|---|---|
| | | 0m | | 500m | 1000m |
| | | 50 dB | 70 dB | | |
| No ACI | Throughput (kbps) | 177.62 | 177.62 | 177.62 | 177.62 |
| | Outage | 7.78% | 7.78% | 7.78% | 7.78% |
| w. GB SISO | Throughput | 30.17 | 92.23 | 156.86 | 165.85 |
| | Throughput Loss | 83.0% | 48.1% | 11.7% | 6.6% |
| | Outage | 85.4% | 52.1% | 18.6% | 13.9% |
| | Capacity Loss | 84.2% | 48.1% | 11.7% | 6.6% |
| w. GB Tx BF | Throughput | 45.15 | 106.36 | 160.93 | 169.27 |
| | Throughput Loss | 74.6% | 40.1% | 9.4% | 4.7% |
| | Outage | 76.6% | 44.8% | 16.4% | 12.1% |
| | Capacity Loss | 74.6% | 40.1% | 9.4% | 4.7% |
| w.o. GB SISO | Throughput | 14.12 | 55.85 | 131.39 | 146.59 |
| | Throughput Loss | 92.1% | 68.6% | 26.0% | 17.5% |
| | Outage | 92.7% | 71.4% | 31.8% | 23.9% |
| | Capacity Loss | 92.1% | 69.0% | 26.0% | 17.5% |
| w.o. GB Tx BF | Throughput | 17.33 | 70.62 | 139.53 | 150.43 |
| | Throughput Loss | 90.2% | 60.2% | 21.5% | 15.3% |
| | Outage | 91% | 63.3% | 27.6% | 22.8% |
| | Capacity Loss | 90.2% | 60.2% | 21.5% | 16.3% |

of 50 dB MCL without GB, TxBF gain is still very small. Because in such a case, most UE are in outage, the SINR gap between the required and received SINRs is big, even TxBF can provide larger $SINR_{Increase\_ratio}$ than other cases, but the increased received SINRs of most UE are still below the required SINR. Therefore, the gain on throughput and capacity loss provided by TxBF is still very small.

Table 7 summarizes the performance of M-WiMAX UL when there is ACI coming from WCDMA DL. In this table, we make a comparison on the UL performance between the single antenna and antenna array with 4 antenna elements. From the results, we see that the RxBF gain on the throughput loss is inversely proportional to the ACI, that is, the RxBF gain increases as the distance between the base stations of the two system decreases. And we obtain 14% throughput gain at most under the case of 1000m BS to BS distance with GB, which is about 5% more than TxBF gain shown in Tables 5 and 6. Besides, very high gain on ME (Modulation Efficiency) loss is observed under the case of 0m BS to BS distance. We obtain about 73% gain on ME loss at most under the case of 70 dB MCL without GB. In the M-WiMAX system, AMC (Adaptive Modulation and Coding) technique is applied. As a result, in the case of small ACI, higher modulation level will be used, which induces higher through increases. Therefore, high RxBF gain is observed.

## Ⅴ. Further Improvement considering Commercial Deployment

In the above section, we consider the effect of coexistence between M-WiMAX and WCDMA systems under the worst environment, where we used the minimum coupling loss between two system base stations antennas, low ACIRvalues without any interference mitigation techniques, and small number of antenna elements.

Table 7. Victim M-WiMAX UL performance with and without RxBF when ACI comes from WCDMA DL.

| | Item | Distance between WCDMA BS and M-WiMAX BS | | | |
|---|---|---|---|---|---|
| | | 0m | | 500m | 1000m |
| | | 50 dB | 70 dB | | |
| No ACI SISO | Throughput (kbps) | 420.40 | 420.40 | 420.40 | 420.40 |
| | Modulation Efficiency | 2.31 | 2.31 | 2.31 | 2.31 |
| w. GB SISO | Throughput | 0 | 0.01 | 35.35 | 54.96 |
| | Throughput Loss | 100% | 99.9% | 91.6% | 86.9% |
| | Modulation Efficiency | 0 | 1.01 | 1.89 | 2.02 |
| | Modulation Efficiency Loss | 100% | 56.3% | 18.2% | 12.6% |
| w. GB Rx BF | Throughput | 1.11 | 28.85 | 90.15 | 114.31 |
| | Throughput Loss | 99.7% | 93.1% | 78.6% | 72.8% |
| | Modulation Efficiency | 1.32 | 1.84 | 2.19 | 2.24 |
| | Modulation Efficiency Loss | 43.1% | 20.5% | 5.3% | 3.0% |
| w.o. GB SISO | Throughput | 0 | 0 | 20.60 | 40.53 |
| | Throughput Loss | 100% | 100% | 95.1% | 90.4% |
| | Modulation Efficiency | 0 | 0 | 1.64 | 2.01 |
| | Modulation Efficiency Loss | 100% | 100% | 28.9% | 13.3% |
| w.o. GB Rx BF | Throughput | 0.36 | 21.32 | 72.91 | 89.63 |
| | Throughput Loss | 99.9% | 94.9% | 82.7% | 78.7% |
| | Modulation Efficiency | 1.26 | 1.67 | 2.03 | 2.19 |
| | Modulation Efficiency Loss | 45.7% | 27.7% | 12.2% | 5.3% |

While in this section, we will show the coexistence performance of the two systems with more practical parameters, such as the number of antenna elements, higher ACIR values due to the interference mitigation techniques and more coupling loss between the antennas of the two system induced by the larger antenna separation distance. In this section, we use 8 and 16 antenna elements and the coupling loss between antennas is increased to 89 dB [1].

In this part, we considering the additional channel filters are applied in both M-WiMAX and WCDMA BSs or just in M-WiMAX BS, and the new ACIR values induced by the additional channel filters with 5MHz and 10MHz guard band are shown in Table 8.

### 5.1 Additional Channel Filters at both M-WiMAX and WCDMA Systems

Table 9 shows the performance loss in WCDMA UL with only voice traffic and 10 MHz guard band, when there is ACI coming from M-WiMAX DL. Additional Channel filters are applied in both WCDMA and M-WiMAX base stations. From the table, we found that the TxBF and additional channel filters make the ACI induced throughput and capacity loss only 0.35% and 0.42%, respectively.

The M-WiMAX UL performance is presented in Table 10, with ACI coming from WCDMA DL considering 10 MHz guard band and additional channel filters in both base stations of the two systems. In despite of ACI from WCDMA DL, the utilization of additional channel filters and RxBF

Table 8. Antenna coupling loss and ACIR values considering the additional channel filters in BSs.

| Interference Scenario | Channel Filter | 5 MHz (dB) | 10 MHz (dB) |
|---|---|---|---|
| M-WiMAX DL to WCDMA UL | Both | - | 133 |
| | Only at M-WiMAX BS | 65 | 75 |
| WCDMA DL to M-WiMAX UL | Both | - | 137 |
| | Only at M-WiMAX BS | 57 | 74 |
| Antenna Coupling Loss | 89 dB | | |

Table 9. Victim WCDMA UL performance of voice traffic in the case of ACI from M-WiMAX DL with TxBF and additional channel filters at both systems.

| | Throughput (kbps) | Throughput Loss | Outage | Capacity Loss |
|---|---|---|---|---|
| SISO w.o. ACI | 34.62 | - | 5.2% | - |
| 8 Ant w. ACI | 34.5 | 0.35% | 5.6% | 0.42% |

Table 10. Victim M-WiMAX UL performance with RxBF and additional channel filters at both systems when ACI comes from WCDMA DL.

| | Throughput (kbps) | Throughput Loss | Modulation Efficiency | ME Loss |
|---|---|---|---|---|
| SISO w.o.ACI | 420.40 | - | 2.311994 | - |
| 8 Ant w. ACI | 505.44 | -20.2% | 2.787045 | -20.5% |

Table 11. Victim WCDMA UL performance of voice traffic in the case of ACI from M-WiMAX DL with TxBF and additional channel filter only at M-WiMAX BS.

| | Throughput (kbps) | Throughput Loss | Outage | Capacity Loss |
|---|---|---|---|---|
| SISO w.o.ACI | 34.62 | - | 5.2% | - |
| 8 Ant w. ACI | 34.25 | 1.07% | 6.2% | 1.05% |
| 16 Ant w. ACI | 34.46 | 0.46% | 5.7% | 0.53% |

Table 12. Victim M-WiMAX UL performance with RxBF and additional channel filter only at M-WiMAX BS when ACI comes from WCDMA DL.

| | Throughput (kbps) | Throughput Loss | Modulation Efficiency | ME Loss |
|---|---|---|---|---|
| SISO w.o. ACI | 420.40 | - | 2.311994 | - |
| 16 Ant w. ACI w.o. GB | 336.3 | 20.0% | 2.274468 | 1.62% |
| 8 Ant w. ACI & GB | 438.44 | -4.3% | 2.634913 | -13.97% |
| 16 Ant w. ACI & GB | 503.21 | -19.7% | 2.748749 | -18.89% |

in M-WiMAX UL, can 20.2% and 20.5% gain on throughput and modulation efficiency, respectively.

### 5.2 Additional Channel Filter only at M-WiMAX System

In this subsection, we consider the additional channel filter is applied only in M-WiMAX system and the characteristics of WCDMA base station are kept same as the parameters in Section IV.

Table 11 presents the WCDMA performance in UL with only voice traffic and ACI coming from M-WiMAX DL. Besides, 10 MHz guard band and TxBF are applied in M-WiMAX DL with 8 or 16 antenna elements. From the results, we find that TxBF with 8 antenna elements in M-WiMAX DL cause around 1% loss on throughput and capacity. But the TxBF with 16 antenna elements induces only around 0.5% performance loss.

The M-WiMAX UL performance is shown in Table 12 with ACI coming from WCDMA DL. We find that RxBF with 8 antenna elements and GB can provide 4.3% and 13.97% gain on throughput and modulation efficiency, respectively. While in the case of without guard band, even though 16 antenna elements are applied, 20% and 1.62% loss on throughput and modulation efficiency are observed.

## Ⅵ. Conclusions

In this paper, we investigate the effect of the adjacent channel interference between M-WiMAX TDD system with smart antenna and WCDMA FDD system. To reduce ACI to WCDMA system, TxBF is applied in M-WiMAX DL. In addition, an ACI modeling methodology is proposed to capture the effect of ACI to WCDMA system when TxBF is applied in M-WiMAX DL. For M-WiMAX UL, RxBF is utilized to increase the received signal power and to reduce the interference. Through system level Monte Carlo simulation with voice and data traffic in WCDMA UL, considering the ACI coming from M-WiMAX DL, we find that 5MHz guard band can provide about 19% gain on throughput and capacity loss in WCDMA UL at most. Applying TxBF with 4 antenna elements in M-WiMAX DL is able to provide another 8% and 9% gain at most in WCDMA UL comparing the case of SISO system for voice and data services, respectively. While in the scenario of WCDMA DL interfering to M-WiMAX UL, around 14% gain on the throughput loss and 73% gain on the modulation efficiency are observed at most in M-WiMAX UL due to the utilization of RxBF with 4 antenna elements. Through the observation on the simulation results, we find that the TxBF gain on throughput and capacity loss is proportional to the ACI decrease, which is also simply proved in theory. But the gain provided by the RxBF in M-WiMAX UL is inversely proportional to the ACI. Through considering more practical environment and the effect of additional channel filter, we find that RxBF can provide 4.3% and 13.97% gain on throughput and modulation efficiency with 8 antenna elements when ACI coming from WCDMA DL, respectively. TxBF with 8 antenna elements in M-WiMAX DL, can reduced the ACI induced loss to 1.07% and 1.05% on throughput and capacity, respectively. Based on the simulation results in the more practical environment and the effect of additional channel filter and smart antennas, we conclude that guard band is necessary to protect the M-WiMAX and WCDMA systemsfrom adjacent channel interference, and 8 antenna elements are enough to make the influence of adjacent channel interference negligible.

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