Uplink Performance Analysis in Multiple MIMO Rayleigh Interference Channel for WCDMA

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Abstract- *WCDMA has emerged as the most widely adopted air interface technology for Third Generation Systems as defined by the 3GPP. Evolved from CDMA and providing high spectrum efficiency, the percentage of lost call per cell represents the percentage of established calls that were lost as a result of either pilot pollution or any other reason, most importantly interference. This paper evaluates the Bit Error Rate (BER) of MIMO uplink WCDMA system in multiple interference with Maximum Mobile Transmitted Power and Equivalent Isotropic Radiated Power (EIRP) of 21dBm and 18dBm respectively. The paper further presents simulation results to support the theoretical analysis on reverse link capacity analysis in terms of cell load factor.*

Keywords: WCDMA, MIMO, Interference, Uplink load Factor

1 Introduction

The Code Division Multiple Access (CDMA) system is an interference limited system in which link performance depends on the ability of the receiver to detect a signal in the presence of interference. Therefore, the key issue in a CDMA network design is to minimize multiple access interference that can be achieved by critical power control. Interference on the voice channels causes cross talk where the subscriber hears interference in the background due to an undesired transmission on control channels, leading to missed and blocked calls due to errors in the digital signaling. Interference is more severe in the urban areas, due to the greater RF noise floor and the large number of base stations and mobiles [1] and therefore, has been recognized as a major bottleneck in increasing capacity responsible for dropped calls [2]. Sources of interference include another mobile in the same cell, a call in progress in a neighboring cell, other base stations operating in the same frequency band, or any cellular system which inadvertently leaks energy into the cellular frequency band. In [3], Heiska et al analyzed capacity reduction of WCDMA downlink in the presence of interference from adjacent narrow-band system by taking into account different downlink interference mechanisms such as wide-band noise from the transmitter as well as adjacent channel interference, intermodulation, and cross-modulation originating in the mobile receiver, and concluded that capacity per cell is sensitive to the cell size, and therefore, very careful network planning is needed in order to operate the WCDMA networks efficiently. The Interference Performances, when WCDMA and HSDPA coexist as analyzed by Pei Li [4], provided simulation results indicating that the system performance in the hybrid cells is better than the pure macro cell for WCDMA and HSDPA. After investigation of WCDMA inter-operator adjacent channel interference , Joyce et al [5], proposed a number of measures which both operators and vendors should take to avoid deadzones in an operational WCDMA network.

Extensive studies have been done by Gao Peng et al [6] where they analyzed the interference between WCDMA and WIMAX systems to evaluate the impact of inter-system interference produced by coexistence of systems in the same geographical area in adjacent frequency and concluded that WCDMA and WiMax systems could coexist, and gave the proposals of interference mitigation method in the case of coexistence of two systems. Results on the other-cell to own-cell interference values and traffic capacity for dedicated indoor WCDMA systems were presented in [7]. Also, Kiiskila et al [8] discussed receiver complexity and presented optimal and suboptimal spatial maximum, a posteriori receivers in a concatenation of Linear Minimum Mean Square Error (LMMSE) equalizer structure for Multiple-Input-Multiple-Output (MIMO) Wideband Code

Division Multiple Access (WCDMA) systems, and further, proposed that in frequency selective fading channels where LMMSE part mitigates the Multiple Access Interference (MAI) and Inter-Antenna Interference (IAI) is by the spatial MAP or its approximation. Potential GPRS 900/180-MHz and WCDMA 1900-MHz Interference to Medical Devices were also investigated by Iskra et al and compared the potential for interference to medical devices from Radio Frequency (RF) fields radiated by GSM 900/1800-MHz, General Packet Radio Service (GPRS) 900/1800-MHz, and Wideband Code Division Multiple Access (WCDMA) 1900-MHz handsets. Performance analysis of MQAM for MIMO WCDMA systems in fading channels has been extensively studied [10] with authors developing an analytical framework that could handle an arbitrary number of transmit and receive antennas in both open-loop and closed-loop systems with numerical results showing that the system could achieve significant performance improvement by using the combined transmit and receive antenna diversity.

The above analyses and importance notwithstanding, WCDMA needs further investigation especially in the context of its performance in coexistence with other systems. In this context the uplink WCDMA was analyzed in Raleigh fading channel in the present study. Specifically we present an accurate BER analysis of a MIMO uplink WCDMA system in multiple interference employing Maximum Mobile Transmitted Power and Equivalent Isotropic radiated power (EIRP) of 21dBm and 18dBm respectively with emphasis on the interference from adjacent cells. This paper further presents simulation results to support the theoretical analysis on reverse link capacity analysis in terms of cell loading factor.

Organization: In section two, the uplink load factors and efficiency of multiuser receiver of CDMA system are analyzed. Section three focuses on the MIMO system. Intercell interference and the reverse link capacity in single-cell and multi systems are analyzed in section four. In section five, numerical and simulation results are shown and discussed, while section six concludes this paper.

2 CDMA Uplink Load Factors

2.1 Uplink Load Factors

The (E_b/I_t) for the ith user is expressed as

$$\left(\frac{E_b}{I_t}\right)_i = \frac{\beta_c}{(\beta_i v_i)} \cdot \frac{R_i}{(I_{total}-R_i)} \qquad (1)$$

Where β_c is the chip rate, R_i is the received signal power from ith user, the channel activity factor of ith user is represented by v_i. β_i is the bit rate of the ith and I_{total} as total received power including thermal noise power at the base station. Let $R_i = \varphi_i \cdot I_{total}$ where φ_i is the load factor of the ith connection [1], then

$$\varphi_i = \frac{1}{1+\frac{\beta_c}{(E_b/I_t)_i \cdot \beta_i v_i}} \qquad (2)$$

The total received interference [1], without the thermal noise N_T, can be expressed as the sum of the total received powers from all M user in the same cell $I_{total} - N_T = \sum_{i=1}^{M} R_i = \sum_{i=1}^{M} \varphi_i \cdot I_{total}$. If *noise rise* of the entire system is expressed as $noise\ rise = I_{total}/N_T = 1/(1-\sum_{i=1}^{M}\varphi_i) = 1/(1-\delta_{ul})$, where δ_{ul} is the uplink load factor and is expressed as $\delta_{ul} = \sum_{i=1}^{M}\varphi_i$. When δ_{ul} approaches 1, the corresponding noise-rise approaches infinity and the system reaches its pole capacity. If γ is the interference factor due to other cells, in terms of interferences from other cell, the interference factor can be expressed as

$$\gamma = \frac{other\ cell\ interference}{own\ cell\ interference}$$

Then uplink load factor can then be written as

$$\delta_{ul} = (1+\gamma).\sum_{i=1}^{M}\varphi_i \qquad (3)$$

$$= (1+\gamma).\sum_{i=1}^{M}\left(\frac{1}{1+\frac{\beta_c}{(E_b/I_t)_i \cdot \beta_i v_i}}\right) \qquad (4)$$

The load equation at (4) predicts the amount of *noise-rise* over *thermal-noise* due to interference, and also could be used to make semi analytical predictions of the average capacity of CDMA cell and finally could also be employed in predicting cell capacity and planning noise-rise for dimension purposes [1]. The noise-rise is equal to $-10\log(1-\delta_{ul})$. The interference margin in the link budget must be equal to the maximum planned *noise-rise*

2.2 Multiuser Receiver Efficiency

The interference caused by the presence of other users in the cell is called Multiple Access Interference [MAI]. Conventional signal detectors detect only single user's signal. When there are multiple users in the same environment, the conventional detectors treat other users' signals as noise or interference. MAI affects system capacity and system performance. When there are more users, the MAI is high [1]. The system performance is also affected by the near-far problem. Mitigation of the MAI is possible by, good cross-correlation code waveform design, open-loop power control for mobiles and closed-loop power control for the base station, forward error correction code and sectorized or adaptive antennas that focus reception over a narrow desired angle range. The use of multiuser detection techniques has also been suggested in the WCDMA UMTS system. Multiuser detection (MUD) and interference cancellation (IC) technique improve the system performance by canceling the intercell interference. MUD also known as co channel interference suppression or multiuser demodulation exploits the considerable structure of the multiuser interference in order to increase the efficiency with which channel resources are employed [11].

Since MUD efficiency varies in different radio environment, the capacity improvement attainable by MUD is not fixed. The impact of MUD on coverage introduces a new variable to the network planning process, since MUD efficiency needs to be taken into account in the coverage design. The efficiency of MUD is estimated from the load that can be supported with a specified E_b/I_t value with a multiuser received. In the analysis, the number of users with a RAKE receiver is represented by M_{RAKE} and those with a MUD receiver by M_{MUD}. The efficiency of MUD receiver also denoted by η at a give E_b/I_t is [12] $M_{RAKE} = (1-\eta)M_{MUD}$. The capacity of the network MUD receiver in base transceiver station (BTS) in terms received signal power R_{sp}, power control efficiency γ_c is expressed as

$$\frac{E_b}{I_t} = \frac{R_{sp} P_G \gamma_c}{(1-\eta)\psi_{intra} + \psi_{inter} + N_o} \quad (5)$$

Where N_o is thermal noise, ψ_{intra} is the intracell interference from own cell mobiles, ψ_{inter} is the interference from the mobiles not connected to this particular base station, and P_G is the processing again. But $\mu = \psi_{intra}/\psi_{intra} + \psi_{inter}$ and hence $\psi_{inter} = ((1-\mu)/\mu)).\psi_{intra}$. Therefore, substituting it into Equation (5) and neglecting the effect of thermal noise. Equation (5) becomes

$$\frac{E_b}{I_t} = \frac{R_{sp} P_G \gamma_c}{(1-\eta)(M-1)R_{sp} + \left(\frac{1-\mu}{\mu}\right) M R_{sp}} \quad (6)$$

Where M is the number of users associated with the BTS. Further solving equation (6) for M, will result in

$$M = \frac{\mu[\gamma_c P_G (E_b/I_t)^{-1} + (1-\eta)]}{(1-\mu\eta)} \quad (7)$$

In an unloaded network, the uplink limits the achievable range and coverage, as the maximum transmission power of the mobile station is lower compared with the maximum transmission power of the base station in the downlink. In a loaded network, the downlink may limit the range if there is more load and thus more interference in the downlink than the uplink. The received signal-to-interference ratio at the base station is given as

$$\frac{E_b}{I_t} = \frac{E_{b,loaded}}{\psi_{intra} + \psi_{inter} + N_o} \quad (8)$$

Where E_b is the received energy per bit, ψ_{intra} is the intracell interference from own cell mobiles, ψ_{inter} is the interference from the mobiles not connected to this particular base station, and N_o is the thermal noise. In case of an unloaded network $\psi_{intra} = 0, \psi_{inter} = 0$, and the required E_b/N_o for range calculations is equal to E_b/I_t. In the loaded network, the fraction of own-cell interference from total interference is defined as

$$\varpi = \frac{\psi_{intra} + S}{\psi_{intra} + S + \psi_{inter}} \quad (9)$$

Where $S = E_b/P_G$ the received signal is power from one user and P_G is the processing gain. ϖ depends upon propagation environment. The higher the path-loss attenuation factor, the higher the ϖ. ψ_{inter} can be expressed in term of ψ_{intra} as

$$\psi_{inter} = \psi_{intra}\left(\frac{1}{\varpi} - 1\right) + \frac{E_{b,loaded}}{P_G}\left(\frac{1}{\varpi} - 1\right) \quad (10)$$

but

$$\psi_{intra} = (M-1)\frac{E_{b,loaded}}{P_G} \quad (11)$$

therefore,

$$(\psi_{inter} + \psi_{intra}) = \left(\frac{M}{\varpi} - 1\right)\frac{E_{b,loaded}}{P_G} \quad (12)$$

$$\frac{E_{b,loaded}}{I_t} = \frac{E_{b,loaded}}{\left(\frac{M}{\varpi} - 1\right)\frac{E_{b,loaded}}{P_G} + N_o} = \left(\frac{E_b}{N_o}\right)_{unloaded} \quad (13)$$

Solving the required E_b/N_o in the loaded case gives

$$\left(\frac{E_b}{N_o}\right)_{loaded} = \frac{1}{\left(\frac{E_b}{N_o}\right)^{-1}_{unloaded} - \left(\frac{M}{\varpi} - 1\right)\frac{1}{P_G}} \quad (14)$$

The effect of the MUD receiver can be taken into account by using the efficiency of the MUD η as a measure of performance of the MUD receiver. With MUD receiver, the intracell interference $\psi_{intra,MUD}$ can be written as

$$\psi_{intra,MUD} = (1-\eta)\psi_{intra}$$

$$= (1-\eta)(M-1)\frac{E_b}{P_G} \quad (15)$$

and

$$\psi_{inter} =$$

$$\left(\frac{1}{\varpi} \quad 1\right)(1 \quad \eta)(M \quad 1)\frac{E_b}{R_a} \mid \frac{E_b}{R_a}\left(\frac{1}{\varpi} \quad 1\right) \qquad (16)$$

the total interference will be

$\psi_{inter} + \psi_{intra,MUD}$

$$= \frac{E_{b,loaded}}{R_a}\left[\frac{M(1-\eta)+\eta}{\varpi} - 1\right] \qquad (17)$$

The required E_b/I_t in the loaded network with MUD receiver becomes

$$\left(\frac{E_b}{N_o}\right)_{loaded,MUD} \qquad (18)$$

$$= \frac{1}{\left(\frac{E_b}{N_o}\right)^{-1}_{unloaded} - \left[\frac{M(1-\eta)+\eta}{\varpi} - 1\right]\frac{1}{R_c}}$$

The transmitted power from a mobile is given as

$S_{TX,MS}$

$$= \frac{E_b}{N_o} + R_b + N_f + kT - G_{HO} - G_{MS} - G_{BS} \qquad (19)$$

In Equation (19) above all the terms are the same except for E_b/N_o, regardless of the base station receiver algorithm. $S_{TX,MS}$ is determined only from the E_b/N_o requirement. The decrease in the required transmission power with MUD receiver is thus given as

$$\frac{S_{TX,MS}}{S_{TX,MS,MUD}} = \frac{\left(\frac{E_b}{N_o}\right)_{loaded}}{\left(\frac{E_b}{N_o}\right)_{unloaded,MUD}}$$

$$= \frac{\left(\frac{E_b}{N_o}\right)^{-1}_{loaded} - \left[\frac{M(1-\eta)+\eta}{\varpi} - 1\right]\frac{1}{R_c}}{\left(\frac{E_b}{N_o}\right)^{-1}_{unloaded} - \left[\frac{M}{\varpi} - 1\right]\frac{1}{R_c}} \qquad (20)$$

3 Frequency Selective MIMO Channel

The general expression of frequency-selective MIMO channel indicates N_I signals $x_\mu[k], 1 \leq \mu \leq N_I$ from the input of the system at each time instant k and we obtain N_o output. Therefore, the v^{th} output at time instant k can be expressed as [13]

$$y_v[k] = \sum_{\mu=0}^{N_I} \sum_{\kappa=0}^{L_T - 1} h_{v,\mu}[K,\kappa] \, . \, x_\mu[K-\kappa] + n[K] \qquad (21)$$

where L_t denotes the largest number of taps among all the contributing channels. The channel matrix has the form [14].

$$H[K,\kappa] = \begin{bmatrix} h_{1,1}[K,\kappa] & \cdots & h_{1,N_I}[K,\kappa] \\ \vdots & \ddots & \vdots \\ h_{N_O,1}[K,\kappa] & \cdots & h_{N_O,N_I}[K,\kappa] \end{bmatrix} \qquad (22)$$

3.1 Receiver Processing

If coherent single-user matched filter is used where the receiver is assumed to know the fading coefficients of the user of interest and the transmitted signal from each antenna $K = 1$ [15], then an antenna will receive

$$\begin{aligned} y_1 &= A_{11} b s_{11}(t) + \sigma n_1(t) \\ &\vdots \\ y_D &= A_{D1} b s_{D1}(t) + \sigma n_D(t) \end{aligned} \qquad (23)$$

Optimum decision rule selects $b \in \{-1,1\}$ that minimizes

$$\int_0^T \sum_{d=1}^{D} |y_d(t) - A_{d1} b s(t)_{d1}|^2 \, dt \qquad (24)$$

According to the optimum decision rule [10] the inner product of the $y(t)$ and $s(t)$ is the sufficient statistic [14]. This means that the optimum rule decision for a single –user case is expressed as

$$\hat{b} = sgn\left(\Re\left\{A \sum_{d=1}^{D} A_{d1} y_{d1}^{*}\right\}\right) \qquad (25)$$

Therefore, the probability of error of a MIMO system could be expressed as [14].

$$P_k^{Dc}(\sigma) = E\left[Q\left(\frac{\sum_{d=1}^{D}|A_{dk}|^2}{\sum_{d=1}^{D}|A_{dk}|^2\left(\sigma^2 + \sigma^2_{I_{UWB}^{(k)}}\right)}\right)\right] \qquad (26)$$

3.2 Channel Capacity of MIMO Systems

The Space Division Multiplexing (SDM) over MIMO channels using multiple transmitting and receiving antennas is one of the most promising technologies for improving bits per Hertz (bit/s/Hz). In an Additive White Gaussian Noise (AWGN) channel the channel capacity C is given by

$$C = log_2(1 + \beta)$$

Where β is the signal-to-noise ratio. The MIMO channel capacity is given by [6].

$$C = log_2\left[det\left(I_{n\times n} + \frac{\beta}{N_T}H.H^H\right)\right]. \qquad (27)$$

As the parallel channel capacity, where I is n by n identity matrix, H is a channel matrix, N_T and N_R denote the number of transmitting and receiving antennas, and $(\;)^H$ denotes the complex conjugate transpose. This equation indicates that the channel capacity can be increased in proportion to the number of antennas if $N_T = N_R$. This possible increase in terms of bits per Hertz is why SDM/MIMO is attracting a significant amount of attention these days.

4 Intercell Interference

Considering an omnidirection cell site serving a given set of mobiles, if mobiles are divided into two groups which are mobiles that are powered up and mobiles that are not powered up, the mobiles that are powered up are further, divided into four subgroups: Active and transmitting mobiles, Active but not transmitting mobiles (mobiles in non conversational mode), Idle and transmitting (mobiles in access mode) and Idle and not transmitting (mobiles in non access mode) [1]. Assume that interference at the cell site by mobiles and the access mode is typically small and neglected. This may be accounted for as a source of some degradation in system quality and capacity. We focused only on the active mobiles in our analysis.

Assume there are M mobiles transmitting at a given time in a cell. In a CDMA environment for each mobile, there are (M – 1) interferers. At the cell site, the average signal power received from the *ith* mobile is S_{ri}. This signal power provides bit energy equal $E_b = S_{ri}/R$ where, R is the mobile transmission rate in bps. The thermal noise power is N_0B_W where N_0 is the thermal noise power spectral density (psd), and B_W is the spreading bandwidth. The average interference (psd) at the base station is expressed as

$$I_o = \frac{1}{B_W}\sum_{i=1}^{M-1} V_f . S_{ri} \qquad (28)$$

Where, V_f = channel activity factor.

In equation (28), assuming a perfect control in the reverse link and that the signals transmitted from all the mobiles arrived at the base station with the same received power. i.e. $S_{ri} = S$ for all values of *i (i.e.* $(1 \le i \le M-1)$. The total interference andthermal noise (psd) will be

#

$$I_t = I_0 + N_0 = \frac{1}{B_W}\sum_{i=1}^{M-1} V_f . S_{ri} + N_0 . \qquad (29)$$

#

Recognizing that $S_{ri} = S$, I_t then becomes#

$$I_t = \frac{(M-1).V_f.S}{B_W} + N_0 \qquad (30)$$

The E_b/I_t will be given as,

$$\frac{E_b}{I_t} = \left(\frac{B_W}{r}\right).\frac{S}{[N_0B_W + (M-1).V_f.S]} \qquad (31)$$

$$= G_p.\frac{S}{[N_0B_W + (M-1).V_f.S]}$$

Where G_p = processing gain = B_W/r. The signal strength, S in dB as,

$$S = R_m + G_m + G_b + G_{dv} + G_{sho} + L_p + M_{fade}$$

$$+ L_{body} + L_{pent} + L_{cable}$$

Where

$G_m = transmit\ antenna\ gain\ of\ the\ mobile\ (dB)$

$G_b = receive\ antenna\ gain\ of\ base\ station\ (dB)$

$G_{dv} = base\ station\ antenna\ diversity\ (dB)$

From (31)

$$M = 1 + G_p.\left[\frac{1}{(E_b/I_t).v_f}\right] - \frac{N_0.B_W}{S.v_f} \qquad (32)$$

also,

$$S = \frac{(E_b/I_t).N_0}{\frac{1}{R} - \frac{(M-1)v_f(E_b/I_t)}{B_W}} \qquad (33)$$

Let [illegible] represent the interference factor from other cells (31) can be expressed as

$$G_p.\frac{S}{[N_0B_W + (M-1).V_f.S(1+ [illegible])]} \# \qquad (34)$$

Include an imperfect power factor, φ and rewrite equation (34) as,

$$G_p \cdot \frac{S}{B_W . N_0 + (M-1) . V_f . \left(\frac{S}{\varphi}\right) . (1+i)} \quad (35)$$

Solving equation (35) for M, we get,

$$M = 1 + G_p \cdot \left[\frac{\varphi}{\left(\frac{E_b}{I_t}\right) . V_f . (1+i)}\right] - \frac{N_0 . B_W . \varphi}{S . V_f . (1+i)} \quad (36)$$

Solving equation (35) for S, we get

$$S = \frac{\frac{E_b}{I_t} . N_0}{\frac{1}{R} - \frac{(M-1) . V_f . (1+i) \frac{E_b}{I_t}}{B_W . \varphi}} \quad (37)$$

From equation (36), the maximum value of M is,

$$M_{max} = 1 + G_p \cdot \left[\frac{\varphi}{\left(\frac{E_b}{I_t}\right) . V_f . (1+i)}\right] \quad (38)$$

M_{max} is called the pole point or asymptotic cell capacity that is achieved as $S \rightarrow \infty$. For simplification, neglecting 1 and rewriting equation (38) gives,

$$M_{max} \approx G_p \cdot \left[\frac{\varphi}{\left(\frac{E_b}{I_t}\right) . V_f . (1+i)}\right] \quad (39)$$

equation (33) can further be expressed as,

$$\frac{S/\varphi}{N_0 B_W} = \frac{1}{M_{max} . V_f . (1+i) . (1-\rho)} \quad (40)$$

where, $\rho = \frac{M}{M_{max}} =$ cell loading factor.

5 Results & Discussions

In this study, a maximum cell loading factor of 18% and signal to noise ratio of $30dB$ were used for the capacity analyses. With M mobiles of 20 and received antenna gain of the base station of $9dB$ and with maximum mobile transmitted power and equivalent isotropic radiated power of $18dBm$ and $21dBm$ respectively, the bits per second performance for the 4*4 MIMO System shown in figure 1 for $30dB$ is around 35bps that overwhelmed the other systems. Figure 2 also provides the BER analysis of the various systems in multiple interferers. With cell loading factor of 0% and signal to noise ratio of $10dB$ the 4*4 MIMO systems performed better. With cell load of 50% and a cell range of 1.02km the allowable path loss without MUD was around $98.48dB$. With path loss with MUD at a cell range of 1.357km was around $110.67dB$. It was also realized that as the cell range and allowable path loss in dB decreases the cell load increases dramatically. Interestingly, similar results were obtained in [1] where they further observed that base station multiuser detection (MUD) receiver can provide good coverage even with high system load after initial deployment and, finally, concluded that the effect of MUD on cell range depends on propagation environment.

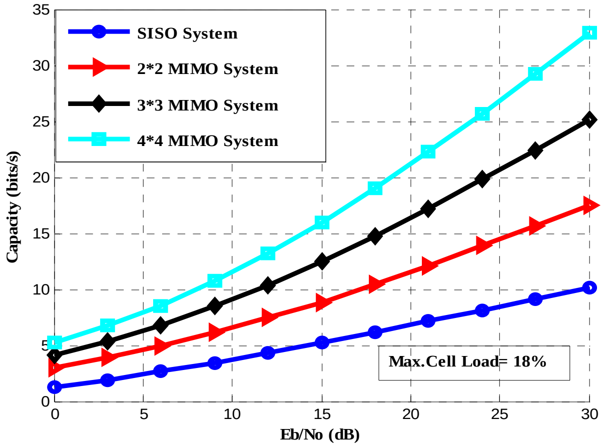

Fig. 1 Capacity performance of WCDMA with 18% Cell Load factor

6 Conclusion & Future Work

Analyses of coverage of a loaded and unloaded WCDMA network conducted in this paper revealed that the propagation environment affects the cell range with a given cell loading. Furthermore, for efficient CDMA operation the spectrum must be cleared in a sufficient guard band and guar zone. Also, spectrum monitoring is highly recommended as early as possible in the CDMA system since it is tedious to identify the source of external interference. Intermodulation interference, adjacent and co-channel interference could be considerd in further studies.

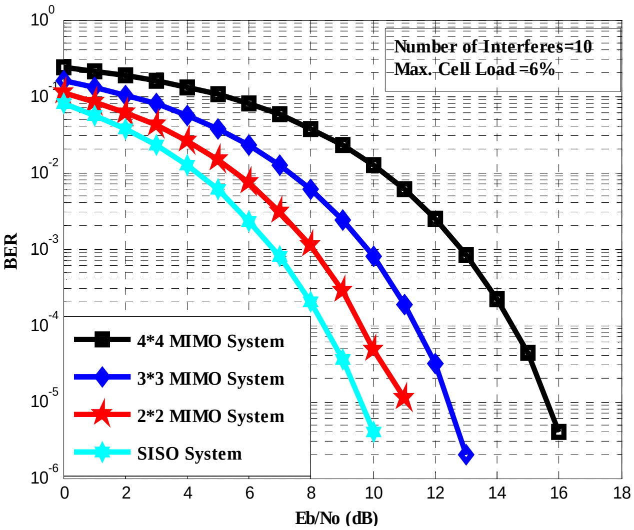

Fig. 2 BER performance of WCDMA in Multiple

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