The Impact of Beamforming, Power Control, and Sectorization on CDMA Capacity

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Abstrak

Kapasitas CDMA dibatasi oleh interferensi dan dapat dioptimalkan dengan menekan interferensi sehingga memenuhi kebutuhan layanan multiclass. Pada penelitian ini, dianalisa pengaruh penggunaan antena beamforming, pengendalian daya tak sempurna dan sektorisasi tak sempurna pada kapasitas user dari sistem CDMA reverse-link berdasarkan signal to interference ratio (SIR) pada pengirim mobile station (MS) dan penerima base station (BS). Beamforming digunakan dengan asumsi setiap elemen memiliki amplitudo arus identik dan jarak antar elemen yang sama. Sistem CDMA yang diteliti berbentuk sel makro heksagonal yang terdapat pada homecell-BS dan dibagi kedalam 3 sektor dengan beamwidth 120^o. Kapasitas user dipengaruhi oleh faktor pengendalian daya, jumlah elemen antena beamforming, jumlah sektor, besar sudut overlap akibat sektorisasi tidak sempurna, dan pengendalian daya tak sempurna, SIR dan processing gain CDMA. Hasil Penelitian menunjukkan bahwa Pengendalian daya dan Sektorisasi dengan antena beamforming menghasilkan kapasitas sistem multiclass CDMA lebih besar dibandingkan tanpa antena beamforming.

***Kata Kunci** : Beamforming, Pengendalian daya, sektorisasi, Multiclass, CDMA.*

Abstract

Capacity of CDMA was limited by interferences and could be optimalyzed by reduce interferences to fulfill requirements of multiclass services. In this research, the impact of imperfect power control and imperfect sectorization to reverse-link user capacity of CDMA system based on signal to interference ratio (SIR) by using beamforming at mobile station transmitter and base station receiver have been analyzed. Beamforming would be used with assumed each element has uniformly excited, equally spaced linear array. CDMA system use hexagonal macro cell in home cell base station, which divided effectively into 3 sectors with 120^o beam width. User capacities was influenced by power control factor, number of antenna beamforming elements and sectors, overlap angle due to imperfect sectorization, imperfect power control, SIR and processing gain CDMA. Results of this research indicate that the system with power control and sectorization using beamforming has larger capacity of multiclass system than without beamforming.

***Keywords**: Beamforming, Power Control, Sectorization, Multiclass, CDMA.*

1. Introduction

In the *code division multiple access* (CDMA) system, any user or mobile station (MS) using the same frequency at the same time, and only distinguished by the pseudo-noise code (PN-code) that cannot be perfectly orthogonal between users of one with others, resulting in interference between users [1] - [3]. CDMA capacity is limited by interference, so that to increase capacity by reducing interference. There are several methods to increase capacity, such as the power control (power control), sectorization, voice activity monitoring, beamforming (antenna arrays) and multiuser detection.

CDMA capacity analysis on reverse-link with sectorization, voice activity monitoring, and control of power has been investigated [1]. The results showed an increase in user capacity. CDMA system capacity analysis on reverse-link and forward-link with imperfect power control has been investigated [2]. From the calculation, imperfect power control on the reverse link causes the system capacity decreases. On the forward-link used two power control schemes. The results showed that the power control scheme based on carrier-to-interference (C / I) is better than distance-based scheme. In [3], has studied the capacity and outage probability of the reverse-link CDMA cellular system for microcell and microcell with perfect/imperfect power control and perfect/imperfect sectorization. The results showed that the user capacity is more decrease if the imperfect power control and imperfect sectorization is increase. [4] have investigated the imperfect power control on reverse-link capacity of CDMA systems with fast power control and multipath fading. The results showed a reduction in user capacity due to the imperfect power control. In [5], the reverse-link capacity of CDMA systems using beamforming has been investigated. Beamforming was used at the sender and receiver, and power control was assumed by the signal to interference ratio (SIR). The results of this study indicate that an increase in capacity by using beamforming.

To support third-generation technology (3G), the CDMA has been selected as a technology for 3G systems to meet the service needs of audio, data, and video with a large capacity system. Audio, data and video services can be viewed as a multiclass CDMA system.

The result of imperfect sectorization is the interference increases then the capacity of multiclass CDMA system decreases. Therefore, to minimize the interference impact and increase capacity of multiclass CDMA system used beamforming for sectorization.

In this research, the effects of imperfect power control and imperfect sectorization in the reverse-link capacity of multiclass CDMA systems with beamforming have been analyzed. Beamforming is used at the sender and recipient of BS and MS is assumed each element have an identical current amplitude and have the same spacing between elements (uniformly excited, equally spaced linear array). Capacity was defined as the maximum number of users per cell that is affected the number of beamforming antenna elements, the number of sectors, and overlap angel due to imperfect sectorization, imperfect power control, SIR target, and processing gain CDMA.

2. Research Method

In this research, to analyze and calculate the capacity of multiclass CDMA system on the reverse link, there is a model system used in Figure 1. In the model system, the cells contained in home cell BS with BS0 and the ring (tier), the first consisting of cells that surround home cell BS with BSj, where j = 1,2, ... 6. Each BS is placed center of each macro cell is hexagonal. To analyze the influence of imperfect sectorization, then home cell BS is divided into several sectors by using antenna beamforming, where home cell BS is divided into three sectors with an effective beamwidth of 120^o.

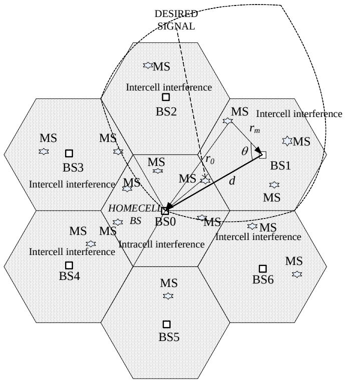
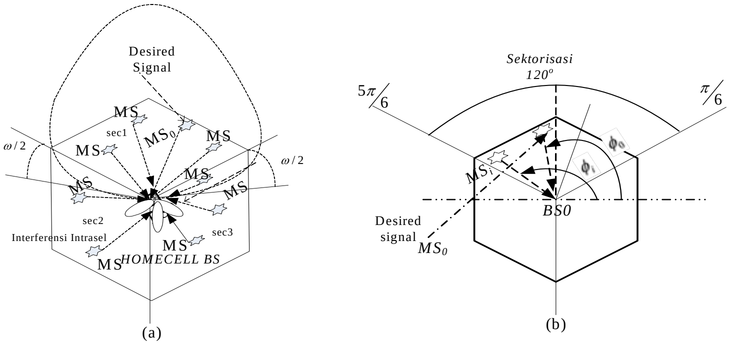


Figure 1.The Model System



(a) (b)

Figure 2(a). Intra cell Interference, (b). 1 sector *120°* with beamforming antenna.

In Figure 2(a), intra cell interference on home cell BS, derived from a number of MS present in these cells. When home cell BS is sectorized and beamforming antennas is used, as shown in Figure 2(b), then the amount of interference from the user would decrease. In Figure 2 (b) indicated angel notations of BS0 beamforming receiver, ϕ_0 is the azimuth angle from MS_0 to BS0 and ϕ_i is the azimuth angle of the MS_i to BS0, these angles evenly distributed from $\pi/6$ *to* $5\pi/6$ for the three sectors. Gain antenna toward the receiver from MS_0 to MSi BS0 for three sectors is given by [5]:

$$G_r = E_{\phi_0,\phi_i}\left[G_r(\phi_i,\phi_0)\right] = \int_{-0.5}^{0.5} \frac{\sin^2(0.5K_r\pi\phi)}{K_r^2\sin^2(0.5\pi\phi)} f(\phi)d\phi \qquad (1)$$

By using beamforming antenna, the total of intra cell interferences for sectorization with beamforming becomes:

$$S_{trs} = F_z \sum_{i=1}^{N-1} S_i.G_r \qquad (2)$$

Where

$$F_z = \frac{S_{sektor}}{S_{non-sektor}} = \frac{1}{z} + \frac{\omega}{360^0}$$

z is number of sector, and ω is *overlap* angel between sektor [3].

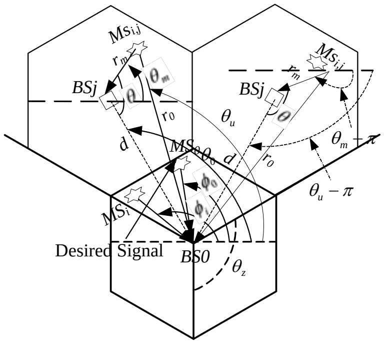


Figure 3.Sectorization 3 sector with beamforming and angel notations of beamforming.

In Figure 3 is shown home cell BS sectorize into 3 sectors with 120° beamwidth per sector. Sectorization is performed using beamforming antennas in BS0. If the beamforming antenna is also used on the MSi, j, then the total inter cell interference with sectorization Sz at BS0 can be expressed by

$$S_z = F_z \int_0^R \int_0^{2\pi} S_i \left(\frac{r_m}{r_0}\right)^{\mu} 10 \frac{(\xi_0 - \xi_j)}{10} \varnothing \left(\xi_0 - \xi_j, \frac{r_m}{r_0}\right) \quad (3)$$
$$\times \rho G_t(\theta_u, \theta_m) G_r(\theta_u, \phi_o) r_m dr_m d\theta$$

$G_t(\theta_u, \theta_m)$ and *$G_r(\theta_u, \phi_0)$* are the gain pattern beamforming of MS sender and BS receiver . θ_u and θ_m is the azimuth angle of MSi, j to BS0 and BSj who serve it. θ_0 is the azimuth angle of BSj to BS0. In Figure 3 is shown angel notations on the sender beamforming at MSI, j. When there is a sender Kt beamforming antenna element in MS, then the antenna gain of sender in the direction MSi, j to BS0 [5] is

$$G_t(\theta_u, \theta_m) = \left| \frac{\sin(0.5K_t \pi(\sin(\theta_u - \pi) - \sin(\theta_m - \pi)))}{K_t \sin(0.5\pi(\sin(\theta_u - \pi) - \sin(\theta_m - \pi)))} \right|^2 \quad (4)$$

If there are elements of the receiving antenna beamforming Kr at BS0 to receive signals from ms0, then the gain of the receiving antenna from MSi,j to BS0 [5] is

$$G_r(\theta_u, \phi_0) = \left| \frac{\sin(0.5K_r \pi(\sin\theta_u - \sin\phi_0))}{K_r \sin(0.5\pi(\sin\theta_u - \sin\phi_0))} \right|^2 \quad (5)$$

In this research, each traffic audio, data, and video on multiclass CDMA system uses a different spreading code with processeing gain G_a, G_d, and G_v. In this way, the services with different rates are accommodated with a spreading sequence with a variety of processing gain. If the processing gain is normalized by $G = G_a$, then the processing gain has been normalized to the audio, data, and video services into g_a, g_d, and g_v .The total inter cell interference from all traffic is $S_z = S_{za} + S_{zd} + S_{zv}$ then

$$E[S_z] = E[S_{za}] + E[S_{zd}] + E[S_{zv}] \quad (6)$$

Three types of spreading sequences with different processing gain Gg_a, Gg_d, dan Gg_v used to meet the needs of the different rate. To achieve the target SIR (γ_a, γ_d, γ_v) for different services, and P_a, P_d, and P_v is the power received for each service, where $S_a = P_a g_a$, $S_d = P_d g_d$,and $S_v = P_v g_v$ is a normalization of the power received for each traffic audio, data, and video, so that the E_b/I_o multiclass CDMA system for each class:

$$\left(\frac{E_b}{I_0}\right)_a = \frac{GS_a}{\frac{2}{3}\left(\frac{(N_a - 1)S_a G_r F_z}{g_a} + \frac{N_d S_d G_r F_z}{g_d} + \frac{N_v S_v G_r F_z}{g_v} + S_z\right) + \eta_0 W} \geq \gamma_a$$

$$\left(\frac{E_b}{I_0}\right)_d = \frac{GS_d}{\frac{2}{3}\left(\frac{N_a S_a G_r F_z}{g_a} + \frac{(N_d - 1)S_d G_r F_z}{g_d} + \frac{N_v S_v G_r F_z}{g_v} + S_z\right) + \eta_0 W} \geq \gamma_d \quad (7)$$

$$\left(\frac{E_b}{I_0}\right)_v = \frac{GS_v}{\frac{2}{3}\left(\frac{N_a S_a G_r F_z}{g_a} + \frac{N_d S_d G_r F_z}{g_d} + \frac{(N_v - 1)S_v G_r F_z}{g_v} + S_z\right) + \eta_0 W} \geq \gamma_v$$

In equation (7), if the E_b/I_o for different traffic equal to the target SIR of each traffic, then S_a, S_d, and S_v can be expressed in Sz:

$$S_a = \frac{S_z + 1.5\eta_0 W}{C}$$
$$S_d = B_d S_a$$
$$S_v = B_v S_a$$

Where

$$C = \frac{G_r F_z}{g_a} + \frac{1.5G}{\gamma_a} - G_r F_z \left(\frac{N_a}{g_a} + \frac{N_d B_d}{g_d} + \frac{N_v B_v}{g_v} \right)$$

$$B_d = \frac{\dfrac{1}{g_a} + \dfrac{1.5G}{G_r F_z \gamma_a}}{\dfrac{1}{g_d} + \dfrac{1.5G}{G_r F_z \gamma_d}}$$

$$B_v = \frac{\dfrac{1}{g_a} + \dfrac{1.5G}{G_r F_z \gamma_a}}{\dfrac{1}{g_v} + \dfrac{1.5G}{G_r F_z \gamma_v}}$$

The averages of the total inter cell interference by using beamforming for sectorization Sz in multiclass system can be rewritten into the following equation:

$$E[S_z] = E[S_{za}] + E[S_{zd}] + E[S_{zv}]$$

$$= E[S_a]\frac{N_a}{g_a}F(\mu,\sigma)F_z + E[S_d]\frac{N_d}{g_d}F(\mu,\sigma)F_z + E[S_v]\frac{N_v}{g_v}F(\mu,\sigma)F_z \qquad (8)$$

$$= \frac{1.5\eta_0 W\left(\frac{N_a}{g_a} + \frac{N_d B_d}{g_d} + \frac{N_v B_v}{g_v}\right)F(\mu,\sigma)F_z}{\frac{G_r F_z}{g_a} + \frac{1.5G}{\gamma_a} - G_r F_z\left(\frac{N_a}{g_a} + \frac{N_d B_d}{g_d} + \frac{N_v B_v}{g_v}\right) - \left(\frac{N_a}{g_a} + \frac{N_d B_d}{g_d} + \frac{N_v B_v}{g_v}\right)F(\mu,\sigma)F_z}$$

For $F(\mu,\sigma) > 0$, then the capacity of multiclass CDMA system can be expressed as follows:

$$\frac{N_a}{g_a}\left(\frac{1}{g_d} + \frac{1.5G}{F_z G_r \gamma_d}\right)\left(\frac{1}{g_v} + \frac{1.5G}{F_z G_r \gamma_v}\right) + \frac{N_d}{g_d}\left(\frac{1}{g_a} + \frac{1.5G}{F_z G_r \gamma_a}\right)\left(\frac{1}{g_v} + \frac{1.5G}{F_z G_r \gamma_v}\right) \qquad (9)$$

$$+\frac{N_v}{g_v}\left(\frac{1}{g_a} + \frac{1.5G}{F_z G_r \gamma_a}\right)\left(\frac{1}{g_d} + \frac{1.5G}{F_z G_r \gamma_d}\right) = \frac{G_r F_z\left(\frac{1}{g_a} + \frac{1.5G}{F_z G_r \gamma_a}\right)\left(\frac{1}{g_d} + \frac{1.5G}{F_z G_r \gamma_d}\right)\left(\frac{1}{g_v} + \frac{1.5G}{F_z G_r \gamma_v}\right)}{(F(\mu,\sigma)F_z + G_r F_z)}$$

3. Results and Analysis

The parameters used in calculating the capacity of user audio, data, and video on multiclass system is shown in Table 4.1:

Table 4.1 Parameters

Parameter	N_a: User Audio	N_d: User Data	N_v: User Video
Spreading bandwidth (W) [5]	4.096 Mbps		
Processing Gain[5]	G_a =128 / g_a =1	G_d =64/ g_d = 0.5	G_v=32 / g_v=0.25
Target SIR [5]	γ_a= 5 dB	γ_d =10 dB	γ_v= 7 dB
Power Control Factor σ(dB)	0,2,4,6,8[1]		

Konstanta Propagasi (μ)	4[1]
Elemen Antena Penerima[5];	1 - 9
Elemen Antena Pengirim[5];	1 - 4
Sudut Overlap ($^\circ$)	0;5;10;15[3];20
Jumlah Sektor (z)[3]	3

3.1. The Impact of Power Control and Sectorization on CDMA Multiclass System Capacity.

Figure 4 shows the capacity of multiclass system towards effect of power control. Multiclass system capacity with z = 3 sector compared to the system without sectorization. From Figure 4 shows that the capacity of either without or with sectorization decreased with decreasing the effect of power control. As the result of the increasing imperfect power control, the signal interference between users is also increase. The increase means a decrease E_b/I_0 interference signals that can be used to represent the value of SIR. To achieve the target SIR or the desired signal quality then there is a decrease in system capacity.

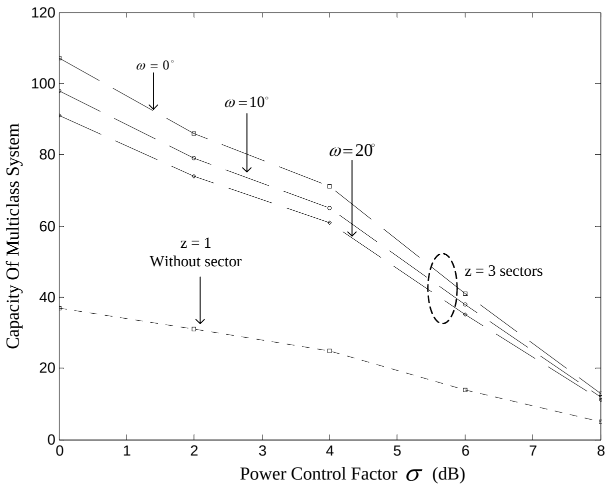


Figure 4 Multiclass System Capacity as a function of power control

For sectorization z = 1 sector and z = 3 sectors, $\omega = 0^\circ$, $\omega = 10^\circ$, $\omega = 20^\circ$.

In Figure 4 is also shown that by imperfect sectorization z = 3 sectors and perfect sectorization ($\omega = 0^\circ$), then the system capacity increase compared to the capacity of the system without sectorization. This occurs because the user on the multiclass system is only serviced by BS which antenna sector is facing the user. As a result, those users are only getting signal interference from users of the same sector. If there are overlap between sectors $\omega = 10^\circ$ and $\omega = 20^\circ$, the sectorization increasingly imperfect so that system capacity decreased compared to perfect sectorization. This occurs because the user is also getting signal interference from some user in other sector. However, In Figure 4 shown that the system capacity with the overlap between sectors is larger than without sectorization.

3.2. The Impact of Beamforming, Power Control,and Sectorization on CDMA Multiclass System Capacity.

Figure 5 shows the effect of addition of element receiving beamforming antenna K_r on the capacity of multiclass system. On BS, the antenna element receiver K_r increases from 1, 3, 5, 7 until 9. While at MS,the antenna element sender K_t = 1. Effect of power control on system capacity indicated by $\sigma = 0$ dB, $\sigma = 2$ dB, and $\sigma = 4$ dB.

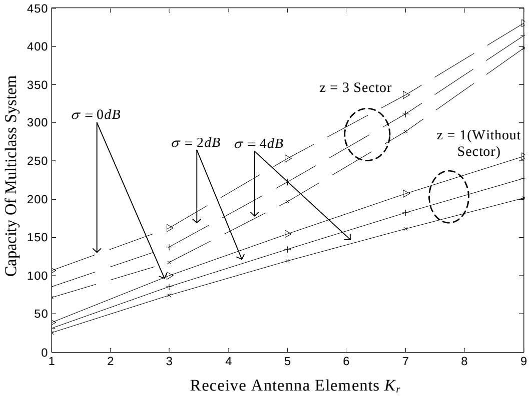


Figure 5.Capacity of multiclass system as a function of receiver antenna elements beamforming K_r, for K_t =1, with power control and sectorization.

Effect of K_r on the capacity of multiclass system is shown without sectorization z = 1 and by performing a perfect sectorization z = 3, In Figure 5 shows that the capacity of multiclass systems with sectorization and beamforming greater than without sectorization. For imperfect power control with $\sigma = 4$ dB, the multiclass system capacity increase with the increase in the number of receiver antenna elements beamforming K_r compared to perfect power control $\sigma = 0$ dB using only one receiver antenna at the BS. This occurs because by adding receiver antenna elements beamforming at the BS for transmitting reverse link, signals from antenna elements are combined to form a movable beam pattern that can lead to the desired destination to follow the movement of MS. Thereby enabling the antenna system to focus radio frequency (RF) at a particular MS and minimize the impact of interference by increasing system capacity.

4. Conclusion

Sectorization with beamforming antennas produce a multiclass system capacity is greater than the use of beamforming antennas without sectorization. Imperfect sectorization can reduce the capacity of multiclass system, with the use of beamforming antennas in imperfect sectorization, can increase the capacity of multiclass system.

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