A Quantitative Performance Analysis of a 3G Wireless Cellular Network

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Abstract—This paper presents a qualitative performance analysis of a 3G wireless cellular Network.Some key traffic parameters like: Erlang traffic, blocking probability and throughput of the existing system in parts of southern and northern Nigeria were quantitatively analyzed and average blocking probability computed.This is to assist mobile operators to explore an optimized way of improving the network to achieve an acceptable threshold without compromising the Quality of Service (QoS).. The analyses are done using the Matlab.

Index Terms— Average Blocking Probability, Blocking Rate, CDMA, Erlang Traffic.Throughput

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1 INTRODUCTION

Code Division Multiple Access (CDMA) is becoming widely used for mobile networks.Unlike other multiple access techniques, such as Frequency Division Multiple Access FDMA) and Time-Division Multiple Access (TDMA), where transmissions share either frequency band or time duration, respectively, CDMA transmissions use all of the available time-frequency space. One form of CDMA called direct sequence CDMA uses a set of unique signature sequence or spreading codes, also called chip sequences, to modulate the data bits of different MSs. With the knowledge of these spreading codes, the receiver can isolate and extract the data corresponding to each MS by the process of channel estimation and detection.This process spreads the bandwidth of the underlying data signal, hence CDMA is called a Spread Spectrum Technique [1].There are currently two major CDMA standards for mobile networks: CDMA2000 (aka IS-2000) and Wideband CDMA (WCDMA). CDMA2000, used mainly in the USA, is fully compatible with its predecessor, cdmaOne (aka IS-95), is based on Third Generation Partnership Project 2 (3GPP2), and spreads spectrum across a 1.25MHz bandwidth (backward compatible to cdmaOne systems) and 3.75MHz (to achieve data transmission rates compatible to 3G requirements) [2]. WCDMA, used mainly in Europe, is based on Third GenerationPartnership Project (3GPP) and spreads spectrum across a 5MHz bandwidth [3]. In CDMA systems, time is divided into slots. A number of slots make up a frame.

With the introduction of high-data-rate services, network ca-

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pacity has become an important performance consideration of 3G access networks [4][5]. It therefore must be considered along with network coverage as an objective during network planning [6][7][8][9][10]. Since network capacity strongly depends on how balanced the actual traffic load over all cells is, dynamic load balancing routines that adjust one or more cell parameters in response to changing traffic patterns can be applied after service deployment [6][11][12]. Such load balancing operations, in turn, must include coverage as an additional objective or constraint [8][9].

2 TRAFFIC MODELLING

Traffic statistics is important for evaluating the performance of a network, ensuring QoS, design and sizing of electronic processing and switching systems, etc. Mostly used performance measures for traffic include throughput, delay and packet error probability. Real traffic normally varies over many or all time scale and possesses long-range-dependence (LRD) properties; as a consequence, when traffic congestion occurs, congestion tends to get worse for a substantial period of time. It has been observed that real traffic is usually bustier than Poisson or Markovian traffic and as such cannot be adequately modelled by these models. As such a distribution that possesses the capability of modelling the heavy-tailed characteristics of systems with LRD properties is required.

Traffic modelling and characterization are vital for understanding and solving performance related problems in future wireless and wire-land IP networks [13]. The central goal of traffic modelling lies in constructing models that capture important statistical properties of the underlying measured data. Developing an analytical or simulation model is however challenged by the ability to obtain realistic values for the parameters of both workload and system abstraction. One method is to measure such parameters in an operational system. To this end, we collected and studied data measurements from a 3G

cellular network system operating in Nigeria.

3   RELATED TRAFFIC PARAMETERS

The various traffic parameters which are directly related to the performance analysis under consideration in this work are described below, using known mathematical models:

3.1 Erlang and Poisson distribution:

Poisson distribution

$$f(k;x,\lambda) = \frac{(\lambda x)^k e^{-\lambda x}}{k!} \quad \text{for } x, \lambda \geq 0 \qquad (1)$$

Erlang distribution

$$f(x;k,\lambda) = \frac{\lambda^k x^{k-1} e^{-\lambda x}}{(k-1)!} \quad \text{for } x, \lambda \geq 0 \qquad (2)$$

Where: λ is the arrival rate of a Poisson process, and k is the number of arrival events. The Poisson distribution tells the probability of the number of arrivals over a given amount of time x. The Erlang distribution tells the probability of the time interval over a given number of arrivals k. The difference is that, in Erlang distribution, it is assumed to have an arrival at time $t=0$ (which is not counted toward k) and $t=x$ (which is counted toward k), respectively, whereas Poisson does not.

Poisson is derived using the law of rare events: Assume $B(n,p)$ denote the binomial distribution of n Bernoulli events with "success" probability p. Assume the rate of occurrence of "success" is λ, then $\lambda x=np$ where x is the time to finish n Bernoulli events. Define X_n to be the number of "success" events occurred. So

$$\lim_{n\to\infty} \Pr[X_n = k] = \lim_{n\to\infty} \binom{n}{k} p^k (1-p)^{n-k}$$

$$= \lim_{n\to\infty} \frac{n!}{k!(n-k)!} \left(\frac{\lambda x}{n}\right)^k \left(1-\frac{\lambda x}{n}\right)^{n-k}$$

$$= \lim_{n\to\infty} \left(\frac{n!}{n^k(n-k)!}\right) \frac{(\lambda x)^k}{k!} \left(1-\frac{\lambda x}{n}\right)^n \left(1-\frac{\lambda x}{n}\right)^{-k}$$

$$= \lim_{n\to\infty} \left(\frac{n(n-1)\cdots(n-(k-1))}{n^k}\right) \frac{(\lambda x)^k}{k!} \left(1-\frac{\lambda x}{n}\right)^n \left(1-\frac{\lambda x}{n}\right)^{-k}$$

$$= 1 \cdot \frac{(\lambda x)^k}{k!} \cdot e^{-\lambda x} \cdot 1$$

$$= \frac{(\lambda x)^k}{k!} e^{-\lambda x}$$

The formula for Erlang distribution is derived by induction. The case of $f(x;1,\lambda)$ is trivial because this is the exponential distribution, i.e. the time for the next arrival is x.

$$f(x;1,\lambda) = \lambda e^{-\lambda x}$$

$$= \frac{\lambda^1 x^0 e^{-\lambda x}}{0!}$$

Consider $f(x; k-1, \lambda) = \dfrac{\lambda^{k-1} x^{k-2} e^{-\lambda x}}{(k-2)!}$, then $f(x; k, \lambda)$ is defined by the convolution:

$$f(x;k,\lambda) = \int_0^x f(u;k-1,\lambda) \cdot \lambda e^{-\lambda(x-u)} du$$

$$= \int_0^x \frac{\lambda^{k-1} u^{k-2} e^{-\lambda u}}{(k-2)!} \cdot \lambda e^{-\lambda(x-u)} du$$

$$= \frac{\lambda^k}{(k-2)!} \int_0^x u^{k-2} e^{-\lambda u} e^{-\lambda(x-u)} du$$

$$= \frac{\lambda^k e^{-\lambda x}}{(k-2)!} \int_0^x u^{k-2} du$$

$$= \frac{\lambda^k e^{-\lambda x}}{(k-2)!} \frac{x^{k-1}}{k-1}$$

$$= \frac{\lambda^k x^{k-1} e^{-\lambda x}}{(k-1)!}$$

3.2 Blocking probability

The Erlang-B assumes that blocked transmissions are cleared and that the sender tries again later. The blocking probability P(block) according to the Erlang-B model is given as[14]:

$$P(block) = \frac{\dfrac{\rho^C}{C!}}{\sum_{i=0}^{C} \dfrac{\rho^i}{i!}} \qquad (3)$$

Where;

   C is the number of channels

   ρ is the offered load

The probability distribution function (PDF) of busy channels in any particular cell is dependent on the other cells only through the offered load, ρ. Thus, the probability of number of busy channels in cell (n_i) is dependent on the distribution of other cells in the systems. Using Poisson arrivals this probability is given as:

$$P(n_i) = \frac{\rho^{n_i} e^{-\rho_i}}{n_i!} \qquad (4)$$

If all channels are busy, then; $\sum_{j=1}^{C} n_j = C$ or $\sum_{j=1}^{C} p(n_j) = 1$. Thus the system requires optimization of its channel allocation strategies to cope with the enormous system load at busy periods which results in heavy-tailed traffic.

3.3 Throughput

The Uplink Throughput of user i, normalised by the system bandwidth, in a CDMA network is given as[15];

$$T_i = \frac{R_i}{W}(1 - f(\gamma_i))^{PL} \qquad (5)$$

Where: R_i is the Bit Error Rate (BER) of user i

   W is the System Bandwidth

   PL is the Packet Length

   $f(\gamma_i)$ is the BER as a function of SINR of user i

The function $f(.)$ however, depends on the modulation scheme employed.

To assess the performance of the analyzed system, we compute the system's average Packet Error Probability using the equation:

$$P_e = 1 - (1 - P(block))^{PL} \qquad (6)$$

The average blocking probability of the existing system for a period of one month is 0.297; substituting this value into equation (6) with a packet length of 256 bits or 0.01325 KB, gives:

$P_e = 1-(1-0.297)^{0.01325}$

   $= 1- 0.9953$

   $= 0.0047$

The above computation indicates the current performance of the system. The result shows an increase in packet error probability increases, i.e., the system performance deteriorates with increase in the packet length.

4   RESULTS AND DISCUSSION

The existing CDMA mobile network operating in Nigeria is quantitatively analysed using the Matlab. The aim is to study some key traffic parameters and performance of the existing system in some parts of Southern and Northern Nigeria to enable mobile operators explores an optimized way of improving the system to achieve an acceptable threshold.

4.1 Discussion of Results

A quantitative analysis of the average Erlang traffic at busy/peak periods, for the study area is shown in Fig. 1. We observed from the various plots in Figure 10 that the average traffic in some parts of Southern zone of the Nigeria was high. For instance in Abia and Akwa Ibom States, the traffic was high as 708 Erlang, thus yielding the highest blocking rate of

0.77 and a corresponding low throughput of 8.88, as can be seen in Fig. 2 and Fig. 3 respectively. The reason is not unconnected with the densely populated nature of these areas, as more users are likely to join the network. Though the average traffic in Benue and Anambra States, Bayelsa and Cross River States, and, Delta and Ebonyi States, were 479, 414 and 334, respectively, their average blocking rate were as high as 0.76, 0.76 and 0.72, respectively. This indicates severe network problems caused by other related factors such as faulty equipment and configuration problems, as we expected under ideal condition, a reduction in the average blocking rate for these study areas. Only Enugu and Imo States, and Kogi and Rivers States, showed normal network performance as both study areas had low average traffic (306 and 322), low average blocking rates (0.43 and 0.40) and high average throughputs (9.19 and 9.38). A critical look at Fig. 2, revealed that there was a sudden rise in blocking rate within the last three days of the study, which correspondingly affected the throughput performance of the system.
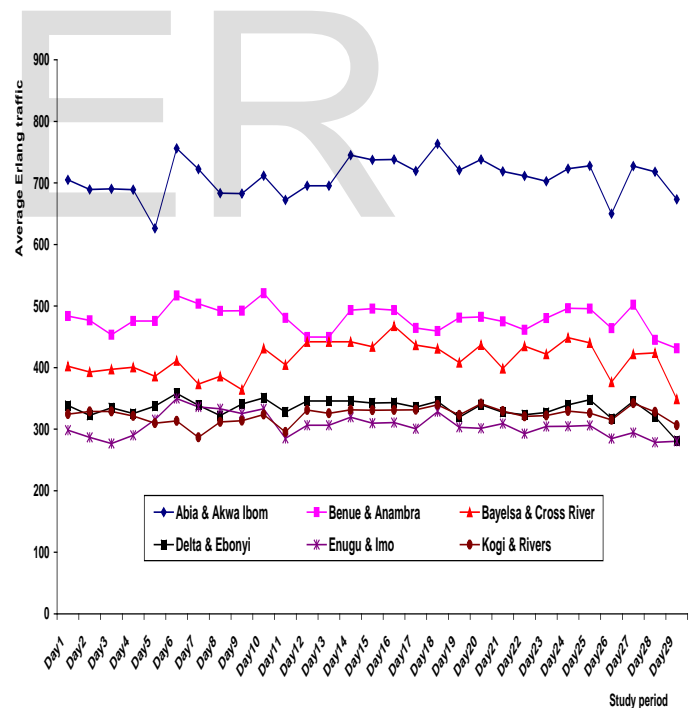

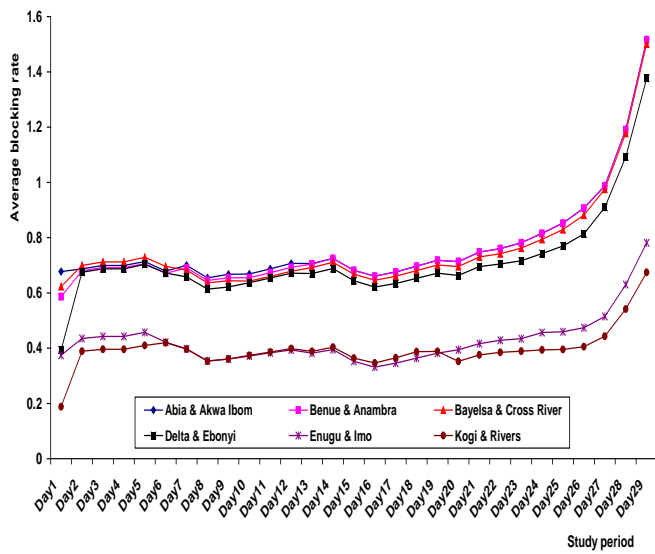Fig. 1: Graph of average Erlang traffic vs. Study period

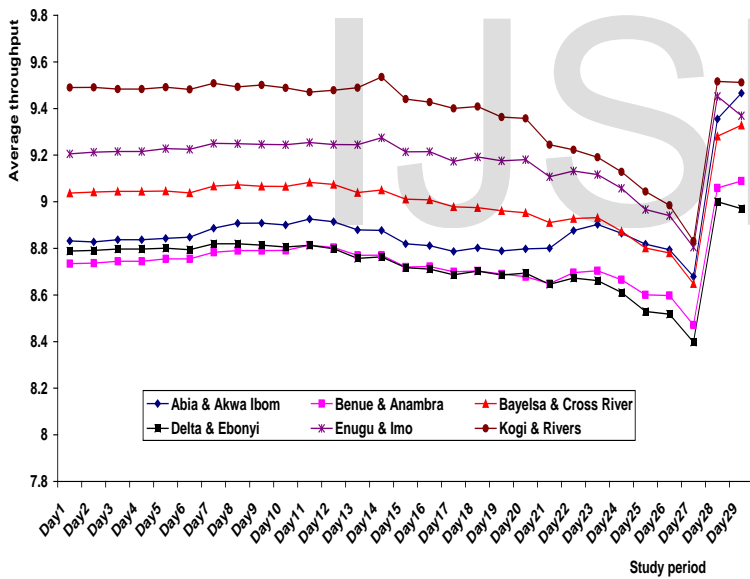Fig. 2: Graph of Average Blocking Rate vs. Study period

Fig. 3:   Graph of average throughput vs. study period

5   CONCLUSION

The performance of an existing 3G cellular wireless network was quantititatively analyzed using some key traffic parameters like: erlang traffic, blocking rate/probability and throughput. The result has shown the effect of one parameter on the other over a period of time.

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