Downlink Capacity Analysis of Collaborative Crossed Timeslots in CDMA TDD Systems

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Abstract

Traffic asymmetry between uplink and downlink is expected to be a remarkable 3G characteristics in cellular mobile multimedia communications. A CDMA system using TDD is a good solution to deal with traffic asymmetry; however, the level of asymmetry may be significantly different between cells. In this paper, the use of crossed slots as a means of tackling this problem and supporting traffic hot spots, is examined. The use of crossed slots is restricted to within a specific range of a cell by an inter-cell interference and an E_b / N_0 requirement. We examine the radius of inner zone and discuss the capacity of downlink crossed slots for various neighboring cell environments. Computational results show that the capacity in the target cell can be increased by reducing the service ranges of neighboring cells. When all six neighbors reduce their service ranges by 20%, the capacity at the target cell crossed slot can be increased by 35%. Monte Carlo simulations are performed with large scale fading to verify the numerical analysis.

Keywords

CDMA-TDD, traffic asymmetry, crossed slot, inner zone, inter-cell interference

1. Introduction

Next generation mobile telecommunication systems which deliver multimedia services have asymmetry in traffic between uplink (UL) and downlink (DL). In spite of the high capacity offered by the symmetric FDD mode of UMTS, the DL bandwidth may be saturated while the UL bandwidth is not fully used. The TDD mode is one solution to alleviate this problem [1].

In a CDMA-TDD system, DL and UL are separated by different timeslots on the same frequency. A TDD system is capable of managing traffic asymmetry by assigning a different number of timeslots to DL and to UL dependent on traffic load. However, when the rate of asymmetry is different in adjacent cells, it leads to additional inter-cell interference. If two adjacent cells independently allocate timeslots according to their traffic asymmetry, some timeslots will be used for DL in one cell and for UL in the adjacent cell at the same time. These timeslots are called crossed slots [2]. Figure 1 illustrates the crossed slot interference problem. In the figure, timeslots are used for DL in cell 1 and UL in cell 2.

Base station (BS) 1 in DL interferes with BS 2 in UL, which causes BS-to-BS interference. On the other hand, mobile station (MS) 2 becomes an interference source to MS 1 in the neighbor cell, which leads to MS-to-MS interference. It is reported that BS-to-BS interference substantially decreases the system capacity [3]. MS-to-MS interference may also result in the degradation of performance when interfering and interfered MSs are close to the cell boundary [4]. It is shown that careful crossed slot allocation can outperform non-crossed slot allocation in terms of maximum capacity and forced termination probability [2, 5].

There are several papers which propose solutions to the crossed slot interference problem. Beam forming [6-8] enables a BS to focus its transmitted signal on the served MSs, decreasing the inter-cell interference at adjacent BSs. This desirable performance may only be achieved if there is no MS that uses the crossed slot on the path between the serving BS and the interfering BS.

The zone division scheme [2, 9] has the advantage of simplicity. It divides each cell into an inner zone and an outer zone and assigns crossed slots to MSs in the inner zone with reduced power. The performance of the zone division scheme is studied in [2, 9-10].

It should be noted that the main purpose of zone division is to reduce BS-to-BS and MS-to-MS inter-cell interference. Thus, the size of inner zone is one of the most important parameters to be determined. In this paper we investigate the maximum size of the inner zone for the crossed slot when adjacent cells collaboratively control the transmission power. The capacity of the crossed slot is also examined.

The remainder of this paper is organized as follows. In Section 2, the system model and timeslot allocation are explained. In Section 3, the capacity of DL crossed slot is analyzed mathematically. In Section 4, numerical and simulation results are presented to verify the results of analysis. Finally, conclusion is provided in Section 5.

2. System model and Distributed Timeslot Allocation

To investigate the size of inner zone that can employ DL crossed slots, we adopt TDD mode in UMTS Terrestrial Radio Access system, which is TD-CDMA technology [13]. A 10 ms frame is divided into 15 timeslots. A timeslot can be assigned for either DL or UL. We assume that the data rate of a timeslot per code is fixed to 8 Kbps by considering spreading factor 16 with 1/2 rate channel coding in both DL and UL. Single frequency allocation is assumed.

By assuming distributed timeslot allocation of each radio network controller (RNC), it collects DL and UL traffic loads in every cell. Then, it divides the 15 timeslots into DL and UL according to the average traffic loads. This is the RNC guideline of DL and UL timeslot allocation for its cells. The guideline is called nominal slot allocation. However, some cells may use more DL timeslots. If a cell uses timeslots at DL against the nominal slot allocation, we call these timeslots DL crossed slots.

To solve the interference problem in the implementation of crossed slots, a cell with crossed slots needs to regulate its interference to adjacent cells. To make DL crossed slots behave just like nominal UL timeslots in terms of interference we propose the following two conditions for the use of crossed slots.

Condition 1-DL: Inter-cell interference from a BS in cell of DL crossed slot should not exceed that from MSs in a cell of nominal UL slot.

Condition 2-DL: The E_b / N_0 [14, 16] in a cell of DL crossed slot should be higher than the minimum required DL E_b / N_0.

Under these conditions, we will investigate the maximum range of inner zone at a target cell and the capacity of each crossed slot in different interference situations. We assume the distance between a MS and a BS is known by GPS [11, 12]. As shown in Figure 2, when cell B with nominal UL slot reduces its service range, cell A with DL crossed slot can increase its inner zone coverage and accommodate more DL traffic. This situation is realistic when the traffic in cell B is sparse and MSs out of service range can be covered by other UL timeslots.

In order to analyze the situation in multi-cell environment, we assume that the target cell with the DL crossed slot is surrounded with six cells. We classify the surrounding cells into the following three groups depending on the DL and UL traffics.

Group A: cells which use DL crossed slot similar to the target cell

Group B: cells which use nominal UL slot and reduce service ranges

Group C: cells which use nominal UL slot and don't reduce service ranges

Cells in Group A have larger DL traffic than UL compared to the cells that use nominal UL slot. Cells in Group B have less UL traffic than cells in Group C enough to reduce their service ranges in the timeslot.

In this study we examine the size of inner zone and capacity increase of the crossed slot at the target cell when adjacent cells are in one of the above three groups. We also investigate cases when adjacent cells are a combination of Group A, B, and C. Note that each timeslot can have different combinations of the groups. The target cell is a member of Group A from the view of an adjacent cell. It can also be regarded as Group B or C in other timeslots if the neighboring cell has more DL traffic than the target cell.

3. Capacity analysis of downlink crossed slots

To simplify our analysis we assume circular cells with average path loss given by $kd^{-\nu}$. Cells are overlapped in their boundaries to allow for handover margin. Notations used throughout the paper are listed in Table 1. Superscripts D and U represent DL and UL respectively. The other superscripts A, B, C, and T indicate Group A, Group B, Group C, and the target cell respectively.

3.1 Analysis between the target cell and adjacent cells in Group C

In the first scenario, the target cell employs the DL crossed slot and all adjacent cells use the nominal UL slots in their full ranges. To have a practical bound of the size of inner zone, we consider the worst case MS in the DL crossed slot. Thus, MS *t* in the DL crossed slot is assumed to be located on the circle with radius *r*.

To decide the transmission power of the BS at the target cell that satisfies Condition 1-DL, let $P^{D,T}$ be the transmission power at target BS for DL crossed slot. Also, let $I^{D,T}$ be the interference power from target BS received at an adjacent BS in Group C, $I^{U,C}$ be the average inter-cell interference that a MS generates, and $n_{\max}^{U}$ be the number of MSs that can be served in one UL timeslot. By Condition 1-DL, inter-cell interference from target BS has to be less than total inter-cell interference from MSs in another cell of Group C as in Figure 3. Therefore, the inequality $I^{D,T} = P^{D,T} k D_{BB}{}^{-\nu} \le n_{\max}^{U} I^{U,C}$ should be satisfied, where D_{BB} is the distance between two BSs. Thus, the maximum transmission power at the target cell $P^{D,T}$ is determined by the following equation.

$$P^{D,T} = \frac{n_{\max}^{u} I^{U,C}}{k D_{BB}{}^{-\nu}} \quad (1)$$

Now, for Condition 2-DL, we need to compute MS-to-MS inter-cell interference from cells in Group C. We employ polar coordinate. We assume that the target BS is located at (0, 0) and the tagged MS t in the target cell is at $(r,0)$. MS t receives MS-to-MS inter-cell interference from MSs using nominal UL slots in adjacent cells in Group C. We assume MSs in Group C are uniformly distributed. Let us consider adjacent cell j whose BS is located at $\left(D_{BB}, \frac{2\pi j}{L}\right)$. When we denote $D_{jt}(r)$ as the distance between MS t in the target cell and BS j, it is given by

$$D_{jt}(r) = \sqrt{D_{BB}{}^{2} + r^{2} - 2D_{BB} r \cos\frac{2\pi j}{L}} \quad (2)$$

To obtain distance from MS t and an arbitrary MS m in cell j, we consider another coordinate where the position of BS j is (0, 0) and that of MS t is $\left(D_{jt}(r),0\right)$. Now, consider an arbitrary MS m in cell j whose position is (a,θ). Then, the distance between MS t and m, $D_{mjt}(a,\theta,r)$, is given by

$$D_{mjt}(a,\theta,r) = \sqrt{D_{jt}{}^{2}(r) + a^{2} - 2D_{jt}(r) a\cos\theta} \quad (3)$$

Let $I_{mjt}^{U,C}(a,\theta,r)$ be the interference power that MS t in the target cell receives from MS m in adjacent cell j. From Equation (3), $I_{mjt}^{U,C}(a,\theta,r)$ is given by

$$I_{mjt}^{U,C}(a,\theta,r) = kP_{a}^{U} D_{mjt}(a,\theta,r)^{-\nu}, \text{ where } P_{a}^{U} = P_{D}^{U}\frac{D^{-\nu}}{a^{-\nu}} \quad (4)$$

Thus, $\bar{I}_{mjt}^{U,C}(r)$, the expected value of $I_{mjt}^{U,C}(a,\theta,r)$, can be expressed as follows.

$$\bar{I}_{mjt}^{U,C}(r) = \int_{0}^{D}\int_{0}^{2\pi} I_{mjt}^{U,C}(a,\theta,r)\frac{a}{\pi D^{2}}\,d\theta da$$

$$= \frac{kP_{D}^{U} D^{-(\nu+2)}}{\pi}\int_{0}^{D}\int_{0}^{2\pi} a^{\nu+1}\left(D_{jt}{}^{2}(r) + a^{2} - 2D_{jt}(r)a\cos\theta\right)^{-\nu/2} d\theta da \quad (5)$$

Since $n_{\max}^U$ MSs simultaneously transmits signals in cell j, the total amount of interference from cell j to MS t, $I_j^{U,C}(r)$, is computed by

$$I_j^{U,C}(r) = n_{\max}^u \bar{I}_{mjt}^{U,C}(r) \tag{6}$$

Let $\left(E_b / N_0\right)^{D,T}$ be the E_b / N_0 value of a MS in DL crossed slot and $n_{\max}^D$ be the maximum number of MSs in a DL slot. Then, we have

$$\left(\frac{E_b}{N_0}\right)^{D,T} = \frac{W}{SR}\frac{kP^{D,T} r^{-\nu} / n_{\max}^D}{(1-\alpha)kP^{D,T} r^{-\nu} + \sum_{j=1}^{L} I_j^{U,C}(r) + P_N} \tag{7}$$

By letting $\left(E_b / N_0\right)^{D,T}$ be the same as the E_b / N_0 requirement γ^D for DL service, the maximum allowable size of inner zone can be obtained. When the radius of the target cell is 0.65km, the maximum size of inner zone that meets $\gamma^D = 7\,\text{dB}$ becomes $r = 0.38\,\text{km}$ which corresponds to 58.8% of the cell radius.

3.2 Analysis between the target cell and adjacent cells in Group B

In the second scenario, we analyze the target cell which is surrounded by cells in Group B. It should be noted that neighboring cells belong to Group B only when their UL traffic loads are small enough to reduce their service ranges.

When the adjacent cells in Group B reduce their service ranges, they generate reduced inter-cell interference. Therefore, inner zone of the target cell is enlarged. As in Section 3.1 the transmission power of the BS at the target cell is restricted by Equation (1). For Condition 2-DL, we assume the reduced transmission range of a cell in Group B is D' and MSs are distributed within the range. Then, the average MS-to-MS interference in the second scenario is computed as

$$\bar{I}_{mjt}^{U,B}(r) = \int_0^{D'}\int_0^{2\pi} I_{mjt}^{U,B}(a,\theta,r)\frac{a}{\pi D'^2}\,d\theta da$$

$$= \frac{kP_D^U D^{-v}}{\pi D'^2}\int_0^{D'}\int_0^{2\pi} a^{v+1}\left(D_{jt}{}^2(r) + a^2 - 2D_{jt}(r)a\cos\theta\right)^{-v/2} d\theta da \tag{8}$$

By computing total amount of interference from cell j to MS t as in Equation (6), the E_b / N_0 of a MS in DL crossed slots is computed as

$$\left(\frac{E_b}{N_0}\right)^{D,T} = \frac{W}{SR}\frac{kP^{D,T}r^{-v}/n_{\max}^D}{(1-\alpha)kP^{D,T}r^{-v} + \sum_{j=1}^{L} I_j^{U,B}(r) + P_N} \tag{9}$$

From Equation (9) the maximum radius r of the inner zone at the target cell is obtained when $(E_b / N_0)^{D,T}$ equals to the minimum requirement γ^D. In this scenario, due to the reduced transmit power of cells in Group B, inner zone of the target cell satisfying the Condition 2-DL is enlarged compared to the first scenario in Section 3.1. When all six adjacent cells reduce their service ranges to 50% of the cell radius, the inner zone is expanded to 72.8% of the cell radius.

3.3 Analysis between the target cell and adjacent cells in Group A

In the third scenario, all adjacent cells employ DL crossed slots as the target cell. By Condition 1-DL, the transmission power at the target BS is limited by $P^{D,A} = \frac{n_{\max}^u I^{U,C}}{kD_{BB}{}^{-v}}$ from Equation (1). With the distance $D_{jt}(r)$ between BS j in Group A and MS t in the target BS, the interference from the cells in Group A is computed as

$$I_j^{D,A}(r) = kP^{D,A}D_{jt}{}^{-v}(r) \tag{10}$$

Note that $P^{D,A}$ is regulated so that a BS of DL crossed slot emits less inter-cell interference than that from a cell of Group C. In other words, $I_j^{D,A}$ is regulated not to exceed $I_j^{U,C}(r)$. Thus, the DL crossed slot of adjacent cells can be regarded as the nominal UL slot in view of inter-cell interference.

3.4 Analysis between the target cell and adjacent cells in Group A, B, and C

When adjacent cells are a combination of Group A, B, and C, the inter-cell interference from adjacent cells depends on the location of MS t in the target cell. Thus, let the location of MS t in the target cell be (r,δ). Then the distance $D_{jt}(r,\delta)$ between the BS in the adjacent cell j and MS t becomes

$$D_{jt}(r,\delta) = \sqrt{D_{BB}{}^2 + r^2 - 2D_{BB} r \cos\left(\frac{2\pi j}{L} - \delta\right)} \tag{11}$$

Using Equation (11), average inter-cell interference can be computed by location of the MS at (r,δ). Thus, the average inter-cell interference is not dependent on the locations of cells in Group A, B, and C, but dependent on the number of cells in each group.

Let b and c represent the number of cells in Group B and C respectively. Then the E_b / N_0 of a MS which uses the DL crossed slot is computed as

$$\left(\frac{E_b}{N_0}\right)^{D,T} = \frac{W}{SR} \frac{kP^{D,T} r^{-v} / n_{\max}^{D}}{(1-\alpha)kP^{D,T} r^{-v} + \left(\sum_{j=1}^{c} I_j^{U,C}(r) + \sum_{k=1}^{b} I_k^{U,B}(r) + \sum_{l=1}^{L-(c+b)} I_l^{D,A}(r) \right) + P_N} \tag{12}$$

In the numerical experiment, we will investigate the capacity and the size of inner zone at the target cell with different numbers of cells in each group.

3.5 Capacity increase at the target cell with adjacent cells in Group C

It is clear that cells in Group C which don't reduce their service ranges generate higher inter-cell interference than cells in Group B. Therefore, the more cells in Group C are adjacent to a target cell, the less the capacity of the DL crossed slots in the target cell.

The high inter-cell interference from cells in Group C can be resolved by employing an advanced time slot assignment in TDD. In a cell of Group C, by assigning UL slots which correspond to the DL crossed slots in a target cell only to those MSs close to the BS, the interference can be reduced as in cells of Group B. UL slots that correspond to UL in the target cell can be assigned to users away from the BS. By letting S_U and S_C be the number of nominal UL and DL crossed slots respectively, a cell in Group C can implement the advanced slot assignment with inner zone radius *r* that satisfies

$$\pi r^2 / \pi(D^2 - r^2) = S_C / (S_U - S_C) \tag{13}$$

Thus, we have

$$r = D\sqrt{S_c / S_u} \tag{14}$$

By assigning UL slots to MSs within the range *r* of cells in Group C, the capacity of DL crossed slot at the target cell increases as in Equation (9), which is the case for cells in Group B.

4. Numerical Results

Numerical results of the analysis in Section 3 are presented with parameters in Table 2, which are widely accepted parameters in the mobile communications practice. k and v are selected to consider Okumura-Hata propagation model for urban area with BS height of 30m, MS height of 1.5m, and carrier frequency of 1950 MHz [14]. Noise figure (NF) of 7dB for DL and 3dB for UL is considered to calculate background noise power P_N. When considering thermal noise density of -174dBm, $P_N = -174\text{dBm} + 10\log_{10}(W) + NF$.

With the maximum transmission power of 10W for BS and 200mW for MS, we obtain $n_{\max}^D = 5.16$ from E_b / N_0 requirement and load factor equation [14, 16] when every cell follows DL slot allocation. We also obtain $n_{\max}^U = 4.93$. Thus, we assume that the target cell and cells in Group A serve $n_{\max}^D = 5.16$ MSs, and cells in Group B and C serve $n_{\max}^U = 4.93$ MSs at one time slot. We consider cell radius of 0.65km throughout experiments since numerical results show similar trend for various cell radiuses.

Figure 4 shows the radius of inner zone at the target cell that uses the DL crossed slots. In the figure, xByC represents that x cells in Group B and y cells in Group C consist of the adjacent cells. Note that cells in Group A are equivalent to those in Group C in terms of inter-cell interference. As the number of cells in Group B increases, the size of inner zone at the target cell increases. When all adjacent cells are in Group C, the size of inner zone becomes 58.8% of the cell radius. It is extended to 72.8% of cell radius if all six neighbors reduce their ranges by 50%.

Figure 5 shows capacity increase at the target cell due to the reduced transmission ranges of neighbor cells in Group B. The capacity of target cell is 5.16 MSs in a slot when all six neighbors do not reduce their transmission ranges. However, its capacity is increasing as the number of cells in Group B increases. Let us assume that the size of inner zone is 58.8% of the cell radius. Then, the number of MSs reaches 7.56 when all six neighbor cells reduce their transmission ranges by 50%.

Table 3 shows the capacity increase with the DL crossed slots. Compared to the nominal slot allocation which employs 8 DL and 7 UL timeslots, the DL capacity is increased by approximately 22 Kbps for each crossed slot when all six neighbor cells reduce their transmission ranges by 50%. The table illustrates that the use of DL crossed slots with reduced transmission ranges in neighbor cells is a promising solution to tackle traffic asymmetry in the target cell.

Monte Carlo simulation is employed to verify numerical results. Parameters in Table 2 are used in the simulation. For the implementation of propagation loss, large scale fading is considered with the Okumura-Hata model. We assume that the large scale fading follows normal distribution in dB scale with zero mean and standard deviation of 8.0dB. The effect of the number of interfering cells is taken into account by examining the cases of 6 and 18 cells. As the number of interfers increases, the radius of inner zone is reduced. However, the difference is marginal. The decreae of inner zone radius is 2.9% with the 6B0C scenario and 3.5% with the 3B3C scenario. It means that the inteference from the closest cells is dominant.

Figure 6 shows the results of numerical analysis and simulation for the two scenarios 3B3C and 6B0C. Similar results are obtained with other scenarios. 18 interfering cells are considered for the simulation because it reflects more practical deployments of cellular systems. From the figure it is clear that the radius of inner zone at the target cell by the simulation well fits to the numerical analysis. The gap in the radius of inner zone between the two scenarios by the simulation is smaller than that by the analysis. This can be explained by the reduced interference effect by the cell nearest to the tagged MS and the shadowing effect by other neighboring cells in Group C.

The effect of large scale fading is shown in Figure 7. It depicts the probability density function of inner zone radius, when the scenario 3B3C is employed with 70% of service ranges for cells in Group B. Although our simulation results well fit to the analysis, each cell has different radius of inner zone due to the different value of large scale fading. It implies that crossed slots can be more useful in cells with larger inner zone. In the figure, 14% of cells have inner zone radius of more than 0.8*D*, while the average inner zone radius is 0.62*D*.

5. Conclusion

The capacity of a DL crossed slot is investigated with various scenarios of adjacent cells. The use of DL crossed slot at the target cell is restricted to an inner zone so that it acts like a nominal UL slot in terms of interference . The size of inner zone is determined by considering the inter-cell interference and the minimum E_b / N_0 requirement. When the radius of the target cell is 0.65km, the maximum size of inner zone r becomes 0.38km which corresponds to 58.8% of the cell radius if all neighbor cells use nominal UL slots.

The capacity increase of the target cell is examined by reducing the service ranges of neighbor cells. This situation is possible when the traffic in neighbor cells is sparse and MSs out of service range can be covered by UL timeslots that does not match the crossed slots. When all six neighbors reduce their service ranges by 20%, the capacity at target cell crossed slot is increased by 35%. The increase is 46%, when the service ranges at the neighbor cells is 50% of cell radius.

Computational results also show that the increase of transmission rate by each additional DL crossed slot well compensates the decrease of UL transmission rate by reducing the service ranges in neighbor cells. It suggests that the CDMA-TDD is a promising solution to cope with the temporary traffic asymmetry of DL and UL among cells when the service ranges are determined in the collaborative fashion.

Monte Carlo simulation is performed with large scale fading to verify the computational results. The result well supports our numerical analysis for the size of inner zone at the target cell that implements crossed slots. It also shows that some cells can employ larger inner zone than average owing to the different value of the large scale fading.

References

[1] J. Nasreddine and X. Lagrange, Time Slot Allocation Based on a Path Gain Division Scheme for TD-CDMA TDD Systems, IEEE Vehicular Technology Conference (VTC), Spring, 2003.

[2] W. S. Jeon and D. G. Jeong, Comparison of Time Slot Allocation Strategies for CDMA/TDD Systems, IEEE Journal on Selected Areas in Communications, Vol. 18, No. 7, 2000.

[3] X. Wu, L. L. Yang, and L. Hanzo, Uplink Capacity Investigations of TDD/CDMA, IEEE Vehicular Technology Conference (VTC), Spring, 2002.

[4] L. C. Wang, S. Y. Huang, and Y. C. Tseng, Interference Analysis of TDD-CDMA Systems with Directional Antennas, IEEE Vehicular Technology Conference (VTC), Fall, 2003.

[5] S. Ni and L. Hanzo, Genetically Enhanced Performance of a UTRA-like Time-Division Duplex CDMA Network, IEEE Vehicular Technology Conference, Spring, 2005.

[6] J. S. Blogh and L. Hanzo, Third-Generation Systems and Intelligent Wireless Networking

– Smart Antennas and Adaptive Modulation. John Wiley and IEEE Press, 2002.

[7] S. Ni, J. S. Blogh, and L. Hanzo, On the network performance of UTRA-like TDD and FDD CDMA systems using adaptive modulation and adaptive beamforming, IEEE Vehicular Technology Conference (VTC), pp. 606-610, April, 2003.

[8] L. C. Godara, Application of antenna arrays to mobile communications, part 2: Beam-forming and direction-of-arrival considerations, Proc. IEEE, Vol. 85, pp. 1195-1245, Aug. 1997.

[9] F. Nazzarri and R. F. Ormondroyd, An Effective Dynamic Slot Allocation Strategy Based on Zone Division in WCDMA/TDD Systems, IEEE Vehicular Technology Conference, Fall, 2002.

[10] J. Lee, Y. Han, and D. Kwon, An Adaptive Time Slot Allocation Strategy for W-CDMA/TDD System, IEEE Vehicular Technology Conference, Spring, 2001.

[11] P. J. Czezowski, A. Morawej, and R. D McLeod, GPS Assisted Resource Allocation in Mobile Networks, Society for Computer Simulation, Vol.31 No.4, 1999.

[12] H. C. Son, J. G. Lee, and G. I. Jee, Mobile Station Location Using Hybrid GPS and a Wireless Network, IEEE Vehicular Technology Conference, pp. 2716-2720, 2003

[13] M. Haardt, A. Klein, R. Koehn, S. Oestreich, M. Purat, V. Sommer, and T. Ulrich, The TD-CDMA Based UTRA TDD Mode, IEEE Journal on Selected Areas in Communications, Vol. 18, No. 8, 2000.

[14] H. Holma and A. Toskala, WCDMA for UMTS, 3rd Edition, Wiley and Sons, 2004.

[15] D. Calin and M Areny, Impact of Radio Resource Allocation Policies on the TD-CDMA System Performance: Evaluation of Major Critical Parameters, IEEE Journal on Selected Areas in Communications, Vol. 19, No. 10, 2001.

[16] K. Sipilä, Z. C. Honkasalo, J. Laiho-Steffens, and A. Wacker, Estimation of Capacity and Required Transmission Power of WCDMA Downlink Based on a Downlink Pole Equation, IEEE Vehicular Technology Conference, 2000.

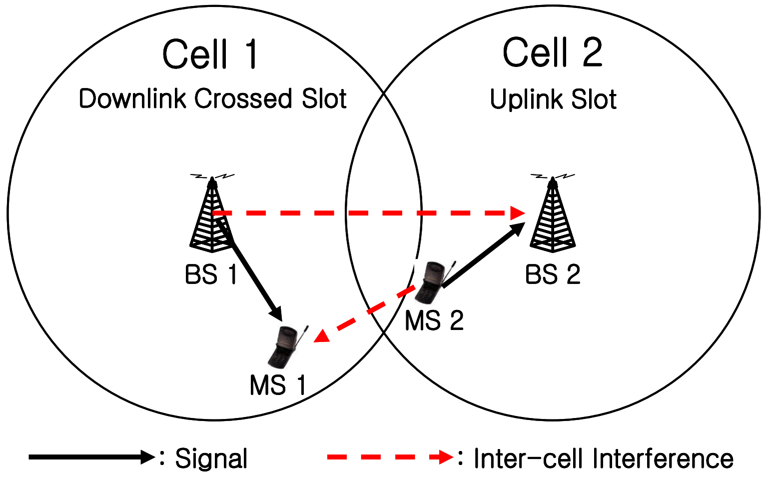

Figure 1. Crossed slot interference problem

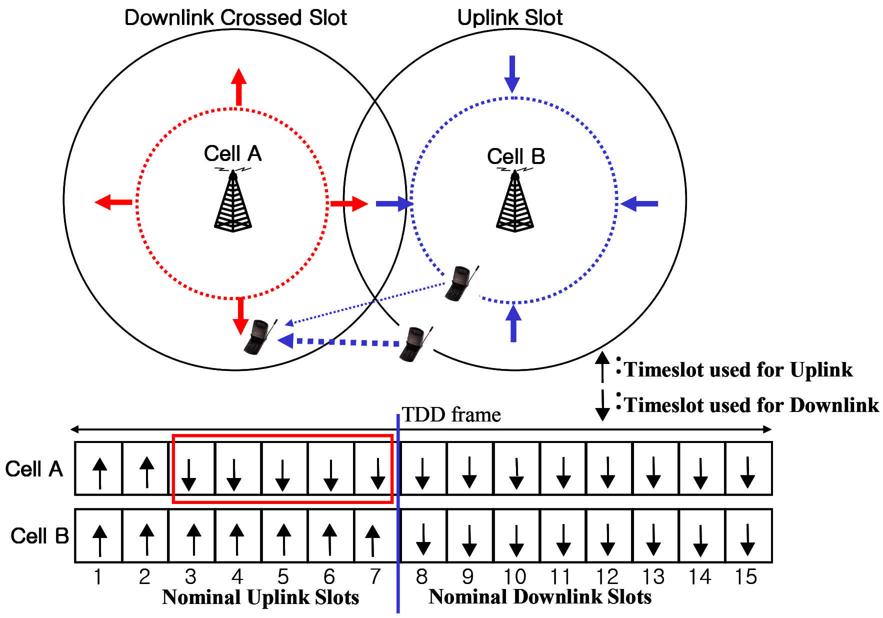

Figure 2. Inner zone of cell A can be enlarged when cell B reduces its range.

Table 1. Notations

Symbol	Definition
W	Spreading bandwidth
R	Data rate of an RU
S	Number of slots in a frame
ν	Path loss exponent
k	Coeffficient that adjusts pathloss with empirical model
α	Orthogonality factor in DL
L	Number of adjacent cells
D	Radius of a cell
r	Radius of inner zone
$P^{D,T}$	Transmission power of a target BS for DL crossed slots
P_x^U	Transmission power of a mobile in a cell (UL slot) when the distance from BS is x
n	Number of MSs in a cell in a timeslot

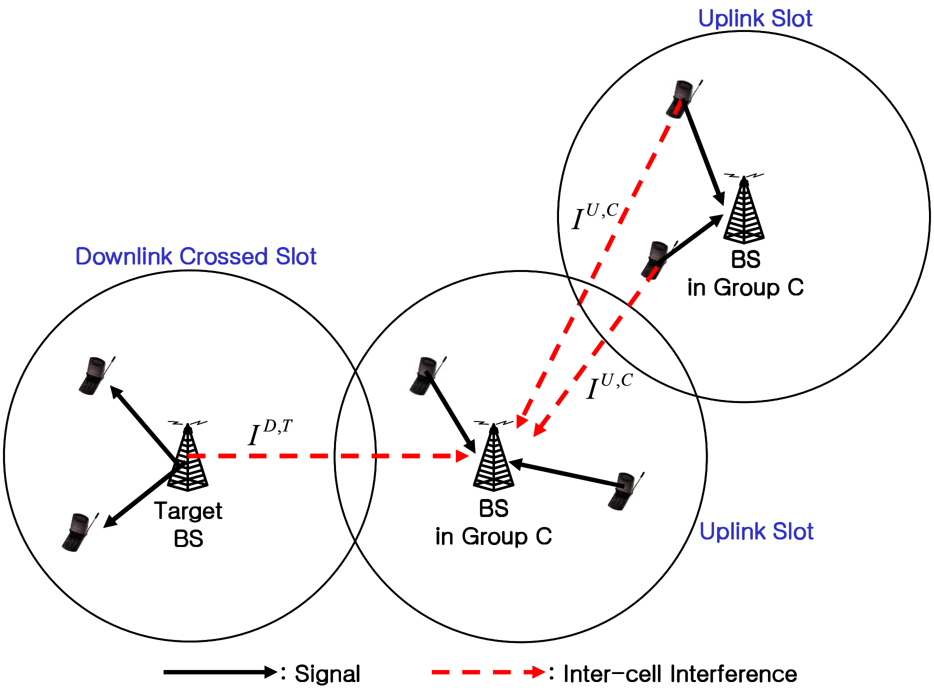

Figure 3. Inter-cell interference from DL crossed slot and UL slot

Table 2. Parameters used in numerical experiments

Parameters	Values
W	3840 Kbps
R	8 Kbps
S	15
L	6
P_N	-101.2dBm for DL -105.2dBm for UL
ν	3.5
k	-137.4dB
α	0.5
γ^D	7dB
γ^U	5dB

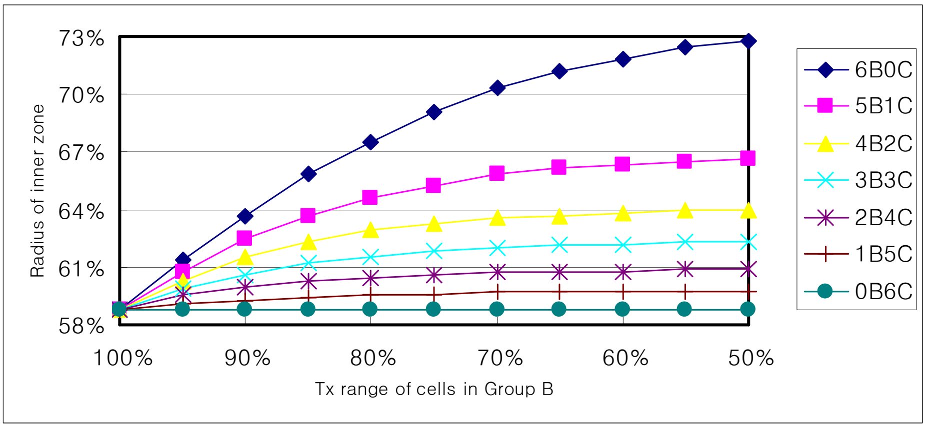

Figure 4. Radius of inner zone at the target cell

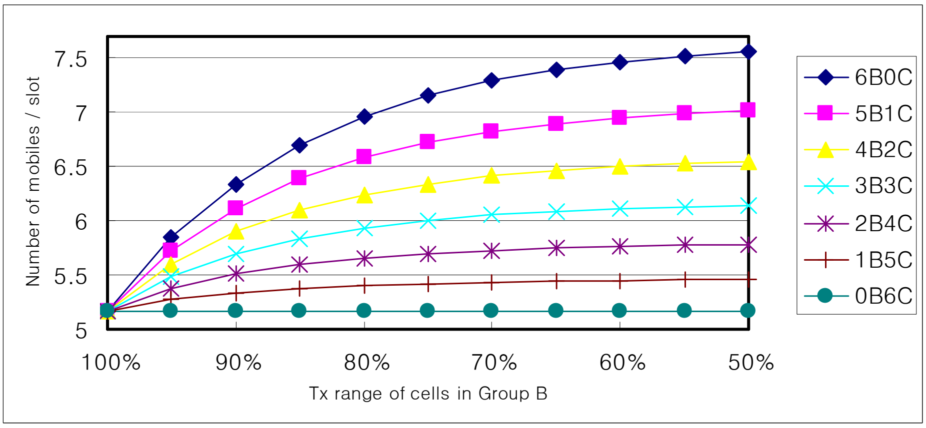

Figure 5. Number of MSs in a DL crossed slot

Table 3. Target cell transmission rate (Kbps) in a frame

Number of time slots			0B6C		6B0C	
Regular Uplink	Regular Downlink	Crossed Downlink	Uplink	Downlink	Uplink	Downlink
7	8	0	276.08	330.24	276.08	330.24
6	8	1	236.64	344.51	236.64	352.12
5	8	2	197.20	358.78	197.20	374.00
4	8	3	157.76	373.06	157.76	395.87

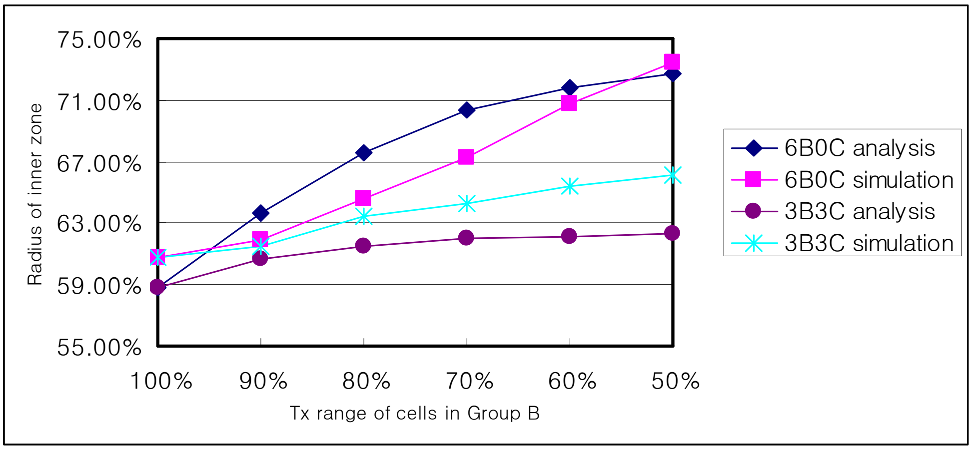

Figure 6. Comparison between analysis and simulation results

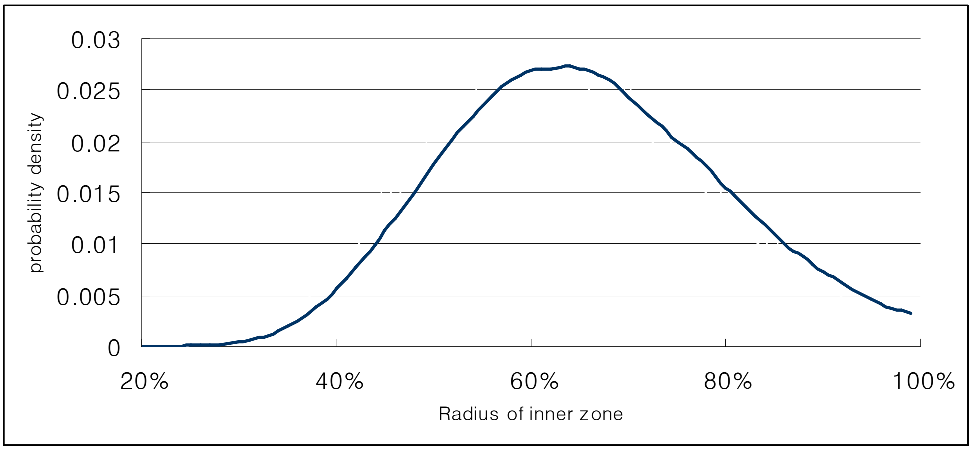

Figure 7. Probability density function of inner zone radius