Mitigation of Inter-Cell Interference in the WiMAX System

Jae-Heung Yeom and Yong-Hwan Lee
School of Electrical Engineering and INMC
Seoul National University
Kwanak P. O. Box 34, Seoul, 151-600 Korea
E-mail: jhyeom@ttl.snu.ac.kr, ylee@snu.ac.kr

***Abstract* - The Worldwide Interoperability for Microwave Access (WiMAX) can provide wireless services at high rates even in high mobility, but it can suffer from serious inter-cell interference (ICI) near the cell boundary. To mitigate the ICI problem in the downlink of mobile-WiMAX, we consider combined use of interference avoidance and cancellation techniques in addition to inter-sector coordination, maximizing the user capacity in a seamless manner. To make the proposed scheme realizable, we maximize the geometry capacity. Simulation results show that the proposed scheme can improve the capacity of users near the cell boundary over the conventional schemes and provide flexibility in resource allocation.**

I. INTRODUCTION

The Worldwide Interoperability for Microwave Access (WiMAX) (or IEEE 802.16e) has been proposed to support wireless data services at high rates comparable to wire-line schemes such as the digital subscriber line (DSL) and it is being considered as a migration path toward next generation wireless systems [1]. Recently, a version of Mobile-WiMAX (m-WiMAX), called WiBro, has been deployed in Korea.

Since m-WiMAX considers the use of universal frequency reuse, it may suffer from inter-cell interference (ICI) near the cell boundary. In fact, the spectral efficiency in the worst channel condition can be reduced up to one 120th of that in the best channel condition (i.e., QPSK-1/12 with 3-time re-transmissions versus 64QAM-5/6 with a single transmission) [12]. As a consequence, when the m-WiMAX provides real-time traffic services at a rate of 512 Kbps near the cell boundary, it may need to allocate the whole downlink resources to a single user, which is practically unacceptable to service providers. Unless the m-WiMAX can significantly improve the spectral efficiency particularly near the cell boundary, it may not be distinguishable from incumbent 3G systems. Thus, it is highly required to alleviate the ICI problem in the m-WiMAX system.

Conventional ICI mitigation techniques for packet-based orthogonal frequency division multiple access (OFDMA) systems include interference avoidance (IA), interference randomization, interference cancellation and inter-sector coordination [2]. IA schemes dynamically allocate the channel resource to avoid ICI by exchanging the inter-cell information [3]. Reuse partitioning techniques determine the reuse factor according to the interference condition for IA in OFDMA systems [3-5]. Fractional frequency reuse (FFR) techniques can be applied to avoid overlapped use of frequency resources by adjacent cells in response to ICI condition. However, they may limit the peak transmission rate due to reduced reuse factors. Besides they have not been considered with combined use of other ICI mitigation techniques such as frequency hopping (FH) and ICI cancellation in the receiver [6]. Interference randomization schemes employ cell-specific scrambling and FH techniques to whiten the ICI. However, they may not be effective in full loading environments. On the other hand, by canceling out the ICI with the use of inter-cell channel state information (CSI), interference cancellation schemes can increase the signal-to-interference power ratio (SIR) even in full loading environments [7]. Inter-sector coordination techniques originated from softer handoff in the CDMA can provide a diversity gain [8]. They can handle real-time traffic services because the information between the sectors can be exchanged in real-time. By making two sectors transmit the same signal, mobile station (MS) can obtain a delay diversity gain instead of interference [9]. Since this diversity is the same as cyclic shift transmit diversity, the performance depends on the propagation delay between the sectors and the channel coder rate [10].

The shortages of the above conventional ICI mitigation schemes can be alleviated by employing them in a collaborative manner. Although previous works considered the mitigation of ICI in the m-WiMAX system, they did not consider combined use of these ICI mitigation schemes to get somewhat synergy effect [11]. In this paper, we consider combined use of ICI mitigation techniques to maximize the user capacity near the cell boundary. We propose an ICI mitigation strategy applicable to the downlink of the m-WiMAX system in response to the change of ICI condition.

Following Introduction, Section II briefly describes how to combine ICI mitigation techniques in the m-WiMAX system. New strategies to mitigate the ICI in the m-WiMAX system are

This work was in part supported by the KT research project.

1-4244-0957-8/07/$25.00 ©2007 IEEE

discussed in Section III and their performance is verified by computer simulation in Section IV. Finally, conclusions are given in Section V.

II. SYSTEM MODELING

A. Combined use of IA and FH

We consider combined use of IA and FH techniques for better mitigation of ICI in the m-WiMAX. The m-WiMAX can support multiple zones each of which utilizes subcarrier permutation and multi-antenna techniques according to the operation environments [12]. Subcarrier permutation is deeply associated with ICI mitigation techniques. A mode called partial usage of subchannels (PUSC) first permutes the subcarriers in the major group that comprises several clusters and then in the clusters [12]. The FH pattern of neighboring cells can be controlled using parameter *DL_PermBase*. Although parameter *Use_All_SC_indicator* is set to 1, IA techniques can be employed when the neighboring cells use the same *DL_PermBase* and the resource allocation described in what follows.

Consider the resource allocation for IA in the PUSC mode as illustrated in Fig. 1. The whole frequency resource is divided into three bands; F_a, F_b and F_c, where F_{abc} denotes the use of band F_a, F_c and F_c, and F_{ac} denotes the use of band F_a and F_c (i.e., the frequency reuse factor is 2/3). The divided frequency resources are allocated to users according to the ICI condition. For example, when the MS in sector α receives strong interference from sector γ, the frequency resource in F_{ab} is allocated to users in sector α and β, not to users in sector γ. If the MS in sector α receives strong interference from sector β and γ, the frequency resource in F_a is allocated to users in sector α, not to users in sectors sector β and γ. Although the IEEE802.16e-2005 specification recommends the use of two reuse factors, it can be possible to use multiple reuse factors by allocating the frequency resource as in Fig. 1 by making the neighboring cells use the same *DL_PermBase*. Thus, IA and FH schemes can simultaneously be applied to the PUSC mode.

B. Cooperation with transmitter for interference cancellation

The receiver can cancel out the ICI in the spatial domain using multiple receive antennas when the signal is transmitted using a less spatial dimension than that of the receiver [14]. The use of transmit beamforming can compensate for the signal level reduction due to interference cancellation in the receiver and can also increase the received level of dedicated pilot signal, enhancing the channel estimation performance. Thus, the receiver may cancel out the ICI at each frame by decorrelating the desired signal with the ICI with full CSI. It is required for the transmitters to use inter-cell scrambling patterns orthogonal to each other by properly managing parameter *PRBS_ID* [12].

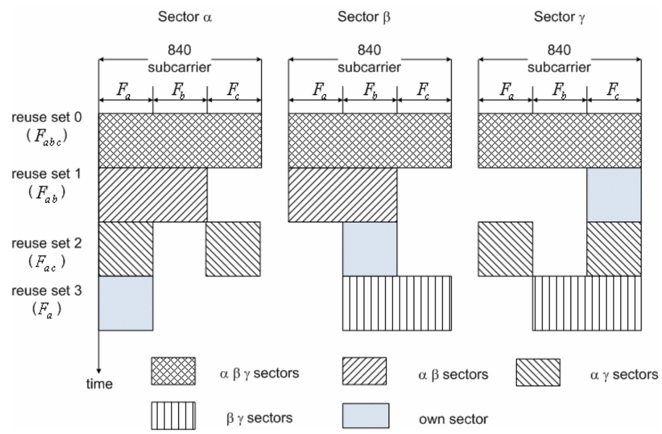


Fig. 1. Resource allocation according to the reuse factor in the PUSC mode.

C. Inter-sector beamforming

Inter-sector beamforming can be employed to alleviate the shortcomings of the inter-sector diversity with time division duplex (TDD) reciprocity. The uplink sounding signal transmitted near the sector boundary can be received at least by two sectors, enabling the use of inter-sector beamforming. The inter-sector beamforming can yield an array gain at least two times that of the single-sector beamforming. It can also avoid dominant inter-sector interference as being described in Section III.

Consider the use of a (2×2) MIMO in the downlink and a (1×2) SIMO in the uplink as in the m-WiMAX operation profile [13]. Fig. 2 illustrates an inter-sector beamforming, where sector α and β can generate beam-formed signal based on the received uplink sounding signal $\mathbf{u}_\alpha$ and $\mathbf{u}_\beta$ from antenna 1 of MS. The ICI represented by $\mathbf{H}_i x_i$ can be suppressed in the downlink by using a linear minimum mean squared error (MMSE) type filter with coefficient [14]

$$\mathbf{v_{opt}} = \mathbf{K_z^{-1}g} \tag{1}$$

where $\mathbf{g}$ is given by

$$\mathbf{g} = \mathbf{H}_\alpha \mathbf{u}_\alpha + \mathbf{H}_\beta \mathbf{u}_\beta = \begin{bmatrix} \|\mathbf{h}_{\alpha,1}\| \\ \mathbf{h}_{\alpha,2} \dfrac{\mathbf{h}_{\alpha,1}^*}{\|\mathbf{h}_{\alpha,1}\|} \end{bmatrix} + \begin{bmatrix} \|\mathbf{h}_{\beta,1}\| \\ \mathbf{h}_{\beta,2} \dfrac{\mathbf{h}_{\beta,1}^*}{\|\mathbf{h}_{\beta,1}\|} \end{bmatrix} \tag{2}$$

and $\mathbf{K}_z$ is the covariance of the noise plus interference given by

$$\mathbf{K}_z = \mathbf{H}_i \mathbf{H}_i^* + N_0 \mathbf{I} \tag{3}$$

Here, $(\bullet)^*$ denotes transpose conjugate and N_0 denotes the spectral density of additive white Gaussian noise.

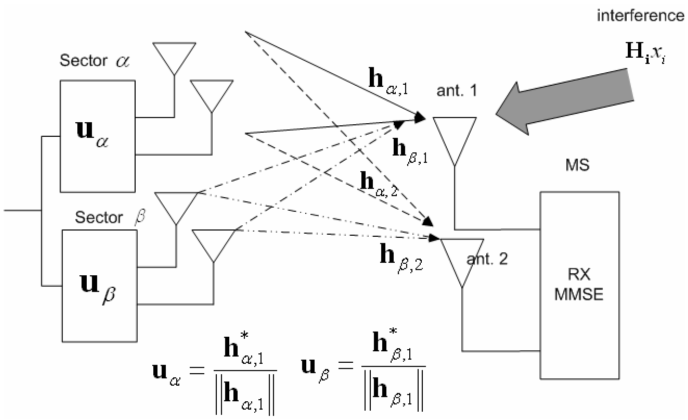


Fig. 2. Inter-sector beamforming with two sector antennas and MMSE receiver.

III. Proposed ICI Mitigation Strategy

Most of conventional IA techniques only consider the amount of ICI. If the ICI environment (e.g., dominant inter-sector interference in its own cell and dominant ICI from other cells) can be considered in addition, they may further increase the capacity. Previous section has briefly discussed how various ICI mitigation techniques can be combined for further improvement of m-WiMAX performance. In this section, we consider combined use of ICI mitigation techniques to maximize the capacity of users near the cell boundary.

The capacity can be represented in terms of the reuse set and the carrier-to-interference-and-noise power ratio (CINR) as [14]

$$C_i = \rho_i \log_2(1+\eta \cdot \gamma_i) \qquad (4)$$

where i is the index of reuse set, η is a parameter related to the implementation loss, ρ_i is the reuse factor for index i and γ_i denotes the SINR for index i. Since the CINR is mainly affected by the ICI in the cell boundary environments, we consider the improvement of the capacity with and without the use of IA techniques.

We first determine the reuse set that maximizes the user capacity with the use of IA. Then, we consider the use of inter-sector coordination according to the ICI environment to additionally consider the use of frequency resource which is not considered by IA. When the receiver is equipped with multiple receive antennas, we also consider the cancellation of dominant interference from a neighbor cell to further utilize the frequency resource by IA.

Consider the use of three sectors for each cell, called sector α, β and γ. Assuming the target user is in sector α of cell 0, define the reuse set φ_i of the target user by

$$\varphi_0 = \{\alpha, \beta, \gamma\},\ \varphi_1 = \{\alpha, \beta\},\ \varphi_2 = \{\alpha, \gamma\},\ \varphi_3 = \{\alpha\}. \qquad (5)$$

Note that φ_0, φ_1, φ_2 and φ_3 correspond to F_{abc}, F_{ab}, F_{ac} and F_a in Fig. 1, respectively. Then, the corresponding reuse factor is given by $\rho_0 = 1$, $\rho_1 = \rho_2 = 2/3$, and $\rho_3 = 1/3$. Let P_{3n+k} be the received signal strength (RSS) from sector k of cell n, via parameter *MOB_SCN_REP* [12].

STEP 1: Determine the reuse set index i_1 achieving maximum geometry capacity for IA as [14]

$$i_1 = \arg\max_{i\in\{0,1,2,3\}} \rho_i \log_2(1+\eta G_{i,1}). \qquad (6)$$

Then, the corresponding maximum geometry capacity is given by

$$C_{i_1,1} = \rho_{i_1} \log_2(1+\eta G_{i_1,1}) \qquad (7)$$

where the geometry with the use of reuse set φ_i is given by [17]

$$G_{i,1} = \frac{g_{array} P_0}{\sum_{k\in\varphi_i} S_k + \sigma_w^2}. \qquad (8)$$

Here, σ_w^2 is the noise power of the MS, and g_{array} and S_k respectively denote the array gain and the interference from sector *k*. g_{array} is equal to 2 when transmit diversity is used. When the transmit beamforming is employed, it can be shown that [14]

$$\begin{aligned} g_{array} &= E\left[\mathbf{g}^*\mathbf{g}\right] \\ &= E\left[\left\|\mathbf{h}_{\alpha,1}\right\|^2 + \frac{\left|h_{\alpha,11}\right|^2\left|h_{\alpha,21}\right|^2 + \left|h_{\alpha,12}\right|^2\left|h_{\alpha,22}\right|^2}{\left\|\mathbf{h}_{\alpha,1}\right\|^2}\right] \approx 1.5 \end{aligned} \qquad (9)$$

where h is assumed to have zero mean and unit variance. S_k is represented by

$$S_k = \sum_{n=0}^{N_c-1} P_{3n+k,\neq 0} \qquad (10)$$

where N_c is the number of adjacent cells, and *k*=0, 1 and 2 correspond to sector α, β and γ, respectively. Note that the RSS P_0 from the serving sector is excluded in the calculation. After determining the optimum reuse set φ_{i_1}, we consider inter-sector coordination to increase the user capacity.

STEP 2: Determine the reuse set index i_2 achieving the maximum geometry capacity for inter-sector coordination as [14]

$$i_2 = \arg\max_{i\in D} 0.5\rho_i \log_2(1+\eta G_{i,2}) \qquad (11)$$

where $D = \{0\}$ for $i_1 = 1,2$ and $D = \{1,2\}$ for $i_1 = 3$. The corresponding maximum geometry capacity is given by

$$C_{i_2,2} = 0.5\rho_{i_2} \log_2(1+\eta G_{i_2,2}) \qquad (12)$$

where the constant 0.5 is due to simultaneous sharing of the same resource by two sectors and the geometry $G_{i,2}$ is given by

$$\mathrm{G}_{i,2} = \frac{g_{array} P_0}{\sum_{k \in \varphi_i} S_k - P_\mu + \sigma_w^2} \tag{13}$$

where $\mu \in \varphi_0 - \varphi_{i_1}$ for $i = 0$ and $\mu = i$ for $i = 1, 2$. Here, g_{array} denotes the inter-sector coordination gain and is equal to 4 when inter-sector diversity is used. When the inter-sector beamforming is employed, it can be shown that [14]

$$\begin{aligned} g_{array} &= E\left[\mathbf{g}^* \mathbf{g}\right] \\ &\approx E\left[\begin{array}{l} \left(\|\mathbf{h}_{\alpha,1}\| + \|\mathbf{h}_{\beta,1}\|\right)^2 + \dfrac{|h_{\alpha,11}|^2 |h_{\alpha,21}|^2 + |h_{\alpha,12}|^2 |h_{\alpha,22}|^2}{\|\mathbf{h}_{\alpha,1}\|^2} \\ + \dfrac{|h_{\beta,11}|^2 |h_{\beta,21}|^2 + |h_{\beta,12}|^2 |h_{\beta,22}|^2}{\|\mathbf{h}_{\beta,1}\|^2} \end{array}\right] \\ &\approx \left\{6 + 2\left[\Gamma\left(\frac{5}{2}\right)\right]^2\right\} \end{aligned} \tag{14}$$

where $\Gamma(\bullet)$ denotes the gamma function [15]. Since $G_{i,2}$ corresponds to the case when the transmitter additionally considers sector μ of all cells in addition to sectors in reuse set φ_{i_1}, the target user may have additional ICI from sector μ of neighbor cells but it can be free from the interference from sector μ of its own cell due to the inter-sector coordination. When the MS is equipped with multiple receiver antennas, it can mitigate dominant interference by a filtering process, enabling the transmission with the increase of reuse factor.

STEP 3: Determine the reuse set index achieving the maximum geometry capacity for the cancellation of specific interference as

$$i_3 = \arg\max_{i \in D} \rho_i \log_2(1 + \eta G_{i,3}). \tag{15}$$

The corresponding maximum geometry capacity is given by

$$C_{i_3,3} = \rho_{i_3} \log_2(1 + \eta G_{i_3,3})$$

where the geometry $G_{i,3}$ is given by

$$G_{i,3} = \frac{g_{array} P_0}{\sum_{k \in \varphi_i} S_k - P_{3\hat{m}+\mu} + \sigma_w^2} \tag{16}$$

where

$$\hat{m} = \arg\max_{0 \le m \le N_c - 1} P_{3m+\mu}. \tag{17}$$

Note that $G_{i,3}$ corresponds to the case when the transmitter additionally considers sector μ in addition to sectors of φ_{i_1} as in STEP 2, but it specifically excludes sector μ of cell $\hat{m}$ as the most dominant interference source. Thus, the target user may experience additional ICI from sector μ of all cells except the interference from sector μ of cell $\hat{m}$, which is suppressed by a cancellation filter. The use of a cancellation filter does not allow to get an array gain [16] and thus g_{array} is reduced by one half in (16).

Finally, the optimum reuse set index i_{opt} can be determined by finding the index of the proposed step that yields the maximum geometry capacity as

$$i_{opt} = i_{\hat{l}} \tag{18}$$

where

$$\hat{l} = \arg\max_{l \in \{1,2,3\}} C_{i_l, l}. \tag{19}$$

IV. Performance Evaluation

The performance of the proposed ICI mitigation scheme is verified in the downlink of WiBro by computer simulation. The simulation parameters are summarized in Table I. We assume that the MS can obtain the CSI of the strongest interfering cell using pilot signal scrambled by a cell-specific randomization code. The PUSC permutation is performed to obtain both IA and FH. For ease of verification, we assume that the BS allocates the resource to the MS at every frame time.

For reference, actual user capacity is calculated by averaging the capacity obtained from link adaptation at every frame. The simulation is performed in two geographical positions to investigate poor interference environments as illustrated in Fig. 3, where MS 1 located in a direction of 30 degrees experiences strong ICI from sector γ of cell 2 and inter-sector interference from sector β of its own cell simultaneously. It can also be seen that MS 2 in a direction of 60 degrees experiences strong ICI from sector β of cell 1 and sector γ of cell 2 simultaneously.

Fig. 4 (a) depicts the geometry capacity associated with the reuse set, where *Fabc_step1, Fab_step1, Fac_step1, Fa_step1, Fab_step2* and *Fac_step3* denote the geometry capacity calculated by $G_{0,1}$, $G_{1,1}$, $G_{2,1}$, $G_{3,1}$, $G_{1,2}$ and $G_{2,3}$, respectively. It can be seen that *Fa_step1* with reuse set index 3 is first chosen since reuse set φ_3 has the maximum geometry capacity by STEP 1, and then *Fab_step2* is chosen for the inter-sector beamforming with reuse set index 1 as the optimum reuse set through STEP 2. It can also be seen that the cancellation of interference from sector γ of cell 2 with the use of receiver filtering (i.e., *Fac_step3*) yields a geometry

TABLE I

SIMULATION PARAMETERS

PARAMETERS	Values
Number of 3-Sector Cells	19
Carrier frequency	2.3 GHz
Duplex	TDD
Frame duration	5 ms
Channel bandwidth	8.75 MHz
Cell radius	1 km
BS EIRP	57 dBm
MS noise figure	7 dB
# of BS TX/ RX antenna	TX: 2, RX: 2
# of MS TX/ RX antenna	TX: 1, RX: 2
Transmit antenna scheme	Beamforming
Max number of retransmission	3
HARQ feedback delay	2 frames
MCS	Profile for code type CTC [12]
Subcarrier allocatoin	PUSC
Path loss model	COST 231 - Hata Suburban [18]
BS antenna pattern	65°(-3dB) with 20dB front-to-back ratio
BS height	30 meters
MS height	1.5 meters
Cell loading factor	1
Channel model	ITU-R Pedestrian A 3km/h
Channel estimation	Perfect
Receiver algorithm	Linear MMSE

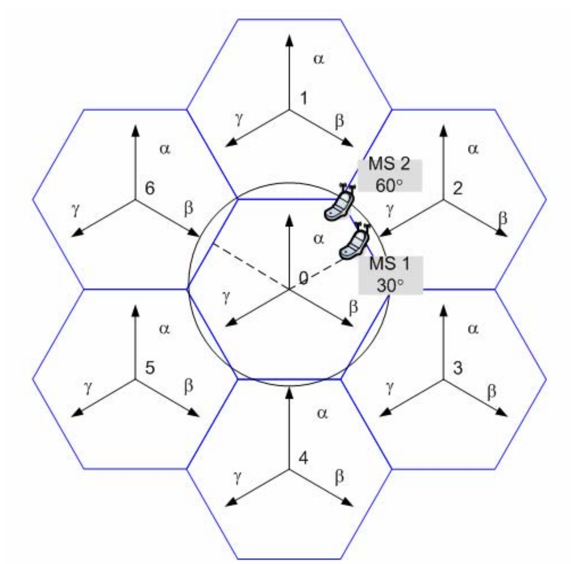
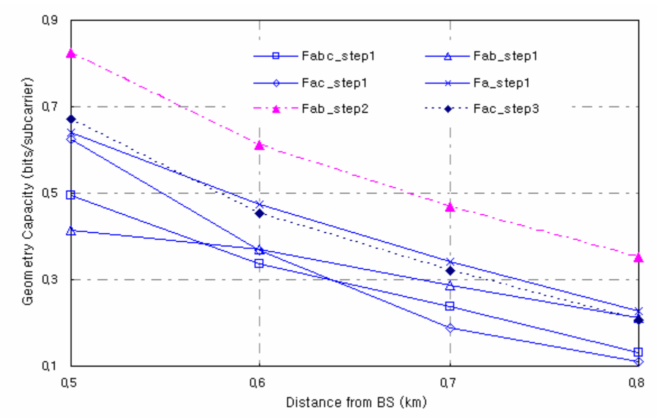


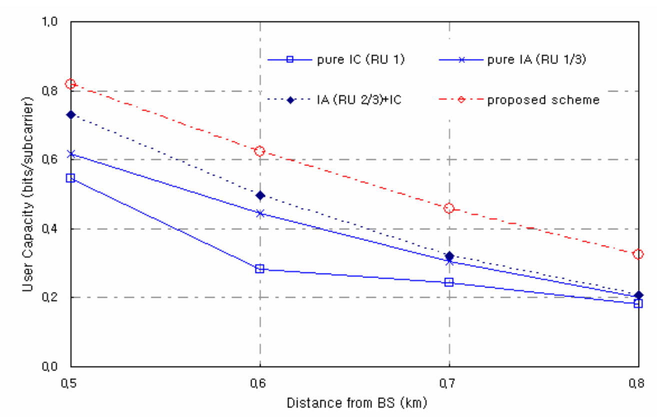
Fig. 3. Location of two MSs in sector α of cell 0

capacity similar to *Fa_step1*. Fig. 4 (b) depicts the user capacity, where legend IC and RU denote the interference cancellation and the reuse factor, respectively. It can be seen that the user capacity has a tendency similar to the geometry capacity. This indicates that the proposed steps can easily be applied to real ICI environments, enabling to determine the reuse set that maximizes the user capacity. It can be seen that the proposed scheme that combines IA and inter-sector beamforming outperforms the pure IA [5] and the pure IC [7] which do not consider combining other ICI mitigation schemes. It is shown in Fig. 4 (b) that the scheme (i.e., *IA (RU 2/3)+IC*) combining both IA and interference cancellation can be an alternative choice in case when inter-sector beamforming is not available.

Fig. 5 (a) depicts the geometry capacity according to the proposed each step. It can be seen that *Fabc_step1* with reuse set index 0 is chosen at a distance of 0.7 km, *Fab*_step1 with reuse set index 1 at 0.8 km and *Fa*_step1 with reuse set index 3 at a distance between 0.9 km and 1.1 km, respectively by STEP 1. But STEP 2 is not chosen because MS 2 is not in the sector boundary. It is shown that *Fa_step1* corresponding to reuse set

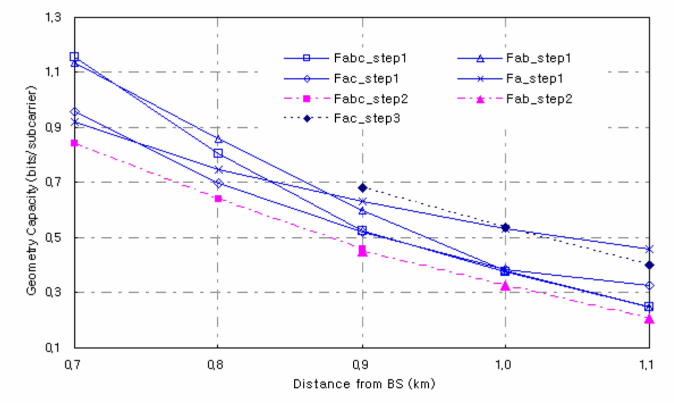


(a) Geometry capacity

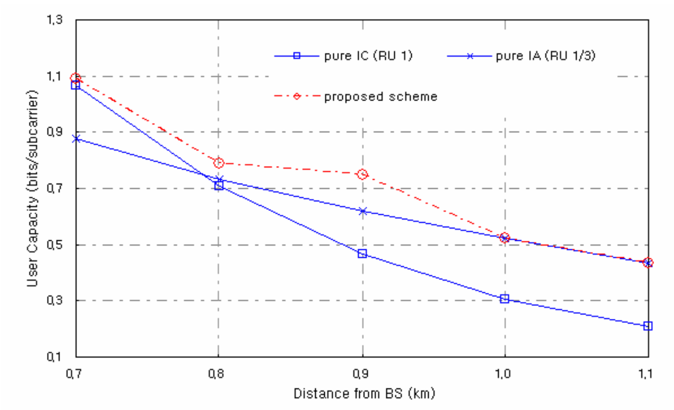


(b) User capacity

Fig. 4: Capacity of an MS in a direction of 30°.



(a) Geometry capacity



(b) User capacity

Fig. 5: Capacity of the MS in a direction of 60°.

index φ_3 is chosen by the STEP 1 from 1.0 km to 1.1 km since MS 2 experiences strong interferences from sector β and γ. *Fac_step3* is chosen by STEP 3 at 0.9 km and has geometry capacity similar to *Fa_step1* since MS 2 can cancel out the interference from sector γ of cell 2 and can avoid the ICI from sector β with IA. The scheme (i.e., *IA (RU 2/3)+IC*) combining both interference cancellation and IA can be an alternative choice when the reuse factor 1/3 is not available. It can be seen from Fig. 5 (b) that the proposed scheme outperforms the conventional schemes in terms of the user capacity. It can also be seen that the user capacity has a tendency similar to the geometry capacity as in Fig. 4.

V. CONCLUSIONS

We have proposed a new ICI mitigation strategy that maximizes the capacity of users near the cell boundary. The proposed strategy combines ICI mitigation techniques according to the ICI condition. We have presented how to generate multiple reuse factors in the PUSC mode according to the ICI environment. We have applied inter-sector beam-forming to avoid inter-sector interference and to obtain the beamforming gain. The simulation results show that the proposed strategy increases the capacity of users near the cell boundary and that the scheduler can allocate the resource with considerable flexibility.

REFERENCES

[1] G. Lawton, "What lies ahead for cellular technology," IEEE computer, vol. 38, pp. 14-17, June 2005.

[2] 3GPP TR 25.814, "Physical Layer Aspects for Evolved UTRA, section 71.2.6," V7.1.0, Sept. 2006.

[3] I. Katzela and M. Naghshineh, "Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: a Comprehensive Survey," IEEE wireless comm., vol. 3, no. 3, pp. 10-31, June 1996.

[4] J. Zander, "Generalized Reuse Partitioning in Cellular Mobile Radio," in Proc. IEEE VTC'93, pp. 181-184, May 1993.

[5] 3GPP TSG-RAN R1-050896, "Description and Simulations of Interference Management Technique for OFDMA Based E-UTRA Downlink Evaluation," Qualcomm Europe, Sept. 2005.

[6] 3GPP TSG-RAN R1-060368, "Performance of Inter-cell Interference Mitigation with Semi-static Frequency Planning for EUTRA Downlink," Texas instruments, Feb. 2006.

[7] 3GPP TSG-RAN R1-061233, "Performance evaluation of STTD and cyclic shift diversity in the presence of inter-cell/sector interference in Downlink MIMO system for LTE," Notel, May 2006.

[8] 3GPP TSG-RAN R1-050615, "Investigations on Inter-sector Diversity in Evolved UTRA Downlink," NTT DoCoMo, June 2005.

[9] A. Morimoto, K.Higuchi and M. Sawahashi, "Performance Comparison between Fast Sector Selection and Simultaneous Transmission with Soft-Combining for Intra-Node B Macro Diversity in Downlink OFDM Radio Access," in Proc. IEEE VTC'06, pp. 157-161, Mar. 2006.

[10] J. Tan and G. L. Stuber, "Multicarrier Delay Diversity Modulation for MIMO Systems," IEEE Trans. Wireless Commun., vol. 3, no. 5, pp. 1756-1763, Sept. 2004.

[11] A. Ghosh, J. G. Andrews, R. Chen and D. R. Wolter, "Broadband wireless access with WiMAX/802.16: current performance benchmarks and future potential," IEEE Comm. Magn., vol. 43, issue 2, pp. 129-136, Feb. 2005.

[12] IEEE Std 802.16e, "Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems," Dec. 2005.

[13] WiMAX Forum, "WiMAX Forum Mobile System Profile v1.0.0," May 2006.

[14] D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, 2005.

[15] J. G. Proakis, *Digital Communications*, Fourth Edition, McGraw-Hill Higher Education, 2001.

[16] A. Paulraj, R. Nabar and D. Gore, *Introduction to Space-Time Wireless Communications*, Cambridge Universe Press, 2003.

[17] 3GPP2 TSG-C C30-20021021-011, "1xEV-DV Evaluation Methodology-Addendum (Proposed V7)," NokIA, Oct. 2002.

[18] V.S. Abhayawardhana and I.J. Wassell, "Comparison of empirical propagation path loss models for fixed wireless access systems," in Proc. IEEE VTC'05, vol. 1, pp. 73-77, June 2005.