International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 4 No. 7, July, 2014

Improved Voice/Data Traffic Performance of Cellular CDMA System

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ABSTRACT

More and more wireless subscribers often access the internet through the cellular networks. The long range dependent (LRD) internet data traffic will soon dominate the conventional voice traffic. In this paper, an analytical approach to evaluate the voice/data traffic performance of cellular CDMA system using an SINR based admission control on the mobile to base station link and long range dependent variables was carried out. The SINR is modelled as an LRD process and its corresponding time-scaled process proved as having slow-decaying tail distributions which was analysed using Gaussian approximated. The results showed significant performance improvement in both voice and data traffic in terms of mean delay as well as Erlang capacity using SINR based admission control. The results also showed that the number of subscribers (voice/data) that can be supported by the trunk during the busy hour for a specified blocking probability is 2% -3%.

Keywords: voice/data traffic, cellular, CDMA, SINR, LRD.

1. INTRODUCTION

Code division multiple access (CDMA) cellular systems with voice-only traffic have been known to offer higher system capacity than the channelized systems [Viterbi, 1995]. Several studies analyzing the capacity of CDMA systems have been reported [Evans and Everrit, 1999], [Karmani and Sivarajan, 2001] and [Elechi, *et al*, 2013]. However, these studies did not take into account admission control strategies based on signal-to-interference ratio (SIR) measurements. In [Anand, *et al*, 2002], CDMA was analyzed, using Chernoff bound and central limit theorem approximations, the capacity and outage performance of a voice-only cellular CDMA system with an SIR based admission control strategy. The study showed that an improvement of about 30% in the system capacity is achieved for an outage probability of 1%. This study, however, did not consider the performance with mixed voice and data traffic, which is typical in the next generation CDMA cellular systems [Holma and Toskala, 2000]. Performance of CDMA systems with voice and data traffic has been studied in [Dimitriou and Tafazolli, 2000], [Liu and Silvester, 1998]. These studies have considered admission control, but based only on code availability. Admission control based on SIR measurements can offer improved performance [Anand, *et al*, 2002]. Elechi, *et al* [2013] modelled the telephone traffic using statistical approach to generate a CDMA blocking probability that is adapted into Erlang B formula for capacity calculations of the blocking probability. The results showed that variation in network parameters affects CDMA capacity and performance and that CDMA has a huge capacity advantage over FDMA and TDMA. Yu, *et al* [2004] proposed a variable period prediction scheme to predict multi-access interference (MAI) to improve the performance of CDMA network in the presence of long range dependent (LRD) data traffic.

Understanding the nature of the traffic in mobile network is critical for efficient network protocol and system design. Code Division Multiple Access (CDMA) [Zigangirov, 2004] is currently the dominant technology for wireless cellular networks, and is expected to continue to play an important role in the next generation cellular networks.

In a CDMA network, traffic transmissions by all other active users contribute to Multi-Access Interference (MAI) of an individual user [Yu *et al*, 2004]. Therefore the characteristics of the aggregated traffic transmitted by all other users affect the characteristics of MAI, and in turn Signal to Interference noise ratio (SINR) which indicate the quality of the received signal of the individual user. While the conventional voice traffic in a CDMA network is usually modelled as poison process with an exponential inter-arrival time of packets or bursts, with the introduction of internet applications, Poisson processes can no longer characterize the aggregated data traffic over a CDMA network.

In this paper, the Weibull Bounded Burstiness (WBB) process in [Yu *et al*, 2005] is used to characterize the long range dependent (LRD) characteristics in a CDMA network and the impact of long range dependency on MAI as well as SINR in a CDMA network with many data users.

The objective of this paper is to model the CDMA blocking probability, and an analytical approach to evaluate the voice/data traffic performance of cellular CDMA system using an SIR based admission control on the mobile to base station link and long range dependent variables.

2. MATERIALS AND METHOD

Consider a voice/data CDMA cellular system with N=61 cells, a voice call or a data burst originating from a mobile system is admitted into the system if a) spreading codes are available for allocation, and b) the interference-to-signal (I/S) ratio measured at the corresponding base station is less than a desired threshold. Voice calls are assumed to be of circuit switched type, each using a spreading code for transmission. Voice calls which are not admitted are blocked, and data burst which are not admitted buffered. For the buffered data, the system behaves like a single virtual queue such that all base stations in the system co-ordinate among themselves and keeps track of a virtual queue of data bursts, by assigning a priority index to each buffered data burst. The priority indices are assigned based on the order of the arrival epochs of data bursts. When a code becomes free and the I/S conditions become favourable following the departure of an ongoing call, the base stations allow the mobile having the data burst with the least priority index to transmit the data burst using the assigned code, and the priority indices of all the other buffered data bursts in the system are decremented by 1. Because the number of users at a given time is random, and the interference power from a user is a random variable, the probability of blocking leads to an estimate of the average number of active users that is termed the Erlang capacity of the CDMA cell sector. The determination of Erlang capacity depends on the assumptions about the probability distributions of the call traffic and user interference [Elechi *et al*, 2013].

2.1. Voice and data interference Performance Analysis

In cellular CDMA, the interference in a given cell is due to the in-cell and the other-cell active mobiles. Assuming the interference seen by a base station is due to the mobiles in its first tier of neighbouring cells and ignoring the interference due to mobiles located in the cells other than the first tier neighbouring cells are negligible.

Assuming each cell has a maximum of $n = 64$ spreading codes available for allocation and that mobiles are uniformly distributed over the area of each cell. The number of interferers with voice traffic seen by cell k, $\Delta_k^{(v)}$, can be written as [Anand and Chockalingam, 2003]:

$$\Delta_k^{(v)} = \Delta_{I_k}^{(v)} + \Delta_{O_k}^{(v)} \qquad (1)$$

where $\Delta_{I_k}^{(v)}$ is the number of in-cell voice interferers and $\Delta_{O_k}^{(v)}$ is the number of neighbouring-cell voice interferers to cell k. Similarly, the number of interferers with data traffic seen by cell k, $\Delta_k^{(d)}$, is given by

$$\Delta_k^{(d)} = \Delta_{I_k}^{(d)} + \Delta_{O_k}^{(d)} \qquad (2)$$

where $\Delta_{I_k}^{(d)}$ is the number of in-cell data interferers and $\Delta_{O_k}^{(d)}$ is the number of neighbouring-cell data interferers to cell k.

Let $Z_k' \left(\Delta_k^{(v)}, \Delta_k^{(d)}\right)$ denote the I/S at the base station of cell k, due to $\Delta_k^{(v)}$ voice interferers and $\Delta_k^{(d)}$ data interferers.

$Z_k' \left(\Delta_k^{(v)}, \Delta_k^{(d)}\right)$ can be written as:

$$Z_k' \left(\Delta_k^{(v)}, \Delta_k^{(d)}\right) = \Delta_{I_k}^{(v)} + I_k\left(\Delta_{O_k}^{(v)}, \Delta_k^{(d)}\right) \qquad (3)$$

where the first term is due to the perfectly power controlled in-cell voice interferers, and the second term is due to the neighbouring-cell voice interferers and all the data interferers.

Assuming the path loss exponent to be 4 and the shadow loss to be log-normally distributed of the form $10^{-\frac{\varphi}{10}}$, where $\varphi \sim N(0, \sigma^2)$.

$Z_k' \left(\Delta_k^{(v)}, \Delta_k^{(d)}\right)$ can be written, in terms of distance attenuation, shadow loss and multipath Rayleigh fading loss, as

$$Z_k' \left(\Delta_k^{(v)}, \Delta_k^{(d)}\right) = \frac{1}{k_d} \sum_{i \neq k} \sum_{j=1}^{\Delta_{ik}^{(v)}} \frac{D^4\left(M_{ji}^v, Bi\right) 10^{-\frac{\varphi_{ji}^v}{10}}}{D^4\left(M_{ji}^v, B_k\right) 10^{-\frac{\varphi_{jk}^v}{10}}} + \sum_{i \in S_k} \sum_{j=1}^{\Delta_{ik}^{(d)}} D^{-4}\left(M_{ji}^d, B_k\right) 10^{-\frac{\varphi_{jk}^d}{10}} R_{jk}^2 \qquad (4)$$

where$\Delta_{ik}^{(v)}$ and $\Delta_{ik}^{(d)}$ are the number of voice and data interferers, respectively, in cell i to cell k. S_k denotes the set of cells containing cell k and its neighbouring cells. Note that $\Delta_{0_k}^{(v)} = \sum_{i \neq k} \Delta_{ik}^{(d)}$ and $\Delta_{k}^{(d)} = \sum_{i \in S_k} \Delta_{ik}^{(d)}$. $D\left(M_{ji}^{v}, B_k\right)$ is the distance between the j^{th} voice interferer in cell i and k^{th} base station, $D\left(M_{ji}^{d}, B_k\right)$ is the distance between the j^{th} data interferer in cell i and the k^{th} base station, and $\varphi_{jk}^{v}, \varphi_{jk}^{d} \sim N(0, \sigma^2)$ corresponds to the shadow loss from the j^{th} mobile in cell i to the k^{th} base station for voice and data interferers respectively. R_{jk}^2 corresponds to the Rayleigh fading loss from the j^{th} mobile in cell i to the k^{th} base station. The k_d^{-1} factor in the first term accounts for the lesser transmit power for voice users relative to that of the data users, because of the difference in the transmission rates of the voice and data traffic.

2.2 Impact of Long Range Dependent on a CDMA system

The concept of long range dependent process is often characterized by heavy traffic bursts that extend over a wide range of time scales [Paxson and Floyd, 1995], [Willinger, *et al*, 1995]. Suppose A is a discrete LRD process, and $A(u)$ denotes the uth sampling of A. A^T is defined as the average of A aggregated in a time interval T.

For the N=61 users in the CDMA network and let $X_i(u)$ be the activity indicator of user i at the uth sampling time. $X_i(u)$ is an ON/OFF process. During the ON period, $X_i(u)$ =1 and the user transmits at a constant rate R_i with a transmission power P_i (per time unit), while during the OFF period, $X_i(u)$ = 0 and the user does not transmit.

Assuming the CDMA system implements power control to achieve the same Signal to Noise Interference Ratio (SINR) at the base station for every user so that no user gains better performance with a transmission power higher than necessary [Yates, 1995],[Zander, 1992]. Time scaled SINR is approximately "Gaussian-like" distributed for a CDMA system with either data users or voice users. The SINR is an LRD process and its corresponding time-scaled process can be proved as having slow-decaying tail distributions for user i at the uth sampling.

$$SINR_i(u) = \frac{G_i}{N_0(u)W/P_i + \sum_{j=1, j\neq i}^{N} X_j(u)\frac{R_j}{R_i}} \quad (5)$$

$$= \frac{G_i}{N_o(u)^W/_{P_i} + K_i(u)} \quad (6)$$

where $G_i = {}^W/_{R_i}$ is the processing gain for user i, W is the spreading signal's bandwidth and $N_o(u)$ is the instantaneous sampling receiving power of the white Gaussian noise. In general, the SINR measured in a finite time scale T is of interest for performance evaluation in a CDMA system. For voice users, SINR is expressed in terms of long term average measurement of noise $E[K_i]$ because the short term average value can be well approximated with the long term average value, hence, the SINR is approximated as a probability distribution function of Z.

2.3 Time Scaled SINR Approximation for CDMA Probability Distribution

Since the SINR approximation is "Gaussian-like", the approximation methods to be considered as probability distribution are:

- Gaussian approximation: Based on the fact that Z is a sum (central Limit Theorem), then

$$Q_z(x) \approx Q(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} e^{-t^2/_2}\, dt \quad (7)$$

Under the Gaussian assumption, the mean and variance of Z can be approximated as $B_{CDMA} = Pr\{Z > Z_0\}$ [Elechi *et al*, 2013]

$$Pr\left\{G > \frac{Z_0 - M_M}{\sigma M}\right\} \quad (8)$$

According to Elechi *et al*, 2013, the general expression of the CDMA blocking probability under the Gaussian approximation for the interference statistic is:

$$B_{CDMA} = Q\left(\frac{\frac{W}{R_b}(1-\eta_0)-\bar{M}\overline{\propto_r}\rho_{med}e^{1/2\beta\sigma_{dB}^2}(1+\xi)}{\sqrt{\bar{M}\overline{\alpha_r^2}\rho_{med}^2 e^{2\beta^2\sigma_{dB}^2}(1+\xi')}}\right) \quad (9)$$

In which the Erlang capacity is$\bar{M}$, ξ *and* ξ' are the first and second-order frequency reuse factors and can assume typical experimental values such as 0.55, $\propto_r$ are random variable, $\frac{W}{R_b}$ is the spread spectrum processing gain, ρ_{med} *and* σ are the median and standard deviation of the probability distribution in dB. R_b is the date bit rate and β expresses the natural logarithm.

- Lognormal approximation: Based on the fact that the SINRs in the sum are lognormal, Z itself can be approximately characterized as a lognormal variable.
-

Under lognormal assumption, the mean and variance of Z are identified as the mean and variance of ξ, where $\xi = e^{m_M+\sigma m_G}$
The mean, mean square, and variance of ζ are given by

$$E\{\zeta\} = e^{m_M} E\{e^{\sigma_M G}\} = e^{m_M+\frac{1}{2}\sigma^2 M} \quad (10)$$

$$E\{\zeta^2\} = e^{2m_M} E\{e^{2\sigma_M G}\} = e^{2m_M+2\sigma_M^2} \quad (11)$$

$$Var\{\zeta\} = E\{\zeta^2\} - [E\{\zeta\}]^2 = e^{2m_M+\sigma_M^2}[e^{\sigma_M^2} - 1] \quad (12)$$

Solving for m_M and σ^2_M: gives

$$\bar{M}\,\overline{\alpha_r}\, e^{\beta m_{dB}+\frac{1}{2}\beta^2\sigma_{dB}^2}(1+\xi) = e^{m_M+\frac{1}{2}\sigma_M^2} \quad (13)$$

And

$$\bar{M}\,\overline{\alpha_r^2}\, e^{2\beta m_{bB}+2\beta^2\sigma_{dB}^2}(1+\xi^1) = e^{2m_M+\sigma_M^2}\left[e^{\sigma^2 m} - 1\right] \quad (14)$$

The solution is

$$\sigma_M^2 = ln\left[\frac{\overline{\alpha_r^2}\,(1+\xi')e^{\beta^2 a_{dB}^2}}{\bar{M}\,(\overline{\alpha_r})^2(1+\xi)^2} + 1\right] \quad (15)$$

and

$$m_M = In\,[\bar{M}\,\overline{\alpha_r}\,(1+\xi)] + \beta m_{dB} + 1/2\,(\beta^2\sigma_{dB}^2 - \sigma_M^2) \quad (16)$$

Using these parameters, the blocking probability formula for the lognormal approximation is

$$B_{CDMA} = Pr\{Z > Z_O\} \approx Pr\{e^{m+\sigma_M G} > Z_0\}$$

$$B_{CDMA} = Q\left(\frac{InZ_0-m_M}{\sigma_M}\right) \quad (17)$$

Substituting the expressions for m_M and σ_M, we obtain general expressions for the CDMA blocking probability under the lognormal approximation for the interference statistic, given by [Elechi *et al*, 2013]

$$B_{CDMA} = Q\left(\frac{ln\left[\frac{W}{R_b}(1-\eta_0)\right] - ln[\bar{M}\,\overline{\alpha_r}\,(1+\xi)] - \beta m_{dB}}{\sqrt{ln\left[\frac{\overline{\alpha_r^2}(1+\xi')e^{\beta^2\sigma_{dB}^2}}{M(\bar{\alpha})^2(1+\xi)^2}+1\right]}} \frac{\frac{1}{2}\left\{\beta^2\sigma_{dB}^2 - ln\left[\frac{\overline{\alpha_r^2}(1+\xi')e^{\beta^2\sigma_{dB}^2}}{M(\bar{\alpha})^2(1+\xi)^2}+1\right]\right\}}{\sqrt{ln\left[\frac{\overline{\alpha_r^2}(1+\xi')e^{\beta^2\sigma_{dB}^2}}{M(\bar{\alpha})^2(1+\xi)^2}+1\right]}}\right) \quad (18)$$

The blocking probabilities will be plotted as a function of average number of users

3. RESULTS

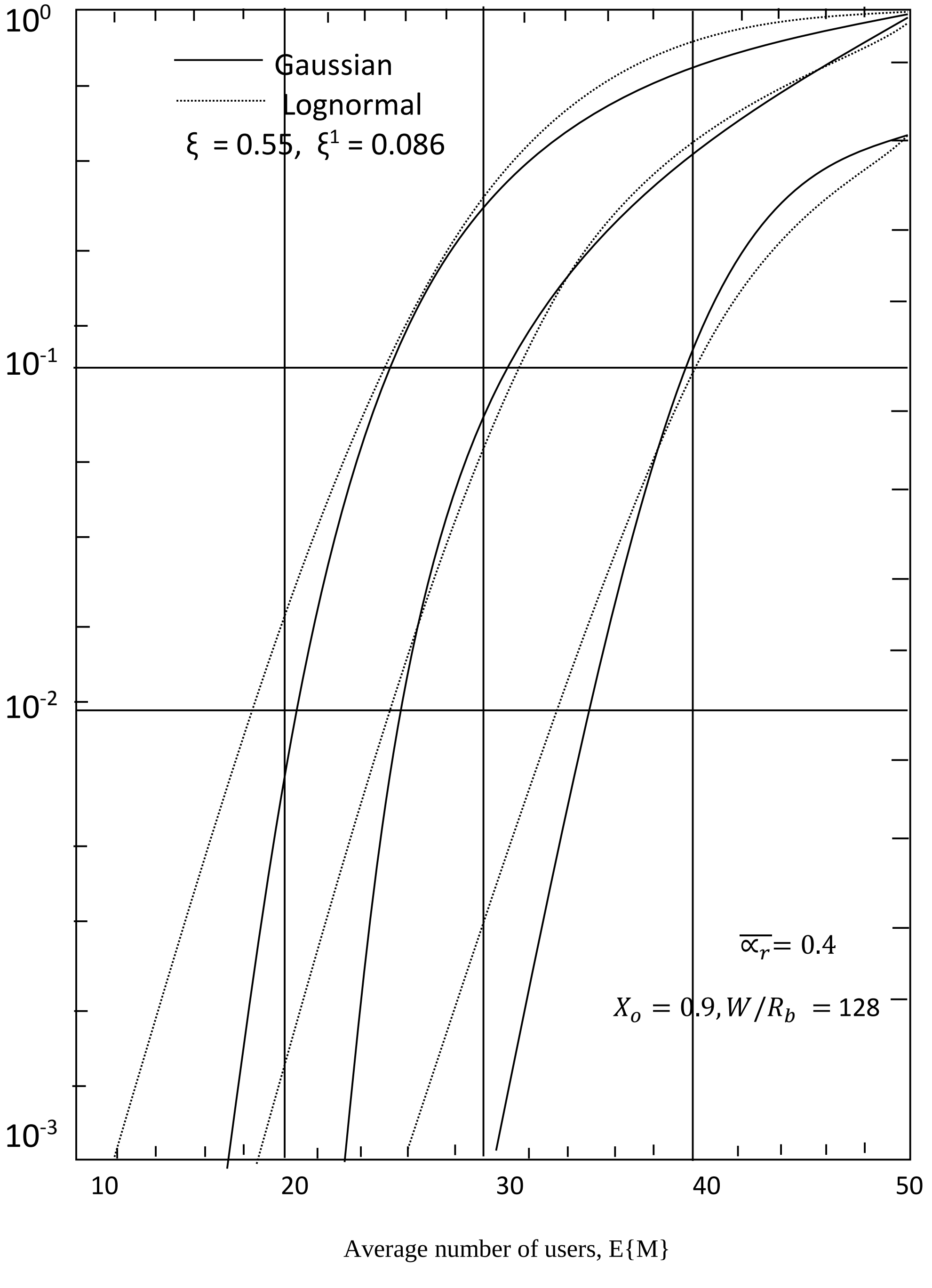

Figure 1: Comparison of Gaussian and lognormal blocking probability approximations for ξ = 0.55 and ξ′ = 0.086.

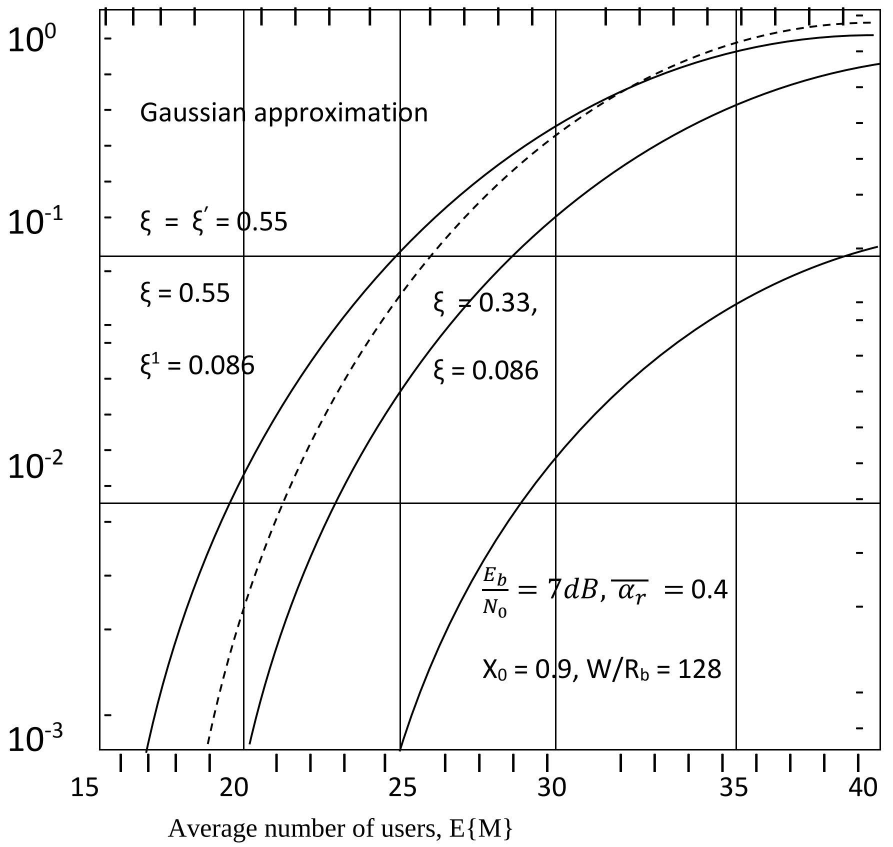

Figure 2: Comparison of CDMA blocking probabilities for different reuse fraction values.

$\overline{\alpha_r} = 0.4,\ \overline{\alpha_r^2} = 0.31, \quad X_0 = 0.9, \frac{W}{R_b} = 128$

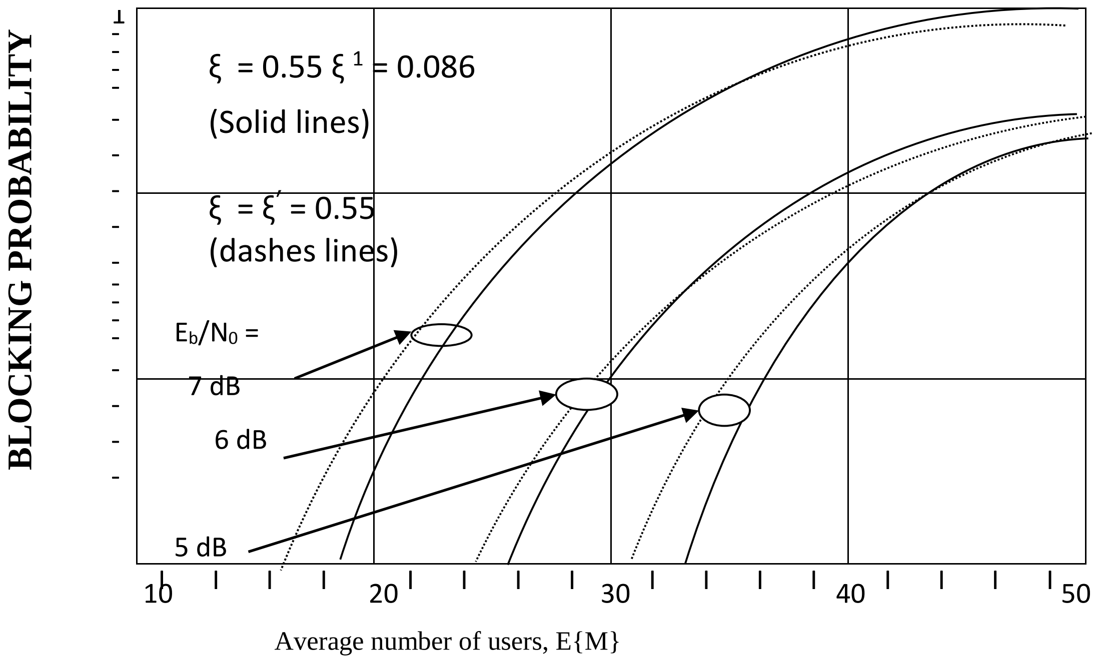

Figure 3: CDMA blocking probability (Gaussian approximation) versus average number of mobile users, reuse fractions varied.

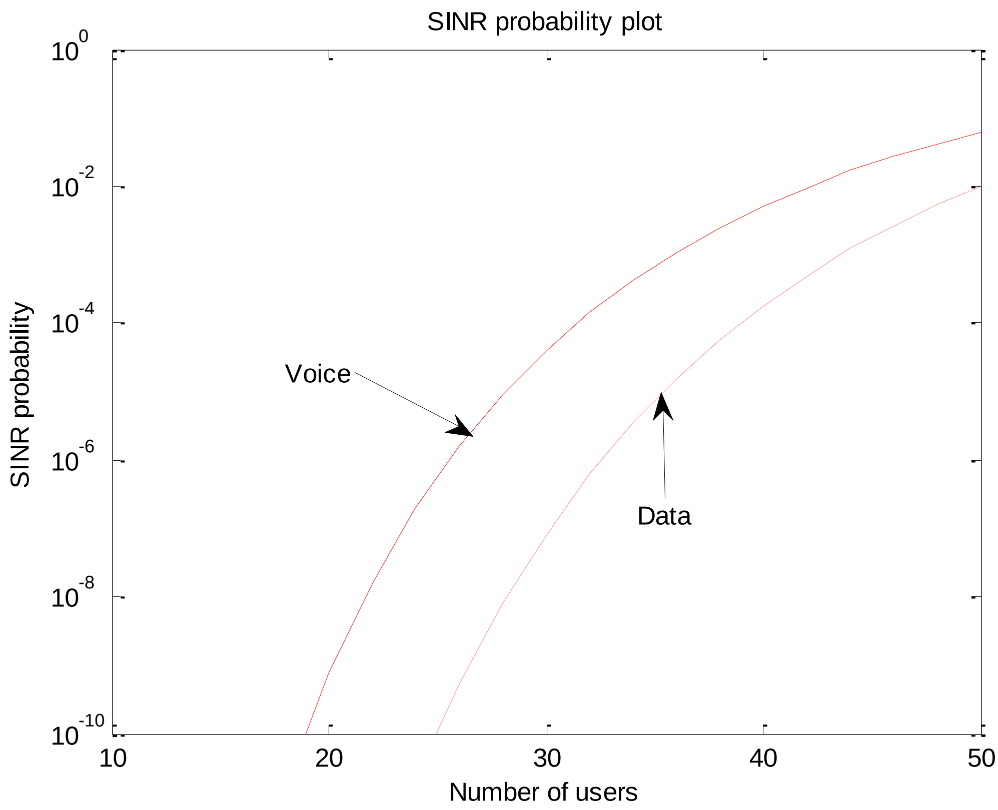

Figure 4: SINR Outage probability plot of voice and data

4. DISCUSSION

4.1: Comparison of CDMA Blocking Probabilities

For the Gaussian approximation, the blocking probability expressions were given in (9), while for the lognormal approximation the blocking probability expressions were given in (18). The blocking probability has been expressed as a function of the interference parameter threshold η_0 and the cell loading threshold X_0. These blocking probabilities were plotted as a function of Erlang capacity $\bar{M}$ with the median value of $m_{dB} = E_b / N_0$ as a parameter for 7 dB. The blocking probabilities plotted in the figures also show two separate cases of using second-order reuse fractions of $\xi' = 0.55$ and $\xi' = 0.086$. Figures 1 and 2 clearly indicate that the blocking probability is insensitive to the value of the second-order reuse fraction ξ' as demonstrated for the cases of $\xi' = 0.55$ and $\xi' = 0.086$.

In Figure 1, a comparison of the Gaussian and lognormal blocking probability approximation is made for $\xi = 0.55$ and $\xi' = 0.086$. Clearly it is demonstrated that the Gaussian and lognormal approximations to the interference statistic give similar results for CDMA blocking probabilities greater than 1%. Therefore, we may choose the simpler Gaussian expression.

4.2: Sensitivity of B_{CDMA} To ξ.

Figure 1, is a plot of the blocking probabilities for two different values of $\xi = 0.33$ and $\xi = 0.55$. For each case, an identical value $\xi^1 = 0.086$ was used and for comparison purposes, the case of $(\xi, \xi') = (0.55, 0.086)$ and the single-cell blocking probability. Note that the effect of changing the value of ξ is significant, in contrast to what we observe about the sensitivity of B_{CDMA} to ξ'. For example, for a blocking probability of 1%, $\xi = 0.33$ gives $\dot{M} = 22.5$, while $\xi = 0.55$ gives $\dot{M} = 20$. This shows that ξ' is bounded between 0.33 and 0.42 as a result of theoretical calculations, while $\xi = 0.55$ is a simulation-based reuse fraction value.

Thus, Figure 3 can be used for Erlang capacity determination for all cases of interest with respect to the values of E_b/N_0. The comparison of Erlang capacities is based on first reading the CDMA Erlang capacity for a specified blocking probability from Figure 3 and then treating it as the offered load, so that we can use the Erlang B probability expression

$$B_{CDMA} = \frac{(\bar{M})^N/N!}{\sum_{i=0}^{n}(\bar{M})^n/n!} \qquad (19)$$

to find N, which is an "equivalent number of channels" to be compared with the numbers of channels in the FDMA and TDMA systems. From figure 3, we read the Erlang capacity $\bar{M} = 20$ Erlangs. Now, for $\bar{M} = A$, the offered load, there is need to find the equivalent number of channels N that satisfies (19).

4.3 Number of Subscribers at the Busy Hour

We are interested in computing not only the number of active users at a given time, but also the number of subscribers that may be supported by the CDMA system in any given cell.

In terms of traffic theory, consider a telephone switch and its trunk of N lines, for system-planning purposes, the traffic during the "busy hour" of the day is used. Typically, a user is likely to be on the telephone at any given time during the busy hour with the probability of 0.02 to 0.03. That is, each subscriber is considered to offer A_0 = 0.02 to 0.03 Erlangs of traffic. The number of subscribers (voice/data) that can be supported by the trunk during the busy hour for a specified blocking probability that results in the total load A then is given by the formula

$$M_S = A / A_0 \qquad (20)$$

where Ms is the number of subscribers.

Figure 4 gives the voice call outage probability performance in a mixed voice/data system. The SINR based admission control is seen to perform better than the call admission based admission control. For instance a 1% outage probability occurs at voice traffic of about 2 Erlangs per cell offering more than 50 users. However in the mixed voice/data system, the voice Erlang capacity is 6 Erlangs per cell in the presence of 5 Erlangs per cell of data traffic. Thus, the voice Erlang capacity comes down while supporting higher rate data users.

5. CONCLUSIONS

Having analysed the performance of CDMA based on the SINR control LRD strategy in a wireless CDMA system network with both voice and data traffic. The expression for the outage probability of the voice and data traffic was derived, the mean delay for data traffic and the average system throughput for a mixed voice/data CDMA system using Gaussian approximation. The result showed significant performance improvement in both voice and data traffic in terms of mean delay as well as Erlang capacity using SINR based admission control. The result also showed that the number of subscribers (voice/data) that can be supported by the trunk during the busy hour for a specified blocking probability is 2% -3%.

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