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The Effects of Propagation Environment on Cellular Network Performance

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Abstract: - In this paper, the effects of the propagation environment are analyzed for an operative GSM network in terms of the following traffic-related parameters: call arrivals (number of call attempts), traffic intensity; call duration; drop-call probability; channel availability; and utilization factor. Four diverse geographical areas were selected for the study with each assumed as representing a separate propagation environment. Starting from performance data obtained from the said network, the stated parameters were either used directly or statistically evaluated for MSC centers from the four geographical areas. The results showed significant variations in these parameters, from one region to another.

Keywords: - *Call Arrivals, Traffic Intensity, Call Duration, Drop-call Probability, Channel Availability, Utilization Factor, MSC, Propagation.*

I. INTRODUCTION

Cellular networks involve radio and wire line links as well as switching hardware, software, and database operations. However, in the most part, it is the performance of the radio network that determines service quality [5]. The radio network is the part of the network that includes the base station otherwise known as Base Transceiver Station (BTS) and the Mobile Station (MS) and the interface between them. As this is the part of the network that is directly connected to the mobile user, it assumes considerable importance. The BTS should be capable of communicating with the mobile station within a certain coverage area and maintaining call quality standards [4]. There are three critical factors that impact the performance of both voice and data networks: radio frequency (RF) signal level (in both uplink and downlink; level of radio interference (also in both uplink and downlink); and available radio channel capacity [4], [9].

To provide any sort of service, the Received Signal Strength Indicator (RSSI) of both uplink and downlink transmissions must be sufficiently above the level of thermal RF noise to allow for successful recovery of the modulated information stream. The ratio of the desired RF carrier signal power to the linear sum of interference power is called C/I [5], [15].

As in the case of marginal RSSI, the required C/I to support voice service in GSM networks is fairly defined while the adaptive coding in GPRS causes data throughput rates to vary over a substantial range of C/I [5].

Traditionally, wireless operators have used a number of metrics that collectively provide a measurement of network service quality from the user's perspective, but overall service quality will generally be determined by a combination of four key performance indicators (KPIs), namely system coverage; call blockage; voice quality; and dropped call rate [5]. Within the cell, coverage and the other KPIs are dependent upon the area covered by the signal. The distance travelled by the signal is dependent upon the radio propagation characteristics in the given area. Radio propagation varies from region to region and should be studied carefully, before predictions for both coverage and capacity are made [4].

The signal that is transmitted from the transmitting antenna (BTS/MS) and received by the receiving antenna (MS/BTS) travels a small and complex path [4], [7]. This signal is exposed to a variety of man-made structures, passes through different types of terrain, and is affected by the combination of propagation environments. All these factors contribute to variation in the signal level, so varying the signal coverage and quality in the network [4], [7], and [14]. Moreover, any signal that is transmitted by antenna will suffer attenuation during its journey in free space. The received signal strength by an MS at any given point in space will be inversely proportional to the distance covered by the signal [4]. Unlike fixed point-to-point systems, there are no simple formulas that can be used to determine anticipated path loss [14]. By the nature of the continuously varying environment of the mobile subscriber, there is a very complicated relationship between the mobile telephone received signal strength and time. As in the typical call placed form a moving car, the signal variation is a formidable problem that can be approached only on a statistical level [14].

The received signal by an MS could be considered as consisting of three components, namely a free space path loss component, a slow fading component due to shadowing, and a fast fading component due to vehicle velocity [4], [14]. However, when determining handover necessities, the received signal is averaged, and over the normal averaging periods, the fast fading component of the signal is averaged out [10,14]. The shadowing component of the signal is a function of the cell propagation environment, and is a random variable that conforms to lognormal distribution. Therefore, the propagation characteristics of the cell environment could be represented by the statistics of the lognormal distribution [4], [10], [14]. The free space path loss component that gives rise to the mean value of the received signal can appropriately be described by the empirical formula given by Hata [4], [10], and [14].

Some major effects of the propagation environment on signal behavior are caused by reflections and multipath, diffraction and shadowing, building and vehicle penetration, propagation of signal over water, propagation of signal over vegetation (foliage loss), fading of the signal, interference [3], [4], [6], [9], [14]. The mobile station may experience a slow or rapid fluctuation in the signal level in a radio network. This may be due to one or more of the factors mentioned above. These factors form the basis of cell coverage criteria. Many previous studies on this subject area were based on the prediction either of the signal power or C/I using various path loss models. Such propagation evaluations are at best an approximation with a relatively high degree of uncertainty [14].

Other models dealing with the subject of cellular network performance evaluation mostly considered handover as the sole contributor to service quality degradation. For instance, the common denominator of drop-call probability modeling due to handover is the assumptions about network characteristics. They implicitly consider that an appropriate radio planning has been carried out; therefore, propagating conditions are neglected [1], such assumptions lead to consider that calls are dropped only due to the failure of the handover procedure. That is, the connection of an active user changing cell several times is terminated only due to lack of communication resources in the new cell [2]. For this reason, researchers have focused their attention on developing analytical models which relate handovers with traffic characteristics [1], [2].

Although such models were very useful in the early phase of mobile network deployment, they are not very effective in a well-established cellular network [1], [2]. In such a system, network-performance optimization is carried out continuously by mobile phone operators so that, the call dropping due to lack of communication resources is usually a rare event (i.e., blocking probability of new calls and handovers is negligible) [1], [2]. One of the latest drop-call probability model was based on the call dropping phenomenon caused by a heterogeneous mixture of drop-call causes. The main conclusion of drop cause analysis was that, in a well-established cellular network, call termination is mainly due to propagation conditions [1].

As a typical example, slightly more than 50% of the causes of drop calls for a single cell was reported to be caused mainly by electromagnetic causes like poor attenuation, deep fading, and so on [1], [2]. A lot of calls are dropped due to irregular user behavior (e.g. mobile equipment failure, phones switched off after ringing, subscriber charging capacity exceeded during the call). Other causes are due to abnormal network response (e.g. radio and signaling protocol error). It is highlighted that only few calls are blocked due to handover failure [1], [2].

II. TRAFFIC CHARACTERISTICS

The aggregate calls including call attempts offered or carried by some defined parts of a network, such as a group of circuits or switches with account being taken of both the number of calls and their duration is referred to as traffic [8,12,13]. In traffic engineering, any occupancy of a circuit or device caused directly or indirectly by a subscriber making or attempting to make use of the system is regarded as a call [8, 12, and 13]. The amount of traffic carried by a group of circuits will always exhibit daily and seasonal variations. Of more significance, however, are the changes that occur with the time of the day, leading to the concept of the busy hour when the traffic carried is at its peak. During such a period, the number of call arrivals and departures are essentially equal and the system is said to be in a state of statistical equilibrium [1, 2, 13, and 15]. In this state, the average number of calls existing simultaneously gives a measure of the density of the traffic.

1.1 Traffic Offered, Traffic Carried and Traffic Lost

The concept of traffic offered, traffic carried, and traffic lost is illustrated in Figure 1 [13], [15], [16].

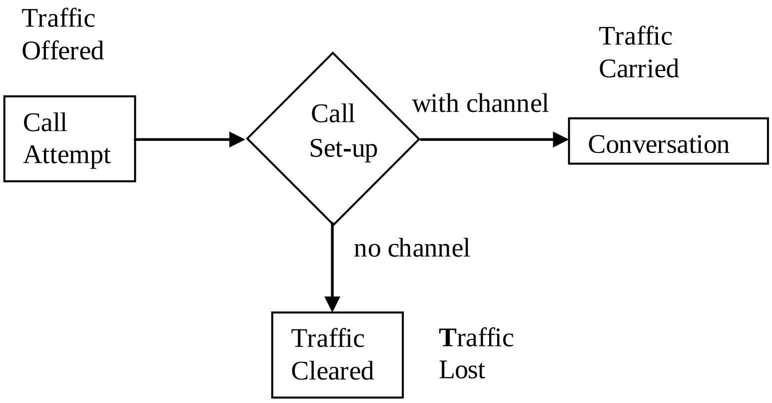

Figure 1: Traffic Offered, Traffic Carried, and Lost Traffic

Traffic carried = Traffic Offered – Traffic Lost (1)

1.2 Traffic Intensity

The traffic carried is the traffic that actually occupies a group of trunks or switches. The average number of simultaneously occupied trunks or switches gives its average intensity in Erlangs [11], [12]. Traffic intensity is the load presented to a system, that is, the amount or volume of traffic carried by the group of trunks or switches and is given by [11] -[13], [15], [16]:

$$A = \lambda h \tag{2}$$

λ= mean rate of calls attempted per unit time, h = mean holding time per successful call, A = average number of calls arriving during average holding period, for normalized λ and is expressed in Erlang-hours.

2.3 Call Arrival Rate

Call arrival rate, λ_t refers to the traffic offered expressed as the number of call attempts per unit time which is given as [11], [12]:

$$\lambda_t = \frac{Number\ of\ Call\ Attempts}{Unit\ Time} \tag{3}$$

2.4 Busy Hour

It is a given period within a day that bears the highest traffic intensity. The "busy hour" traffic is used to work out the equipment quantities of the network. The reason to use busy hour traffic is that this period usually has the highest amount of blocked or lost calls. If the dimensioning of the equipment at this period is correct and the blocked calls can be minimized, all other non-busy hour traffic should then be handled satisfactorily [1], [2], [8], and [12].

2.5 Erlang-B Formula

The Erlang B formula [10], [13], [15] is expressed as GoS or probability of finding N channels busy. The assumptions in the Erlang B formula are:

- Traffic originates from an infinite number of traffic sources independently.
- Lost calls are cleared assuming a zero holding time.
- Number of trunks or service channels is limited.
- Full availability exists.
- Inter-arrival times of call requests are independent of each other.
- The probability of a user occupying a channel (called service time) is based on an exponential distribution.
- Traffic requests are represented by a Poisson distribution implying exponentially distributed call inter-arrival times.

$$B = \frac{\frac{A^N}{N!}}{\sum_{k=0}^{N} \frac{A^k}{k!}} \tag{4}$$

Where B = blocking probability, A = offered traffic intensity in Erlangs, N = available number of channels

2.6 Prediction of Call Dropping

Dropping events constitute a Poisson process; let v_d be its intensity. Hence, if Y is the random variable which counts the number of drops, the probability that there are n drops in the interval $T = t$ is [1], [2]:

$$P(Y=n) = \frac{(v_d t)^n}{n!} e^{-v_d t}, \qquad n \geq 0 \qquad (5)$$

2.7 Channel Utilization

The channel utilization is a measure of trunking efficiency and is defined as [15]:

$$\rho = \frac{Traffic\ Intensity}{Number\ of\ channels} \qquad (6)$$

III. DATA COLLECTION

In this paper, several data have been collected from a GSM network in Nigeria. The data sets collected were from four MSCs carefully chosen as representative of four different propagation environments. The data collection is shown in Table 1.

Table 1. Network Performance Data

MSC	Number of Active Base Stations	Period	Traffic Intensity	Drop Call Rate in busy hour (%)	Drop-call rate with handover (%)	Number of Call Attempts in Busy Hour
Abuja	65	March	5211	2.10	0.05	250014
		April	5190	2.38	0.06	251185
		May	4933	3.17	0.06	248991
		June	5098	2.80	0.08	249492
Kaduna	89	March	3988	1.35	0.07	228825
		April	4315	2.35	0.056	220306
		May	4591	1.92	0.05	231222
		June	3977	1.99	0.04	201650
Port Harcourt	54	March	1836	3.17	0.04	116561
		April	2071	2.69	0.06	129988
		May	1920	2.85	0.06	113818
		June	1848	2.34	0.09	134853
Lagos	51	March	1718	1.99	0.09	117876
		April	1801	2.20	0.065	115928
		May	1698	2.32	0.08	112131
		June	1607	1.98	0.08	113339

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The collected data were first analyzed to determine values, per base station, of the traffic intensity; number of call attempts; number of dropped calls; call duration and drop-call probability for each of the four MSCs. Similarly, using Erlang B calculator, the number of channels and channel utilization factor were estimated. The data analysis is shown in Table 2.

TABLE II: Evaluation of Network Parameters Per Base Station (Cell)

MSC A	Number of Active Base Stations B	Period C	Traffic No. of 24 Hrs D	No. of Call Attempts in Busy Hour E	Drop Call Rate (%) F	No. of dropped Calls G	Traffic No. of 24 Hrs/ cell (D/B) H	No. of dropped calls/ cell (G/B) J	No. of Call Attempts in Busy Hour /cell (E/B) K	Call Arrival Rate(λ_1) (Calls/s) K/(60x60x4) L	Call Duration sec. (H/L) M	Drop-Call Probability (%) N
Abuja	65	March	5211	25001	2.10	5250	80	81	3846	0.27	296	0.5
		April	5190	25118	2.38	5978	80	92	3864	0.27	296	2.8
		May	4933	24899	3.17	7893	76	121	3831	0.27	282	0.6
		June	5098	24949	2.80	6985	78	108	3838	0.27	289	3.0
Kaduna	89	March	3988	22882	1.35	3089	45	35	2571	0.18	250	0.7
		April	4315	22030	2.35	5177	49	58	2475	0.17	288	2.4
		May	4591	23122	1.92	4440	52	50	2598	0.18	289	5.6
		June	3977	23165	1.99	4610	45	52	2603	0.18	250	5.1
Port Harcourt	54	March	1836	11656	3.17	3695	34	68	2159	0.15	227	4.0
		April	2071	12998	2.69	3497	38	65	2407	0.17	224	4.8
		May	1920	11381	2.85	3244	36	60	2108	0.15	240	4.8
		June	1848	13485	2.34	3156	34	58	2497	0.17	200	4.3
Lagos	51	March	1718	11787	1.99	2346	34	46	2311	0.16	213	5.6
		April	1801	11592	2.20	2550	35	50	2273	0.16	219	5.4
		May	1698	11213	2.32	2601	33	51	2199	0.15	220	5.1
		June	1607	11333	1.98	2244	32	44	2222	0.15	213	5.1

Table 3 shows the mean values of these parameters. The results indicate that all the parameters vary from one region to another. There is no better reason that can be used to explain this behavior than the differing propagation conditions in the four MSCs, since each of these parameters is channel related and therefore vary unpredictably, as earlier stated, throughout the propagation environment, and especially as we are dealing with a well-established network.

TABLE III: Mean Values of Computed Traffic Channel Parameters

MSC	Traffic Intensity (Erlangs)	No. of Call Attempts	Call Duration (s)	Drop-call Probability (%)	Number of Channels	Utilization Factor
Abuja	79	3845	291	1.7	82	0.96
Kaduna	48	2562	269	3.5	53	0.90
Port Harcourt	35	2293	223	4.5	41	0.85
Lagos	29	2251	216	5.3	37	0.78

Notice that Abuja stands out uniquely from the rest of the regions with a drop call probability of 1.7%. Lagos at 5.3% and Port Harcourt at 4.5% appears to be going together and Kaduna at 3.5% is oriented either towards Abuja or Lagos in some cases. It can be readily seen how Lagos and Port Harcourt are very close and Kaduna swings between Abuja and the two. This is indeed a very striking outcome since the Lagos and Port Harcourt environments, apart from coming from the same geographical zone of the country, have many common climatic conditions as shown in Table 4. The same thing applies to Abuja and Kaduna, and in many respects, Abuja has a unique terrain and clutter.

TABLE IV: Climatic Conditions of Propagation Environment of the Selected Areas

Propagation Environment	Lat (^{O}N)	Long (^{O}E)	Elevation (m)	Air temp (^{O}C)	Rel humidity (%)	Atmospheric pressure (kPa)	Wind speed (m/s)
Abuja	9.2	7.2	573	24.7	64.9	95.7	2.4
Kaduna	10.5	7.4	615	24.6	59.4	94.7	2.5
Port Harcourt	4.9	7.0	18	26.7	83.0	101.1	2.0
Lagos	6.5	3.5	32	25.7	81.4	100.3	2.8

Source: NASA

The foregoing leads us to conclude that Abuja MSC has the best propagation characteristics, followed by Kaduna, Port Harcourt and Lagos, if drop-call probability is considered, since it has the lowest value for Abuja (see Figure 5). If the number of call arrivals (call attempts), traffic intensity, call duration, number of channels, and utilization factor are considered, again Abuja stands out as the best since these are highest in that region and is followed by the other regions as earlier stated. Therefore, evidently, this study has once again demonstrated the influence of the propagation environment on cellular network performance. Thus, it might be concluded that, the study has given rise to a fairly good approach to network evaluation and optimization.

V. CONCLUSIONS

In this paper, the effects of the propagation environment on cellular network performance have been studied and confirmed. We started with the collection of operations data from four MSCs of a well-established GSM network. The MSCs were carefully chosen as representative of four different propagation environments in Nigeria. Using these data, several network performance indicators, namely number of call attempts (all arrivals); traffic intensity; call duration; drop-call probability; number of channels, and channel utilization factor, were estimated per base station for each of the four MSCs. An analysis of the results showed that these KPIs varied instructively from one region to another. Even the analysis indicated the relative performances of the four MSCs. We conclude that there is no better reason that can be used to explain this outcome than the effects of the differing propagation conditions in the four MSCs, since each of the affected parameters is traffic/channel related and therefore vary unpredictably, as earlier stated, throughout the propagation environment. Therefore, this study has once again demonstrated the influence of the propagation environment on cellular network performance. Thus, it might be concluded that, the study has given rise to a fairly good approach to network evaluation and optimization. The method is particularly most suited for well-established networks in which network performance optimization is carried out continuously so that, call dropping and blocking due to lack of communication resources is usually a rare event.

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