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Enhanced Capacity Analysis in WCDMA System

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Abstract

The wide-band code division multiple access (WCDMA) based third generation wireless communication systems are designed to meet the increasing demands for high data rate applications and greater mobility. High data rate applications include voice, video telephony, Video streaming, File Transfer protocol (FTP), high quality image and wireless full internet access. WCDMA systems are expected to offer high data rate services upto 2Mbps, but there are many factors like loading of cell, intra and inter cell interference, co-channel interference etc. that limits to access these high data rate services or limits the capacity of WCDMA systems. There are various emerging technologies used to improve the capacity of WCDMA systems like sectorization, voice activity services, antenna array and interference cancellation. The later two techniques are particularly suitable for enhanced uplink performance since the additional complexity they require is concentrated at the base station. Both antenna array and interference cancellation (IC) receivers can be deployed to enhance the cell capacity i.e. number of users in a cell. This paper presents the effect of loading, interference, and voice activity on the capacity of a WCDMA system. The capacity can be enhanced by using antenna array structure of 2, 4 and 8 and by using Interference Cancellation (IC) receivers. The complete effect and capacity enhancement analysis is being done for different data rate applications like voice at 12.2 Kbps, video at 64Kbps, 144Kbps and high data rate multimedia services at 768Kbps with 3.84 Mcps spreading rate at 5MHz bandwidth.

Index Terms: WCDMA Capacity, Loading, Interference, Voice Activity, Antenna Array, Interference Cancellation Receivers

Introduction

Wideband code division multiple access (WCDMA) providing different signaling rate services with multi code modulation scheme and with effective multiplexing of user data is emerging as one of the important air interface for third generation (3G) wireless communication systems. In WCDMA, the access scheme used is the direct sequence code division multiple access (DS-CDMA) in which each user is assigned a binary pseudorandom(PN) code which is modulated on carrier with the user data [1]. These PN codes assigned to different users are orthogonal to each other to aviod interference among users. In this technique, transmitter converts an incoming data bit stream into a symbol stream where each symbol represents a group of one or more bits. This direct sequence multiple access technique of spread spectrum is highly reliable and immune to interference than other spread spectrum techniques like frequency and time hoping, and gives an opportunity to multiple users to communicate through single channel.

Multiaccess interference due to increase in number of wireless users and traffic, with new bandwidth consuming applications such as gaming, music downloads and data-video streaming have placed new and high demands of capacity on the WCDMA radio access networks. In order to achieve this high capacity demand that are increasing day by day, the service providers need to augment the capacity frequently, even from the start of radio access network deployment. Proper capacity design is important in order to achieve better Quality of Service (QoS).

In order to determine the capacity of a WCDMA radio access network, it is important to define the term capacity. There are many definitions of capacity like maximum amount of traffic in number of bits in a cell with respect to allotted frequency band i.e. in erg/cell/5MHz, 10MHz, 20MHz and maximum amount of services given by the cell, but most of them define capacity in terms of numbers of users in a cell.

This paper shows the cell capacity estimation in terms of number of users accessing the WCDMA network with different data rate/type of services i.e. voice, video, data and multimedia. The factors which affect the system capacity for different type of services are taken into account. A capacity enhancement expression is also presented by the use of antenna diversity and interference cancellation receivers. Simulation results show the capacity affected and enhanced parameters performances.

The paper is divided into following sections. In section II, a capacity model for WCDMA system is presented which gives the basic capacity equation in terms of number of users. In section III, the factors which affect the capacity of WCDMA system and accordingly modify the basic capacity equation is presented. In section IV, antenna diversity and interference cancellation, the two most promising technique to enhance the capacity of 3G based WCDMA systems is presented. In section V, capacity equation based on antenna diversity and interference cancellation receiver efficiency is presented. The simulation results which show the effect of loading, interference, voice activity factor, Interference cancellation receiver and antenna array on the WCDMA capacity for different data rate services is presented in section VI. Finally, the conclusion and scope for future work is presented in section VII.

WCDMA Capacity Model

The capacity of WCDMA system is an important parameter in Universal Mobile Telecommunication System Networks. The capacity of WCDMA system is basically determined by signal to noise ratio or mostly said E_b/N_o (Bit energy to effective noise power spectral density) and by the processing gain of the system. The processing gain is defined as the ratio of the spreading bandwidth of the system to the data bit rate for the selected application i.e. voice, data & multimedia etc. The interference is already included in noise power spectral density and can be self interference, co-channel interference and multi-access interference.

Now in order to derive the expression for capacity i.e. the number of user in a cell in WCDMA system, it is assumed that there are K number of users accessing the network at same frequency simultaneously and each user has its own PN code sequence. Now if P_S is the signal power, W is the bandwidth of spreading (PN) code sequence, R_b is the data bit rate; E_b is the energy per bit, N_o is noise power spectral density, then energy per bit can be written as

$$E_b = \frac{P_s}{R_b}$$

and

$$\frac{E_b}{N_o} = \frac{P_s}{R_b \cdot N_o} \tag{1}$$

N_o is noise power spectral density and can be defined as interference power per unit spreading bandwidth. It is given as

$$N_o = \frac{P_I}{W} \tag{2}$$

From (1) and (2), we get

$$\frac{E_b}{N_o} = \frac{P_s}{P_I} \cdot \frac{W}{R_b} = \frac{P_s}{P_I} P_G \tag{3}$$

Where P_G is the processing gain. Now if signal power of all users is same and spreading sequence of all users has same rate then the equation for capacity in terms of number of users is given as below [2]

$$\frac{P_I}{P_s} = (K-1) \tag{4}$$

From (3) and (4), we get

$$(K-1) = \frac{P_G}{E_b/N_o}$$

and

$$K = 1 + \frac{P_G}{E_b/N_o} \tag{5}$$

The equation (5) is the basic capacity equation which determines the number of users in a WCDMA cell. This equation completely depends upon the processing gain and E_b/N_o ratio. The capacity of a WCDMA system can be increased or decreased by adjusting the value of processing gain P_G and E_b/N_o. Beside these adjustments, there are some other factors that also affect the capacity of WCDMA network and accordingly the basic capacity equation is modified.

Factor Affecting WCDMA System Capacity

There are many factors that increase or decrease the capacity of WCDMA systems. Some of them are loading of cell, interference factor, voice activity factor, configuration of antenna, type of coding scheme used, Interference cancellation techniques etc. Some of above mention factors that affect the capacity of WCDMA system is discussed as below.

Loading of cell

In cellular system, a single cell is surrounded by many cells and due to handoff's strategies, a particular cell is said to be loaded by users from other cell using the particular cell and producing loading effect. This loading effect decreases the performance of a particular cell or we can say that capacity of cell decreases and this effect is measured by loading factor. The loading factor is given as [3]

$$L.F. = \frac{K'}{1+\frac{P_G}{E_b/N_o}} \tag{6}$$

Where K' is the number of users in a particular cell after loading from other cell. Generally, the loading factor is the percentage of capacity K as referred in eqn. (5) and from this capacity K, a practical cell capacity K' after loading in a WCDMA cell can be calculated as

$$K' = K \times L.F.(\%) \tag{7}$$

From eqn. (7), it is clear that as the loading factor increases in percentage, the number of active users in a particular cell decrease. Mathematically, the effect of loading on the capacity of WCDMA system is also given as [4]

$$K = 1 + \frac{P_G}{E_b/N_o}\left(\frac{1}{1+L.F.}\right) \tag{8}$$

Interference

Interference is an important factor that limits the capacity of WCDMA systems. The interference in a WCDMA cell can be from the same cell, from the neighboring cell i.e. during handoffs and can be due to thermal noise of the cell. In order to calculate the capacity of WCDMA systems in the presence of these interferences i.e. own cell interference I_{own}, other cell interference I_{other} and thermal noise or background noise of the cell I_o, it is necessary to first calculate the noise rise. The noise rise (NR) is defined as the ratio of total wideband power to the thermal noise power (P_o) received at base station during uplink [3] [5]. The noise rise (NR) is given as

$$NR = \frac{P_{total}}{P_o} = \frac{P_o + P_{other} + P_{own}}{P_o} \tag{9}$$

On introducing the other-to-own cell interference ratio/factor $\boldsymbol{i}$ in eqn. (9), the NR can be written as

$$NR = \frac{P_{total}}{P_o} = \frac{P_o + P_{own} \cdot (1+i)}{P_o} \tag{10}$$

The relation between noise rise (NR) and uplink loading μ_{UL} is given as [3]:

$$\mu_{UL} = \frac{1}{1-NR} \tag{11}$$

The uplink loading means number of users accessing the WCDMA cell base station and the users may be from the same cell or from the surrounding cells. In eqn. (6), cell loading is given in terms loading factor and as uplink loading is related to noise rise which in turn is related to total interference as given in eqn. (10) and (11); the capacity in terms of number of users with uplink loading is given as [3].

$$K = \mu_{UL} \left(1 + \frac{P_G}{E_b/N_o}\right) \tag{12}$$

Voice Activity Factor

It is also called service activity factor. Service activity means continuous use of some service in a cell. Monitoring of voice/data activity in a cell is an important technique to reduce interference or to increase the capacity as each transmitter is switched-off during the period of no activity and these periods can be used for other data flow without losing the Quality of Service (QoS).

In CDMA systems, reducing multiple accesses interference from neighboring cells results in a capacity gain. In order to remove multi-access-interference, CDMA system uses speech coding technique in which rate of speech coder is reduced by voice activity detection along with variable data rate transmission. Voice activity factor depends upon the type of vocoder used, channel coding and the actual application. By the use of convolution codes for different type of services like voice/ video, system capacity can be increased by 1.5 times to that of without coding and about 1.2 times to that of block code without disturbing the QoS [6]. The value of Voice activity factor varies according to type of service involved i.e. voice, video or multimedia. The activity factor is set to 0.6 for voice application and 1.0 for video or data application [7]. The relation between activity factor v and cell capacity K is given as [4]

$$K = \left(1 + \frac{P_G}{E_b/N_o}\right) \cdot \frac{1}{v} \tag{13}$$

Antenna Diversity and Interference Cancellation

In antenna diversity, two or more antennas are used at the base station to improve the quality of service, reliability of a wireless link and capacity of the system. There is not a clear line-of-sight (LOS) between mobile station and base station, Instead the signal is reflected along multiple paths before finally being received. These multipath introduce phase shifts, time delays, attenuations, and even distortions that can destructively interfere with one another at the receiving antenna. Antenna diversity is especially effective at mitigating these multipath effects. This is because multiple antennas will produce several observations of the same signal. Each antenna will experience a different interference environment. Thus, if one antenna is experiencing a deep fade, it is likely that another has a sufficient signal. The output of these antenna arrays are applied to maximum ratio combining (MRC) processing technique in addition with an interference canceller system.

In MRC, co-phasing and amplitude weighted sum of received signals at different branches takes place. The Signal to Noise ratio at the output of an ideal MRC can be written as

$$SNR(\gamma) = \sum_{i=1}^{M} \sum_{j=1}^{N} SNR\,(\gamma)_{i,j} \tag{14}$$

Where $(\gamma)_{i,j}$ is the signal to noise ratio at the j^{th} finger of i^{th} antenna and M is the number of antennas and N is the number of rake finger for receiver antenna, assuming signal component at rake receiver are summed coherently and noise component are combined non-coherently [8]. Now for a conventional matched filter receiver, the Signal to Noise ratio of m^{th} user at the i^{th} antenna can be written as

$$SNR(\gamma)_{m,i} = \frac{P_{m,i}}{P_{total,i} - P_{m,i}} \tag{15}$$

where $P_{m,i}$ is the received power from user m at i^{th} antenna and $P_{total,i}$ is the total received power at i^{th} antenna which includes thermal noise power(P_o), other-cell interference power ($P_{other,i}$) and the own-cell interference power ($P_{own,i}$) at the i^{th} antenna.

In a WCDMA system, IC receiver performs well only to reduce own-cell interference [5]. The interference cancellation efficiency β of a receiver is defined as the ratio of own-cell interference removed after the use of IC receiver to the own-cell interference present before the use of IC receiver. It means that with the help of IC receiver, we can remove a fraction β of total interference. Generally, β indicates the quality of signal reconstruction and has value $0<\beta<1$. β =1 represents perfect cancellation and a small positive β represent a signal that is not fully reconstructed and there is residual interference after cancellation. β=0 represents no interference cancellation and a negative value of β represents that we have falsely reconstructed signal, and instead of removing interference, we have added more interference to the waveform. The signal to noise ratio of user m at the i^{th} antenna with IC receiver is given as [9]

$$\gamma_{m,i} = \frac{P_{m,i}}{(P_{own,i}-P_{m,i})\cdot(1-\beta)+P_{other,i}+P_o} \tag{16}$$

Also,

$$P_{total,i} = P_{own,i} + P_{other,i} + P_o$$

If, we put β= 0 in eqn. (16), then this reduces to eqn. (15). It means that if there is no interference canceller at the receiver then the interference/noise level will increase which result into decrease in target signal to noise ratio at the output. In order to maintain the target signal to noise ratio it is necessary to have an IC receiver with sufficient value of β. IC receiver with β=40% can be implemented at the base station with acceptable level of complexity [10], but β= 70% is hardly feasible for practical implementation.

Capacity Calculation

In this section, calculation of capacity from antenna array structure with the effect of interference cancellation (IC) receiver in WCDMA system is presented. The number of antenna used may be 2, 4 or 8 at the base station. So, E_b/N_o required per receiving antenna at the base station for a specific user m including the effect of IC receiver can be written as [9] [11]

$$\left(\frac{E_b}{N_o}\right)_m = \frac{(W/R_b)\cdot P_m}{(P_{own}-P_m)\cdot(1-\beta)+P_{other}+P_o} \tag{17}$$

Where W is the chip rate, R_b is the data bit rate of selected application, P_m is the received power per antenna from user m, P_{own} is the total own-cell power received per receiving antenna, P_{other} is the total other-cell power received per antenna, β is the efficiency of IC receiver and P_o is the background noise power received per receiving antenna. By using other-to-own cell interference ratio/factor $\boldsymbol{i}$ and solving above equation for P_m , we get

$$P_m = \frac{P_{own}\cdot(1-\beta+i)+P_o}{[(W/R_b)/(E_b/N_o)_m]+1-\beta} \tag{18}$$

This is the power received per antenna from single user m and there are a number of users (K) in a cell. So the total own-cell power received per antenna is given as

$$P_{own} = K\cdot P_m = \frac{K\cdot P_o}{[(W/R_b)/(E_b/N_o)]+(1-\beta)-K\cdot(1-\beta+i)} \tag{19}$$

In equation (19) it is assumed that all users in a cell have same E_b/N_o and are transmitting data with same rate with same power level. By the use of eqn. (19), in eqn. (10) and eqn. (11) that is based on noise rise and uplink loading and solving for number of users (K) in a cell, we get

$$K = \mu_{UL}\left[\frac{W/R_b}{E_b/N_o} + (1-\beta)\right]\cdot\frac{\mathbf{1}}{\mathbf{1}+\boldsymbol{i}-\boldsymbol{\beta}\cdot\mu_{UL}} \tag{20}$$

The eqn. (20) is the modified capacity equation that includes the effect of antenna diversity and interference cancellation in WCDMA system and mainly depends upon the interference ratio, IC receiver efficiency and the uplink loading.

Simulation and Results

The main objective of this simulation is to analyze the effect of different parameters on the capacity of WCDMA system when the user is accessing different data rate services. Matlab simulation is used to present the effect of different data rate services, effect of loading, interference and the effect of antenna diversity with IC receiver on the capacity of 3G based WCDMA system. For this, chip rate is taken 3.84 Mcps and data rate 12.2 kbps for voice, 64 kbps for video telephony or video streaming, 144 kbps, 384kbps and 768kbps for multimedia services that includes File Transfer Protocol (FTP), World Wide Web (WWW) etc.

In simulation, each user will use the same data rate application at a time and spreading sequence of all users will have same rate i.e. same chip rate. Capacity performance analysis is mentioned at target bit energy to noise power spectral density (E_b/N_o) of 5db and it is found that the capacity performance decreases with increase in E_b/N_o beyond 5db.

The processing gain will be different for different data rate services and varies inversely with increase in data rate for a constant chip rate condition. The value of processing gain for voice service i.e. at 12.2 kbps is taken as 314, for video service at 64kbps it is 60, for 144kbps service it is 26 and for 768kbps data rate service the value of processing gain is 5. For selected application, given processing gain, varying bit energy to noise ratio and varying affecting factor values like loading factor, interference factor and efficiency of IC receiver is used to analyze the capacity performance of WCDMA system.

In the figure 1, it is shown that for a given spreading bandwidth of 5 MHz i.e. 3.84 Mcps chip rate, as the data rate increases, the number of users in a cell decreases for a given bit energy to noise ratio. For a target E_b/N_o of 5db, there are 100 users of 12.2kbps data rate, 20 users of 64kbps data rate, 9 users using the cell having 144kbps data rate and only approximately 3 users accessing the WCDMA networks with data rate of 768kbps. So as the bit energy of a particular service increases, the number of user decreases.

Figure 2 shows the effect of loading on the WCDMA capacity for 64kbps data rate i.e. used for video services. Result is shown for 75% loading factor and 45% loading factor. From the result, it is observed that as the loading factor i.e. loading on the desire user by the neighboring cell increases, the number of active users in the cell decreases.

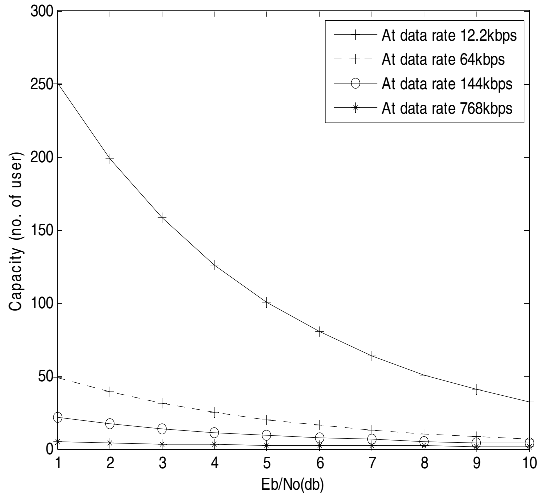

Figure 1: Effect of high data rate services on WCDMA capacity.

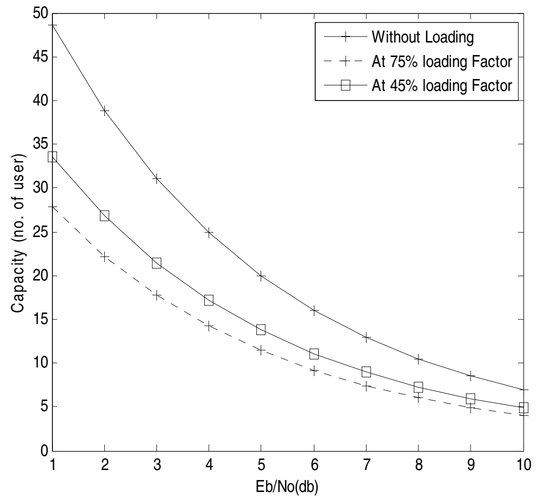

Figure 2: Effect of Loading on WCDMA capacity for video services.

In the figure 3, the effect of interference on the WCDMA capacity for the video services is presented. Result is shown for 60% & 30% interference factor and as the interference from the inter-intra cell increases, the number of active users in a cell decreases. This decrease in number of users in a cell is in order to maintain the quality of service.

Figure 4 shows the effect of voice activity factor as discussed in section (III) on the WCDMA capacity. Result is shown for voice activity factor of 0.6 used for voice services i.e. at 12.2 kbps data rate and the effect of this factor increases the number of users about 1.5 times. For the target E_b/N_o of 5db, the number of user is about 100 without using the effect of voice activity factor and it is about 168 with voice activity factor effect.

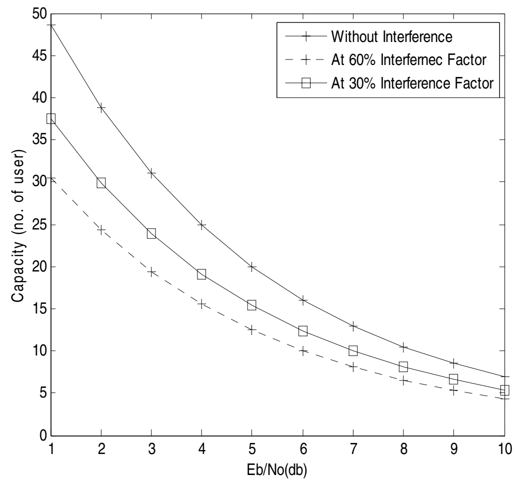

Figure 3: Effect of Interference on WCDMA capacity for video services.

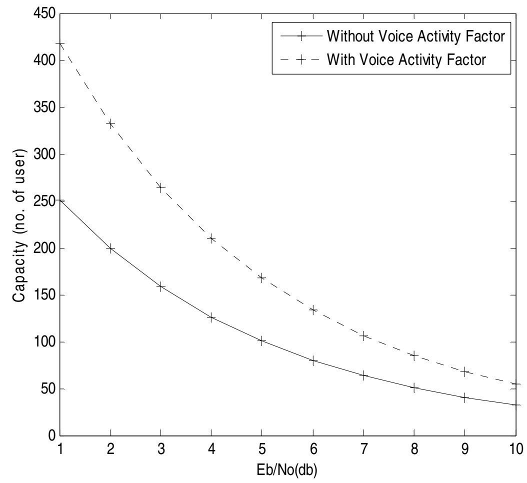

Figure 4: Effect of Voice Activity factor on WCDMA capacity for voice services.

In the figure 5, the effect of IC receiver on the capacity of WCDMA system for video service is presented. Here IC receiver of efficiency 70% and 40% is taken to remove the inter-intra cell interference factor 0.6 that is specified in [7].

For a target E_b/N_o of 5db there are only 12 users in cell at 60% interference level. For the same E_b/N_o and at the same interference level, an IC Rx of 70% efficiency increases the number of user to 41 and IC Rx of 40% efficiency increases number of user to 20.

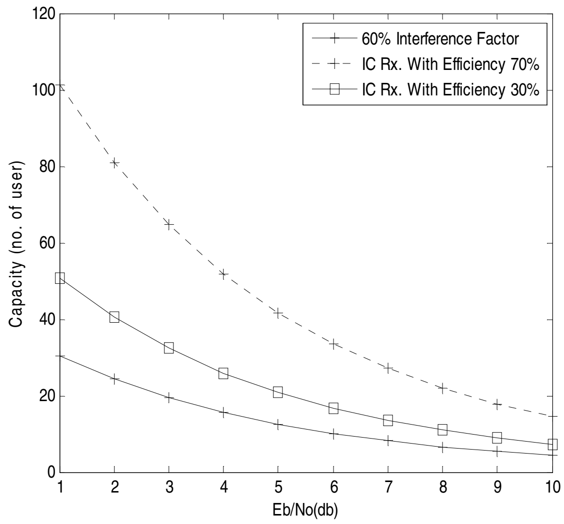

Figure 5: Effect of Interference Cancellation (IC) Receiver on WCDMA capacity for video application.

The next simulation results are related to capacity performance given by the use of antenna arrays and IC receiver for high data rate applications. Here comparison is made between antenna array structure of 2, 4 and 8 with the effect of IC receiver having interference cancellation efficiency of 70% and 40% in the presence of interference factor 0.6.

In equation (20), E_b/N_o is the required bit energy to noise ratio per receiving antenna and this ratio reduces as the number of antennas increases. For the total/target required E_b/N_o of 5db and assuming an ideal Maximum Ratio Combiner (MRC) at the base station receiver, the required E_b/N_o per antenna with 4-branch antenna diversity is -1.02db approximately i.e. 6db MRC gain and with 8-branch antenna diversity, it is -4.03db approximately i.e. 9db MRC gain.

In the figure 6, curve is plotted between capacity and uplink loading for 144kbps data rate application. Here uplink loading means the number of users accessing the WCDMA cell base station. It also includes the other-to-own cell interference factor i.e. of 0.6 and interference cancellation efficiency of 70%. As the cell loading increases, the number of user increases more in 8-branch antenna structure than 4-branch, 2- branch structure. Same is shown in figure 7 for interference cancellation efficiency of 40% i.e. β = 0.4. The difference is that less number of users will accommodate in cell because interference cancellation efficiency is less. But, as the number of antenna arrays increases the number of users per receiving antenna in a cell also increases.

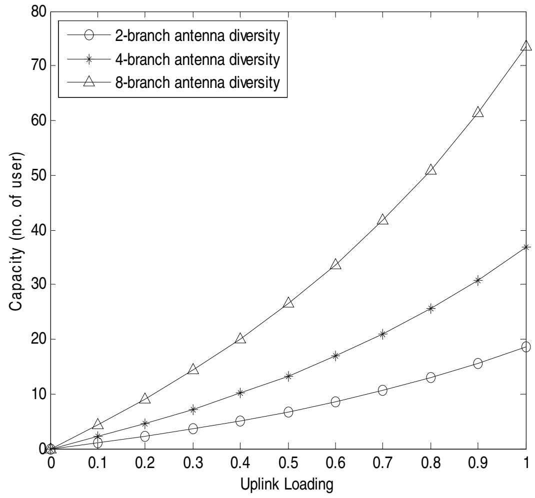

Figure 6: Effect of antenna Diversity on WCDMA capacity with β=0.7 & i=0.6 for 144kbps data rate applications.

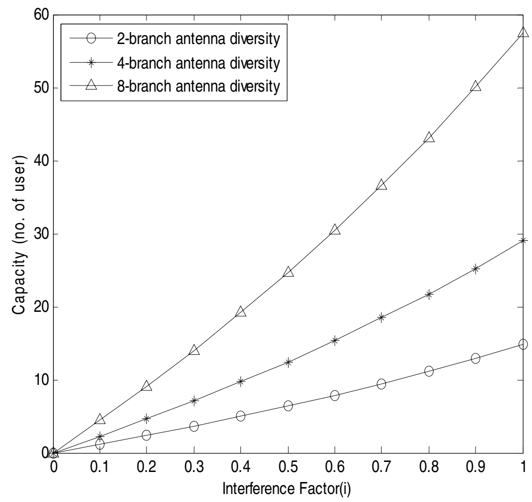

Figure 7: Effect of antenna Diversity on WCDMA capacity with β=0.4 & i=0.6 for 144kbps data rate applications.

Figure 8 & 9 show the effect of antenna diversity i.e. capacity enhancement for variable interference factor under maximum loading condition for high data rate of 768kbps user applications in the presence of IC receiver of efficiency 70% and 40%.

Under the condition of maximum loading and zero interference, 8-branch antenna diversity performs well to great extent than 4-branch, 2-branch antenna structure and same performance are achieved at maximum interference factor. In figure 9, at maximum interference, 8-branch antenna array has approximately 8 users, 4-branch antenna has 4 users and 2-branch antenna structure has only 2 users accessing the high data rate service of 768kbps.

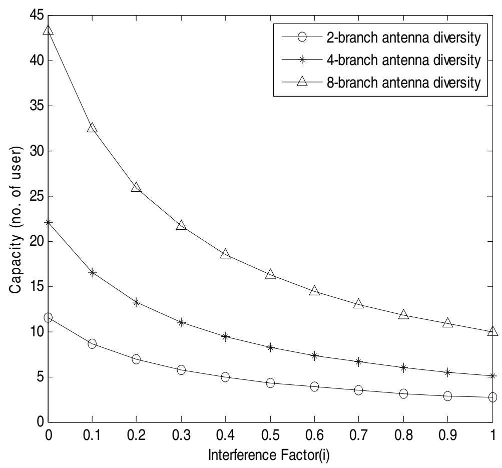

Figure 8: Effect of antenna Diversity on WCDMA capacity with β=0.7 & 100% loading for 768kbps data rate applications.

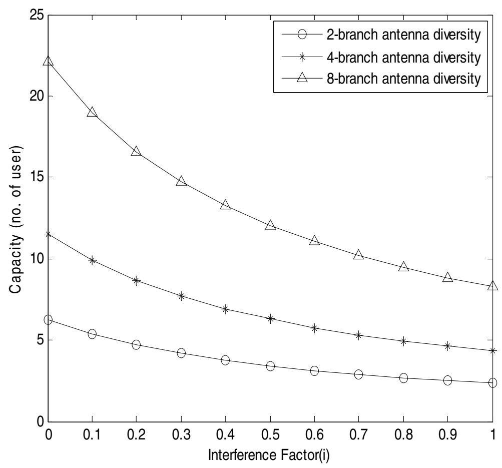

Figure 9: Effect of antenna Diversity on WCDMA capacity with β=0.4 & 100% loading for 768kbps data rate applications.

Conclusion and Future Work

This paper presents the parameters like loading, interference, voice activity that affects the WCDMA capacity and capacity enhancement method using antenna diversity with the effect of interference cancellation receiver. The analysis of capacity in terms of number of users is done for high data rate services utilizing the same channel bandwidth. From the analysis, it is concluded that loading and interference decreases the capacity of WCDMA system and voice activity factor, interference cancellation receivers and antenna array structure increases the WCDMA capacity. The 8-branch antenna diversity supports approximately double number of users than 4-branch antenna diversity and approximately four times in comparison to 2-branch antenna diversity for a given interference factor and interference cancellation efficiency. This work can be extended by the use of smart antenna with adaptive beam forming algorithms and direction of arrival approach that will not only increase the capacity of WCDMA system at high data rates with better quality of service but will also reduce the cost and maintenance approach used in implementing IC receiver of such high efficiency and design of antenna arrays.

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