QoS-Aware SINR-based Call Blocking Evaluation in Cellular Networks with 3G Interface

Moses Ekpenyong[1] **and Imeh Umoren**[3]

[1] **School of Informatics, University of Edinburgh**
EH8 9AB, Edinburgh

[2] **Akwa Ibom State University**
Mkpat Enin, PMB. 1167, Akwa Ibom State, Nigeria

Abstract

A Quality of service (QoS)-aware signal to interference and noise ratio (SINR)-based blocking probability model is simulated in this paper to evaluate the performance of networks with third generation (3G) interface. To arrive at a suitable model, we set a relatively low SINR threshold value ($SINR_{th}$), which results in the admission of more users into the system. But this in turn yields an increased blocking probability and reduces the spectral efficiency. In this paper, we employ an empirical modeling approach, by measuring the occurrence of call blocking under ideal conditions, within a specific time period, from an established cellular network. The observed data parameters are used as model predictors during the simulation phase. Simulation results reveal that increased system capacity degrades the performance of the network due to call blocking which the system is most likely to experience, but the rate of blocking could be minimized by properly guarding the SINR threshold levels.

Keywords: *QoS, SINR, call blocking, spread spectrum.*

1. Introduction

Third generation radio communication systems are designed to offer multimedia services, including voice and video telephony and high speed internet access. In the universal mobile telecommunication system (UMTS), the radio air interface is based on the wide band code division multiple access (WCDMA) technology. Universal mobile telecommunication system (UMTS) WCDMA is a direct sequence CDMA system (DS-CDMA). WCDMA has two basic modes of operation: frequency division duplex (FDD) and time division duplex (TDD). In the FDD mode, the uplink and downlink transmissions use different frequency bands while for TDD mode, the uplink and downlink transmissions can be implemented on unpaired bands, but separated by a squared period. In this paper, a DS-CDMA FDD [1-3] is considered.

The measurement of resource capacity in a spread spectrum system is distinct from that of convectional time division multiple access (TDMA) or frequency division multiple access (FDMA) systems. In conventional TDMA and FDMA systems such as IS-54 TDMA and GSM (hybrid TDMA/FDMA), the number of traffic channels is fixed. This is determined by the number of time slots in the TDMA system or by the number of non-overlapping frequencies in the FDMA system. The spread spectrum such as WCDMA, does not have a fixed number of channels. Instead, the capacity of a CDMA system is limited by the total interference. Normally the interference level increase rapidly when the system load reaches a certain level. Users with different traffic profiles and attributes such as the service rate, the signal-to-interference and noise ratio (SINR) requirement, etc., introduce different amounts of interference into the system. It is therefore essential to exercise some kind of control to meet an acceptable SINR for all users. Hence, maximizing the system capacity by minimizing the blocking probability (i.e., the probability that a call will be dropped due to inadequate SINR level) is the main focus of this paper.

2. Research Background

UTMS technology-based third Generation (3G) wireless networks have either been or are currently being installed in many countries, with the aim of improving upon past technologies and fulfilling users' requirements. In developing countries for instance, many telecommunication companies such as the Mobile Telecommunication Network (MTN), Global Communications Limited (GLO), Airtel Nigeria Limited, Visafone, Starcomms, Etisalat, etc, are now operating fully, the 3G-based CDMA IX-EV-D0 services. Despite the good number of communication companies operating the 3G technologies and services, subscribers' satisfaction and quality service delivery in some countries is far below expectation. There has been series of complaints arising from frequent power outages, call conversation echoes, drop calls, blocked calls, among others, from mobile subscribers. Some users even resort to the option of subscribing to more than one service provider, just to maintain seamless connectivity, thereby losing a fortune to network operators.

Mobile systems require broadband capabilities for effective power control to optimize their spectral efficiency. The power control inherent in CDMA-based networks and mobiles for instance, ensure that each mobile always transmits just enough power to provide acceptable call quality. On the reverse link, CDMA base stations constantly measures the error rate performance from each mobile transmitting a signal, and depending on whether the error rate is above or below an adequate performance level, the power control circuit makes adjustments to the signal-to-interference and noise ratio (SINR). A base station function measures the actual SINR and makes comparison with the target. Should the actual ratio be too high or too low, an "up power" or "down power" command is sent to the mobile, which responds by increasing or decreasing its power in steps of 1dB. These occur at approximately 1,000 times per second at each base station and for each operating mobile. In order to gain more network capacity and improve the network performance there is need for modern techniques such as interference canceling, use of femtocells and picocells and traffic offloading.

A lower bound of SINR that minimizes the outage probability in the reverse link of a single-class CDMA system, is derived in [4]. However, the derived SINR threshold is obtained by assuming that the number of active users per cell is modelled by the Poisson distribution. This assumption is not entirely accurate since the admitted traffic rate is not constant due to its dependence on the number of existing users in the system. This paper considers call blocking and improves on the accuracy of the SINR threshold ($SINR_{th}$) by computing the probability of the number of users using a Markov chain model instead of the inaccurate Poisson distribution in [5].

Our research methodology involves a study of weekly statistics of cell blocking probabilities measured over a period of two weeks (October-December, 2009) from the Airtel Communications Limited, a cellular network operating in Nigeria. The expected value of the observed data is then used to formulate an analytical blocking probability model, which will assist in the network performance analysis. Knowledge of the blocking probability behaviour and other network parameters (e.g., traffic load, call arrival rate, among others) would help network operators to optimize system's performance and improve on the quality of service provisioning.

3. System Model

In SINR-based blocking probability schemes, the SINR of the reverse link is evaluated with a predefined threshold value $SINR_{th}$. The incoming call is admitted only if the reverse link SINR exceeds this threshold value $(SINR_{th})$. To achieve a lower bound that keeps the blocking probability below a maximum value ($(P_{B-\max})$, a relationship between the blocking probability (P_B) and the SINR threshold ($SINR_{th}$), must be established. This value can be expressed as:

$$P_B = \sum_{N=1}^{\infty} P_{B|N} P(N) \tag{1}$$

where

$P_{B|N} = P(SINR < SINR_{\min} \mid N)$ is the blocking probability given that the number of active users per cell is N

$P(N)$ is the probability that there are N active users per cell.

Given the imperfect power control nature of networks, especially in developing countries, the SINR can be represented as a log-normally-distributed random variable [6-7]:

$$= 1 - Q\left(\frac{SINR_{\min}^{dB} - \delta}{\sigma}\right) \tag{2}$$

where

δ *and* σ are the mean and standard deviation of $SINR^{dB}$, respectively

Q is the cumulative normally-distributed function defined as [8]:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_z^{\gamma} e^{\frac{1}{2}x^2} \tag{3}$$

From [9], δ is given as:

$$\delta = \begin{cases} SINR_{trg}^{dB} & N \le N_{\max} \\ 10\log_{10}\left(\dfrac{1}{(N-1)(1+f)+(\eta_0 W \mid S)}\right) & N > N_{\max} \end{cases} \quad (4)$$

where

- η_0 is the noise power spectral density
- S is the target balanced received power level
- W is the spreading bandwidth
- f is the ratio of the inter-cell interference to the intra-cell interference.

In this paper, σ is assumed to be a constant and depends only on the delay and PC errors. It is obvious from equations (1) – (3) that $P_{B|N}$ does not depend on N as long as PC is feasible. When PC becomes infeasible, $P_{B|N}$ increases monotonically with N. For this reason, we model N using a Poisson distribution. So, P(N) in equation (1), can be expressed as:

$$P(N) = \frac{\alpha^N}{N!}\exp(-\alpha) \quad (5)$$

where α represents the mean value of the admitted traffic intensity in Erlang per cell and is expressed as:

$$\alpha = \wedge(1 - P_B) \quad (6)$$

Substituting equation (2) into equation (6) and merging the resulting equation into equation (5) results in:

$$P(N) = \frac{\left(\wedge Q\left(\dfrac{SINR_{th}^{dB} - \mu}{\sigma}\right)\right)^N}{N!}\exp\left(-\wedge Q\left(\frac{SINR_{th}^{dB} - \mu}{\sigma}\right)\right) \quad (10)$$

Expressing P_B as a function of $SINR_{th}$ by substituting equations (2) and (10) into equation (1), gives:

$$P_B = \sum_{N=1}^{\infty}\left(1 - Q\left(\frac{SINR_{\min}^{dB} - \mu}{\sigma}\right)\right) \bullet \frac{\left(\wedge Q\left(\dfrac{SINR_{th}^{dB} - \mu}{\sigma}\right)\right)^N}{N!}\exp\left(-\wedge Q\left(\frac{SINR_{th}^{dB} - \mu}{\sigma}\right)\right) \quad (11)$$

Equation (11) represents our blocking probability model and is simulated and discussed in the next section.

4. Simulation Input and Statistical Analysis of Data

Data were collected from GLO Nigeria and is summarized in Table 1. The data represents an average of the call blocking probabilities experienced by the network in two weeks. Given the increasing number of users in the system which has resulted in the sudden expansion of the network, we establish a 95% confidence interval to predict the system. This interval is obtained as 0.068 ± 0.0088 and guarantees the prediction of new empirical results of the system.

Table 1. Statistics of average blocking probability in GLO Nigeria network

Day 1	***Day 2***	***Day 3***	***Day 4***	***Day 5***
0.065	0.055	0.056	0.063	0.056
Day 6	***Day 7***	***Day 8***	***Day 9***	***Day 10***
0.060	0.069	0.085	0.098	0.081
Day 11	***Day 12***	***Day 13***	***Day 14***	
0.088	0.075	0.049	0.050	

The parameters used during the simulation are given in [9], but in this paper, we study further the effect of an SINR threshold extension on the system. We examine two cases: a reduction in the average traffic intensity and an extension of the SINR upper threshold value.

5. Discussion of Results

In Figure 1, as the SINR threshold is increased, the blocking probability drops contradicting our earlier observation in [9]. The reason for the reverse in performance is the reduction in the number of users per cell causing a corresponding decrease in the average traffic intensity. This action has been observed to improve the performance of the system. In Figures 2 and 3, as the $SINR_{th}$ is increased, the rate of call blocking decreases.

In Figure 4, we attempt to raise the SINR threshold by a factor of -5dB. We observed that the system experienced more blocking, even when the number of users per cell was drastically reduced. The same trend is observed in Figures 5 and 6. It is therefore important that network operators guard their SINR limits and ensure that a suitable threshold is set to deliver the expected quality of service on densely populated networks.

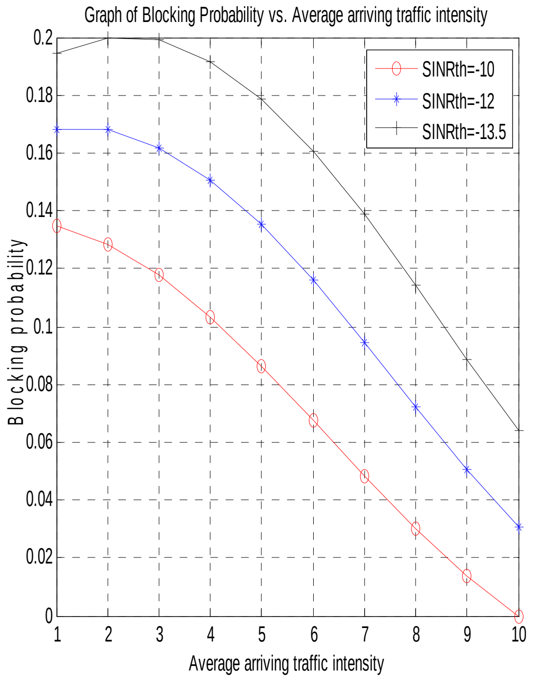

Figure 1. Graph of blocking probability vs. average traffic intensity

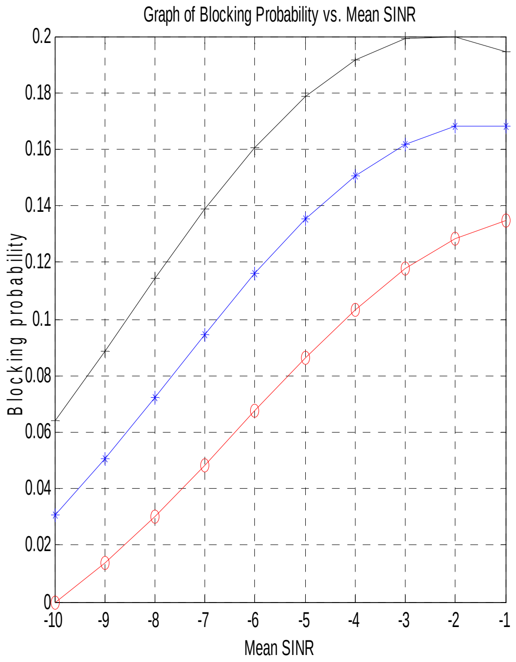

Figure 3. Graph of blocking probability vs. average SINR

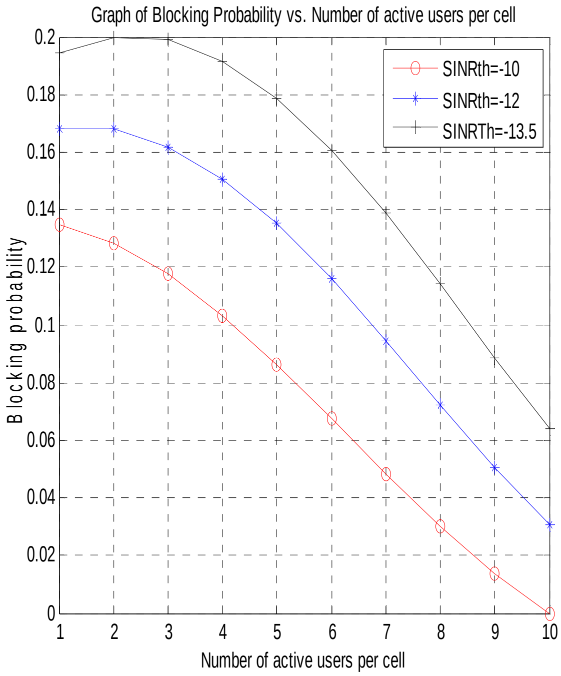

Figure 2. Graph of blocking probability vs. active number of users

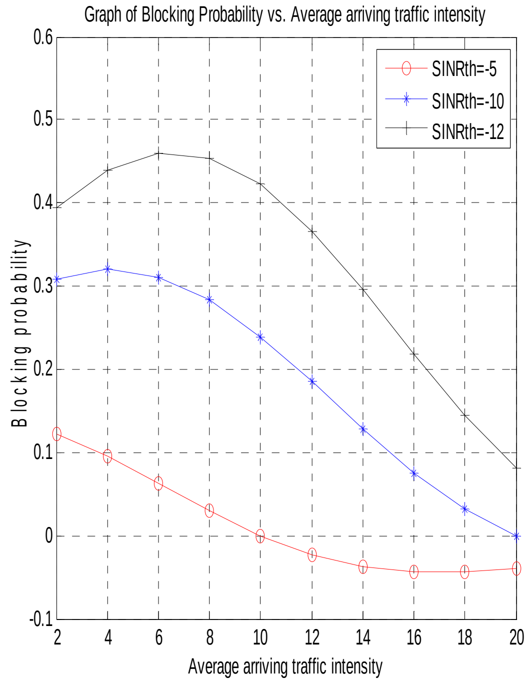

Figure 4. Graph of blocking probability vs. average traffic intensity

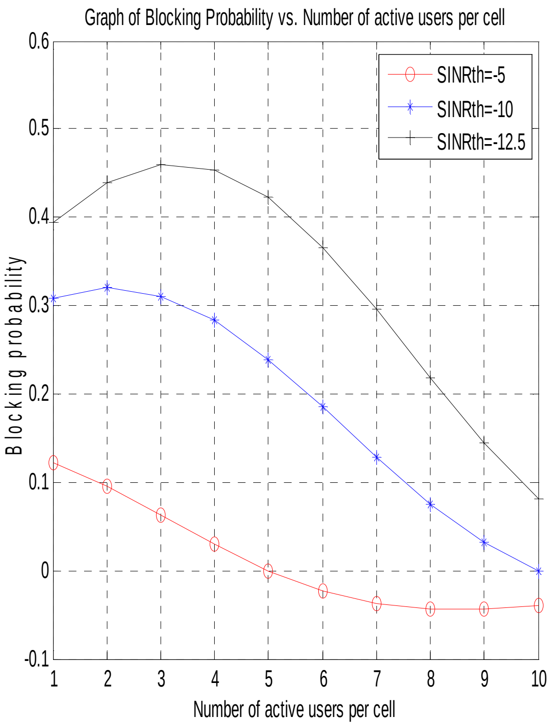

Figure 5. Graph of blocking probability vs. active number of users

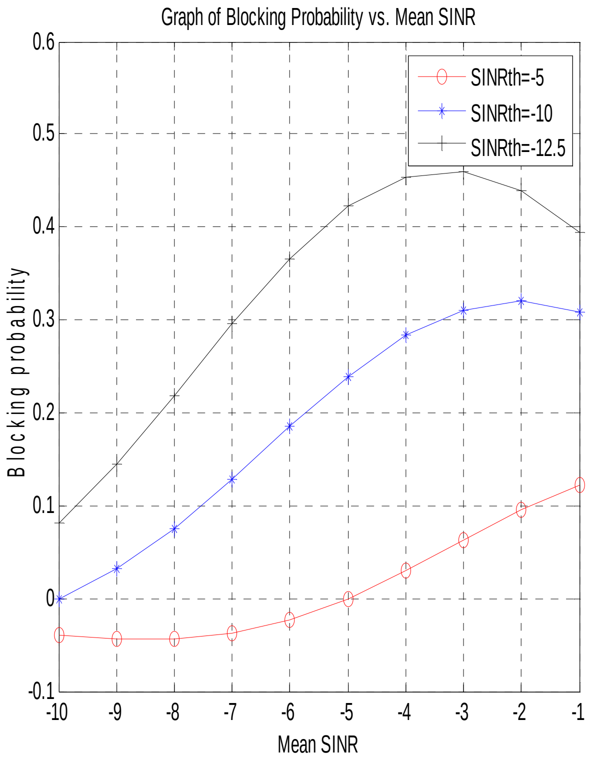

Figure 6. Graph of blocking probability vs. average SINR

4. Conclusions

A blocking probability model has been proposed for 3G related network systems. Also, a model was derived and simulated enable us study the effect of the blocking probability (P_B) on varying parameters such as average arriving traffic intensity (Λ), number of active users per cell (N), and mean of SINR^{dB} (μ). Precisely, we dealt on the SINR threshold and examined its effect on reduced traffic intensity and number of users. We observed that apart from the fact that a constant standard deviation of SINR^{dB}(σ) significantly affects the network performance [9], it is also important to maintain a well defined SINR threshold to avert poor network performance.

Acknowledgments

We are grateful to the field engineers of Globacomm Nigeria, for assisting us during the data collection phase of this research.

References

[1] E. K. Hall, R. B. Ertel, T. R. Giallorenzi and R. R. Sylvester. Synchronous DS-CDMA/FDMA PHY Proposal for IEEE 802.16.3. In IEEE 802.16 Broadband Wireless Access Project. http://ieee.802.org/16, 2000.

[2] H. Holma, M. Kristensson, J. Salonen and A. Toskala. UMTS Services and Applications. In WCDMA for UMTS: Radio Access for Third Generation Mobile Communications. Third Edition, H. Holman and A. Toskala (ed.). The Atrium, West Sussex : John Wiley and Sons Ltd, 2000.

[3] K. R. Kumar and G. Caire. Channel State Feedback over the MIMO-MAC. In IEEE International Symposium on Information Theory, 2009, pp. 2361-2365.

[4] M. Ahmed and H. Yanikomeroglu, H. SINR Threshold Lower Bound for SINR-based Call Admission Control in CDMA Networks with Imperfect Power Control. IEEE Communications Letters, Vol. 9, No. 4, 2005, pp. 331-333.

[6] A. Viterbi and A. Viterbi, “Erlang Capacity of A Power Controlled CDMA System,” IEEE Journal on Selected Areas of Communication, Vol. 11, 1993, pp. 892-900.

[7] S. Ariyavisitakul and L. Chang, “Signal and Interference Statistics of a CDMA System with Feedback Power Control,” IEEE Transactions on Communications. Vol. 41, No. 11, 1993, pp. 1626-1634.

[8] M. Ekpenyong, E. Umoren, and J. Isabona, A Rain Attenuation Model for Predicting Fading Effect on Wireless Communication Systems in the Tropics, Nigerian Journal of Space Research, Vol. 6, 2009, pp. 21-32.

[9] M. Ekpenyong and M. Idio. Soft Blocking in Imperfect Power Controlled Networks. Journal of Computer Science and Its Applications. Vol. 18. No. 2., 2011, In press.

EKPENYONG, Moses obtained his B.Sc. in Computer Science/Statistics in 1995, M.Sc. in Computer Science in 2004. His PhD. research is in Speech Technology. Mr. Ekpenyong is a lecturer in the Department of Computer Science, University of Uyo, Nigeria and has examined both undergraduate and postgraduate dissertations within and outside Nigeria. He is a reviewer to local and international journals and belongs to the following professional bodies: Nigerian Association of Mathematical Physics (NAMP), Nigeria Computer Society (NCS), International Speech and Communications Association (ISCA), Nigeria Mathematical Society (NMS), Nigerian Statistical Association (NSA), West-African Linguistics Society (WALS) and African Human Language Technology (HLT) Society. He is an International Scholar and enjoys interdisciplinary collaborations with other fields where computers can be applied. He is currently an Academic visitor to the Centre for Speech Technology Research (CSTR), University of Edinburgh and has a plethora of publications in his area of interest – Speech technology and wireless communications.

UMOREN, Ime received his B. Sc. degree in Computer Science from the University of Uyo, and a Master of Science, also in Computer Science from the University of Port Harcourt in 2007. He was trained in the University of Calabar, Calabar on Data Processing and Unix Technologies from 1986-1988 respectively. He held a Total E&P Graduate Scholarship from 2010-2012. He is a lecturer at the Department of Computer Science, Akwa Ibom State University (AKSU), Mkpat Enin, Akwa Ibom State, Nigeria. Presently, He is a PhD research student at the University of Port Harcourt, Port Harcourt. His research focus is on wireless communication, ubiquitous learning, sensor mobile and intelligent handover management Systems.