Evaluation of Mobile Communications in a Predominantly Rocky Area

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Abstract

Mobile communication in Nigeria is plagued with unprecedented dropped calls, crosstalk, and service unavailability even when the subscribers are credit-worthy. The reasons for such reprehensible observations are either due to natural causes, inadequate network infrastructure, or poor network design parameters. This paper examines the perturbation of mobile communications to ascertain probable causes. The various causes of impairment are examined. Different scenarios of mobile communications environment are presented. Test runs of the four mobile operators' behavior from a rocky and non-rocky environment in Nigeria are presented. Finally, analysis of percentage call failures and observations are given.

Introduction

The performance of mobile communication systems often experiences a degree of degradation in a multiservice environment, especially in geographical areas with preponderance of rocks, hills, and valleys. It has been established that the received signal by a mobile station is prone to various degrees of attenuation due to path loss and fading; among those notable are Rayleigh, Rice, and Nakagami fading [1, 2, 3]. The issue of signal degradation due to path or multipath propagation loss was discussed in [1], and this led to various models for predicting propagation loss. Even with the existence of various models, mobile communications have continued to experience various levels of perturbations leading to poor reception, especially in rocky environments. Interference militates against wide-area coverage of radio signals and capacity, and because wireless systems must coexist in extremely complicated signal environments as well as terrains, steps must be taken in the design stage to limit these influences.

In an attempt to address the ever-mounting problems of interference in mobile communications the world over, concerted efforts have been made with the sole aim of improving the capacity, coverage, and content—commonly referred to as the 3Cs—for better service delivery. The 3Cs improvement drive, along with compatibility and roaming issues, is responsible for mobile communication networks' developmental stages over the last decade to what is often called next-generation networks (NGNs). Moreover, the adverse effects of many propagation media and limited availability of frequency broadcast spectrum, which has led to strict allocation of frequencies [2], has also not been helpful in addressing the various communications impairments. Despite these efforts, in Nigeria the signal reception of the Global System for Mobile Communications (GSM) using the time division multiple access (TDMA) frames as well as the code division multiple access (CDMA)–based networks have been exhibiting uncomfortably high rates of fades in signal transmission with the constant report of "network not available," even when the mobile station is known to be situated in locations contiguous to several sites and registered with the network.

Abuja, the capital city of Nigeria, is situated in a rocky environment and densely accommodates many tall buildings. It has been observed that the capital city is known for dropped calls, crosstalk, and poor reception of wireless mobile communication signals. In order to understand the causes of the mobile impairment in Abuja, it is important to appraise the contributions of the rocks that are predominant in the city. This gave the impetus for this work.

The prime design objective in a wireless mobile communications system is to provide nearly ubiquitous signal coverage over a wide area of interest and make room for high traffic density while ensuring that an acceptable carrier-to-interference level is maintained [3]. It is the contention of the authors that the levels of observed Abuja mobile communication impairment are very unusual and require re-engineering. Fundamental to this is the need to understand the propagation characteristics of radio signals at frequencies of interest with respect to the propagating environment. This paper investigates the various types of impairments affecting mobile communications networks and compares test runs of four mobile operators' services in Nigeria carried out in a rocky city (Abuja) and a non-rocky city (Ikeja). Section 2 addresses the various mobile communication scenarios with associated impairments. Section 3 examines various modes of perturbations to which the signals are prone and some of the models used to characterize them. Section 4 describes the test scenarios. Analyses of test results are given in section 5, and statistical comparison of the results are given in section 6. Finally, we make observations and give conclusions.

Mobile Communications Scenario

Since mobile communications are essentially radio based, perturbations on the radio path constitute the major constraint to optimum reception. With the bandwidth constraints and in cases of multi-network environment, the reuse rate of allocated frequencies is usually high, leading to a narrow safety margin and more often overlapping of carrier frequencies, especially in crowded urban centers. Thus, at a mobile terminal there is a tendency to record, in addition to signals from its ambient cells or cluster of cells, signals from cells in other clusters presumably outside the reuse distance frequency values. This creates a multipath effect at the receiver, with its result being a weakening (or sometimes a strengthening) of the received signal. Where the reception from outside the cluster carries transmission from another terminal, additional noise/interference is recorded that is often due to the completely different terminal.

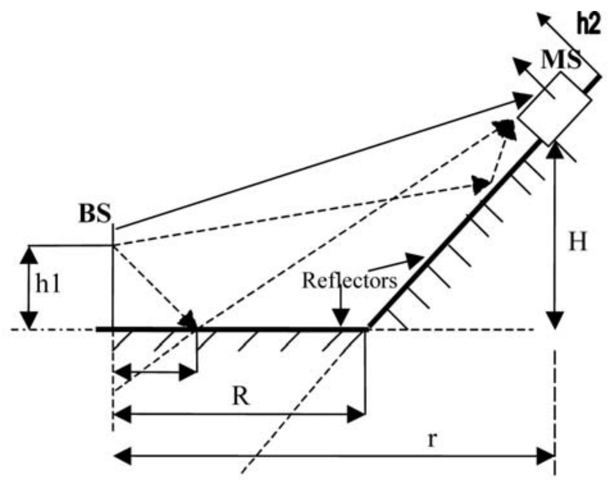
Over rocky terrain there is a considerable increase in the number of rays arriving at the antenna due to the processes of multiple reflections, diffraction, and dispersion. It is not unusual to have a second reflected wave when either the mobile station (MS) or the base station (BS) is on a hilltop and the other on a flatter terrain. The propagation models in this case are represented by *Figures 1* and *2* [1]. *Figure 1* shows an MS scenario where the MS is on the hill and the BS is on a flat terrain. On the other hand, in *Figure 2* the BS is on top of a hill and the MS is on the flat terrain. *Figure 3* depicts another scenario where there are identifiable dominant reflectors and a number of scatterers. The diagram shows a rock and a skyscraper, which are dominant reflectors. The directed arrow represents a signal to the MS. The dotted lines show multiple signals that were reflected by various signal scatterers.

The urban, rocky environment can be assumed to have the same effects on radio-wave propagation as in an environment with tall buildings acting as obstructions to the propagating radio signal. These skyscrapers act as reflectors on the wireless signals in such a manner as to produce interferences (e.g., multipath effects, shadowing) [12].

Consider, in a typical rocky urban city such as Abuja, a given wireless communication cell, which is made up of a BS, a user terminal (MS), and the associated obstructions of the propagating environment. This particular environment

FIGURE 1

Model for Multi-Reflected Wave and MS on the Hills



R = distance over which terrain is flat
r = total distance between BS and MS antenna
h_1 = height of BS above ground level
h_2 = height of MS antenna above ground level
H = difference in height between flat terrain and elevated terrain

FIGURE 2

Model for Multi-Reflected Wave and BS on the Hills

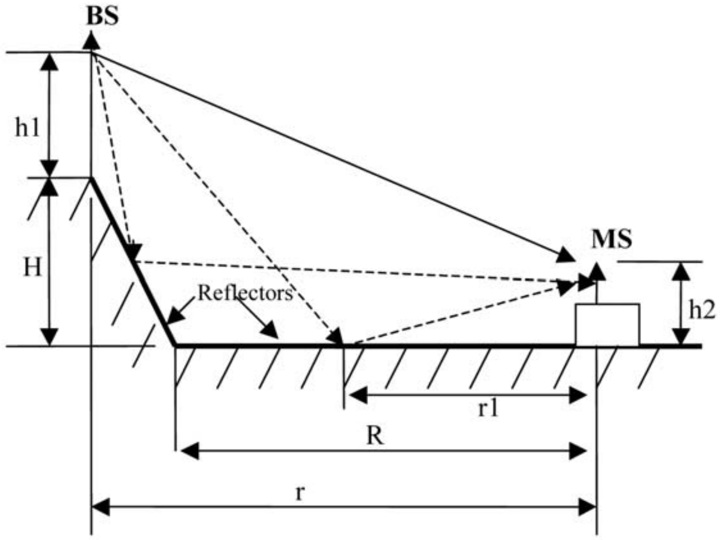
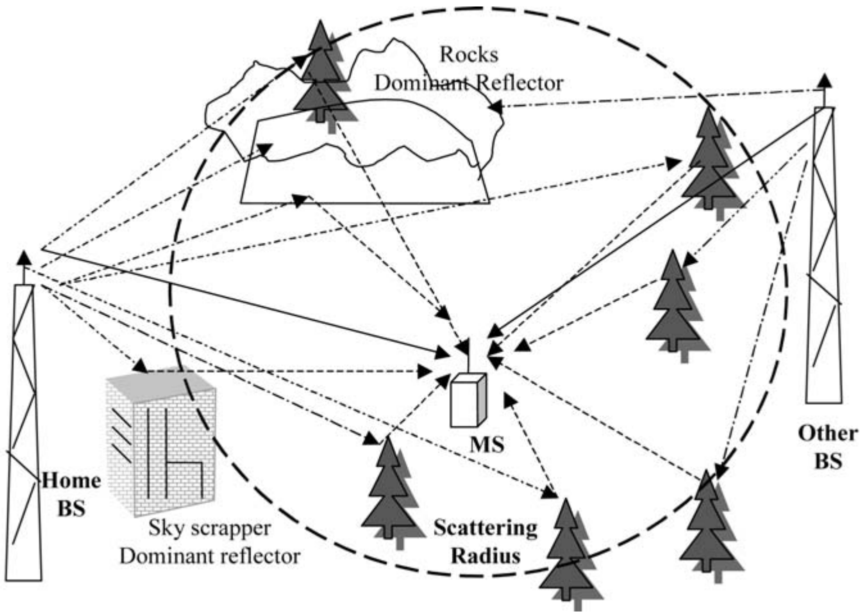


FIGURE 3

Multipath Signal Arrival Model



can be modeled as comprising skyscrapers obstructing, reflecting, diffracting, refracting, absorbing, etc., the transmitted signals from the BS to the user terminal (*Figure 4*).

The Overview of Mobile Perturbation Problems

There are two fundamental sources of problems in the mobile communications: design error of frequency reuse and impairments due to mobility.

Frequencies allocated to operators are often insufficient to meet service and capacity demands. Efficient use of available frequencies is therefore necessary, and as a result a host of techniques [4] has been designed to optimize capacity and frequency reuse. Some of the techniques are cell splitting, cell sectorization, and antenna array. Generally, frequency reuse design must depend on the power of the transmitted signal, the terrain over which the signal is sent, the height of the antenna, the type of antenna used, the

FIGURE 4

Rocky Environment with No Line of Sight

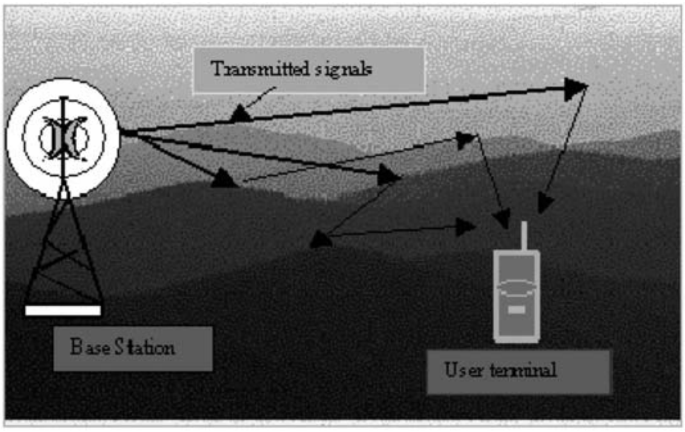
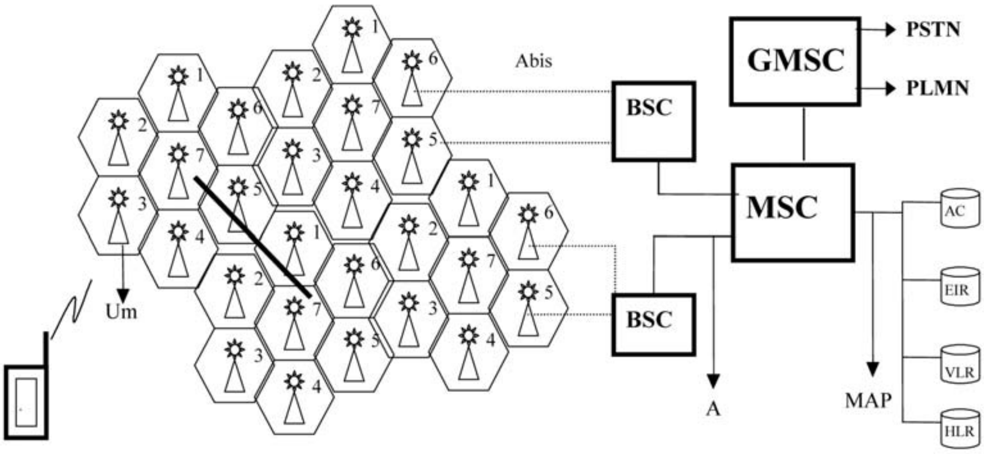


FIGURE 5

A Simple Mobile Architecture with Cell Sites



weather, and the frequency used. Inadequate design of the frequency reuse by an operator would lead to crosstalk and serious signal fading such that at times an MS is reported as unavailable when it is actually available but congested. *Figure 5* shows a mobile communications architecture with seven cell-site clusters. Each cell site is represented with a hexagon, and there are 7 cells in a cluster. A line is also drawn from one cell cluster labeled 7 to another cluster. The line shows the cell's reusable distance. The reusable distance must be properly and optimally calculated to avoid serious degradation due to co-channel interference, which is interference between cells. Moreover, the channel must be properly planned in order to avoid channel interference, which also refers to interference from channels within a cell. The variability introduced by the mobility of the user and the wide range of the environment that may be encountered results in such adverse effects as Doppler spread, multipath propagation, delay spread, and penetration loss, which significantly affect system performance. However, several models have been proposed to optimize mobile communications with reference to the impairments discussed. Chang and Su [13] presented a method based on nonlinear regression channel models on the local time-frequency domain. This model was shown to achieve an excellent bit-error rate (BER) performance that is not far from the theoretical lower bound. Kang et al [14] investigated the efficiency of cellular mobile radio systems with smart antennas. Specifically, the work presented expressions for the situations when the signal is subject to Rice and Rayleigh type fading. Negi et al [15] reported the performance of space-time coding scheme combined with beam forming strategy in smart antennas to reduce frame error rate (FER) in a multiple input, multiple output (MIMO) wireless system.

Multipath Propagation

Multipath occurs as objects in the propagating environment, and it creates reflected signal paths between the BS and the user terminal. It could therefore be said that multipath propagation occurs due to multiple replicas of the same signal arriving with different arrival times at the receiver. The reflected signals arrive at the receiver with random amplitudes and phase shifts because of the different paths followed by the arriving signals. In dense urban environments where multipath propagations occur, the range of times of arrival of the "replica signals" can be very significant [5, 6].

Multipath propagation consists of the direct dominant signal and a Raleigh distribution of the reflected signals with various amplitudes and phase shifts (*Figure 3*). This results in random signal fades as some of the reflected signals destructively cancel the others while some constructively add to the others over brief periods. The degree of cancellations (called fading) depends on the delay spread of the reflected signals. The components of the multipath phenomenon can result in the following effects that can lead to signal impairment.

Fading
Fading occurs because of reflected signals that arrive from different paths that are out of phase at the receiver. These out-of-phase signals, depending on their arrival times, randomly cancel or add to each other. The fading due to multipath can be frequency selective, in which case the channel must have introduced time dispersion resulting in the delay spread exceeding the symbol period. Flat fading can also occur, and in such a case, there is no time dispersion and the delay spread is less than the symbol period.

Fading signal amplitude is statistically described as Rayleigh or Ricean [1]. Rayleigh fades are due to a no-line-of-sight (NLOS) signal component present in the received signal. When there is the presence of a line-of-sight (LOS) signal component in the received signal, the fading is regarded as Ricean [1]. Generally, if there is no LOS path to an MS because of its mobility, the fading in mobile is therefore Rayleigh.

Delay Spread or Time Spread
The arrival times of the multiple reflected signals at the receiver are different, and this can result to inter-symbol interference (ISI), where energy from one symbol could spill over into another symbol, leading to a high BER and, consequently, degradation in the quality of the received signal.

Phase Cancellation
Phase cancellation results from reflected signals that arrive 180 degrees out of phase at the receiver, thus cancelling each other. However, most air interface standards are very resilient to phase cancellations. Thus, a call can be sustained for a certain period of time [8].

Co-Channel Interference
Co-channel interference occurs when the same carrier frequency reaches the same receiver from two separate transmitters. As it is well known, antennas scatter signals across widely disperse areas, and signals intended for a particular location or user can stray to another, thus becoming the interferer for the user on the same frequency in the same cell [4].

Doppler Spread
The Doppler spread explains the random changes in the channel due to the mobility of the mobile wireless user and the relative motions of objects in the channel. Doppler has the effect of shifting or spreading the frequency components of a signal. The Doppler spread is higher for urban environments, where users are relatively mobile compared with rural communities. As the mobile moves through spatial locations with different field strengths, each multipath component of the received signal are subject to a Doppler shift in frequency and a slower change in the relative delay [5].

The coherence of the channel, that is the inverse of the Doppler Spread, determines the rate of fading due to Doppler effect. When the rate of change of the channel is higher than the modulated rate, fast fading occurs. However, when the rate is slower, slow fading occurs.

For a CDMA signal not subject to data modulation, the maximum Doppler frequency, $?_m$, is proportional to the maximum relative velocity of the vehicle, V_m, given in [5] as follows:

$$f_m = V_m / \lambda \text{, where } \boldsymbol{\lambda} \text{ is the carrier wavelength.}$$

Path Loss
This describes the loss encountered as a result of the separation distance between the transmitter and the receiver. The spatial distribution of power (P) transmitted to a receiver separated from the transmitter by a distance, d, is related by the distance power law function of the form [7], as follows:

$$P = 1/d^m \text{, and for free space, m=2}$$

Alexander [9, 10] established that m varies according to building materials encountered between the transmitter and the receiver. Smulders et al [11] showed that path loss also varies with frequency as well as penetration loss, increasing as the frequencies increase. At millimeter wavelength, radio waves cannot penetrate some materials such as concrete, blocks, and bricks. Consequently, millimeter waveband is good for providing broadband services in a high-capacity frequency reuse areas [11].

Penetration Loss
As already known, the propagations of radio signals are affected by the presence of obstacles such as buildings, rocks, and vehicles. The usage of mobile wireless communications system in both indoor and outdoor environments encounters losses as a result of some of the signals trying to penetrate into the walls and/or windows of buildings, vehicles, etc. Penetration loss therefore is one of the critical considerations in the design of radio systems in terms of coverage. However, it has not been easy to characterize penetration loss for different buildings because of much variability in such things as building materials and structures. For in-vehicle coverage, the penetration loss varies differently according to whether it is car or a van [12]. In all these a high penetration loss is assumed in the design so as to ensure good quality of service. However, for the environment under consideration, the dominant penetrations to be considered are the building, rocks, and in-vehicle penetration loss.

Test Scenarios

The test was planned and conducted within one BS subsystem so that near-perfect results were expected because the test scenario was the least common denominator of failure expectancy. The intent of this choice of test scenario was to ensure that no lost call or call failures were observed. If test calls between two phones in different BSs or switching centers were chosen, a more challenging outcome would be expected. Furthermore, rural area calls would even be more challenging. So we postulate that based on the test scenario chosen, a percentage call failure of more than 1 percent represents a serious congested network and was therefore unacceptable. The primary aim of the research was to observe the behavior of calls in a particular operator's network and the behavior of through connected calls between operators. This presupposes that the test measures intra-connectivity behavior of each operator's network and inter-connectivity behavior of the networks.

There are four mobile operators in Nigeria, and each was tested for through-connected calls. The operators shall be referred to as OP1, OP2, OP3, and OP4. The test runs were carried out for Abuja, a predominantly rocky environment and at Ikeja, a non-rocky area. Ikeja is situated in Lagos state and within proximity of an airport. Thus, tall buildings around Ikeja are prohibited by aviation regulations. The tests for Abuja and Ikeja were conducted during the first and second week of February 2005, respectively. It was carried out such that the morning rushes, lunchtimes, and evening rushes, as well as weekend behaviors, were captured for each week under observation. The test for each scenario was conducted on Thursday, Friday, Saturday, Monday, and Tuesday. Six thousand five hundred calls were made for each scenario, and the distribution of the calls are given in [16] and detailed results from the test run are reported elsewhere [16, 17]. The authors wish to state that at the time of the research, OP3 reported network problems and so readers must factor that fact when they read the tables. The research for each operator was carried out with two stationary phones, which are registered with the same BS that is within a one-mile radius. The eight phones used for the test runs are of the same make and model and were purchased at the same date and time. It should be noted that every mobile call in Nigeria is a toll call. Mobile calls are not differentiated. So, calls made between two subscribers in the same building cost the same as calls between two subscribers who are 500 km apart. The test architecture and average percentage call failures (APCFs) for intraconnectivity and interconnectivity test results are given below. The APCF is defined as follows:

APCF = (Total calls – Through-connected calls) * 100 / Total calls

Intraconnectivity Observation

Intraconnectivity test investigates the internal behavior of the GSM networks. As you would observe from *Figure 6*, the calls are made between two subscribers from the same base station (BTS), base station control (BSC), and mobile switching center (MSC). The connectivity test results of APCF are given in *Table 1*. The table shows that all the GSM networks except OP2 are severely internally congested since many of the APCF results for both Ikeja and Abuja are much greater than 1 percent. Intraconnectivity is heretofore referred to as connectivity.

Interconnectivity Test

The interconnectivity test measures the ability of one operator to interconnect with other GSM operators. *Figure 7* shows the architecture of the interconnectivity test calls. Calls are made from one operator's mobile network to the other networks. The calls go from one operator through the gateway MSC (GMSC) to the public switched telephone network (PSTN). The link is via the incumbent PSTN; there is no direct link to the public land mobile network (PLMN) at

FIGURE 6

Connectivity Call Failure Test Architecture

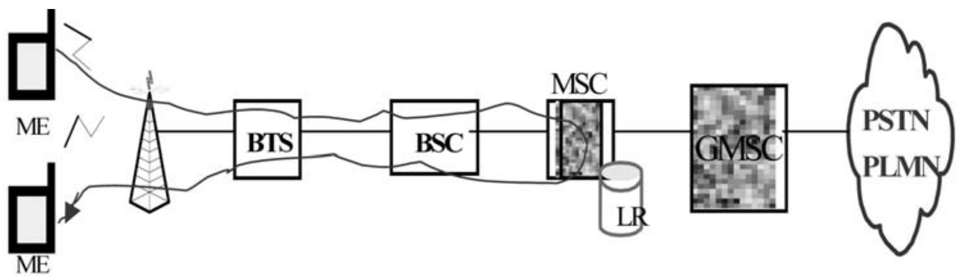


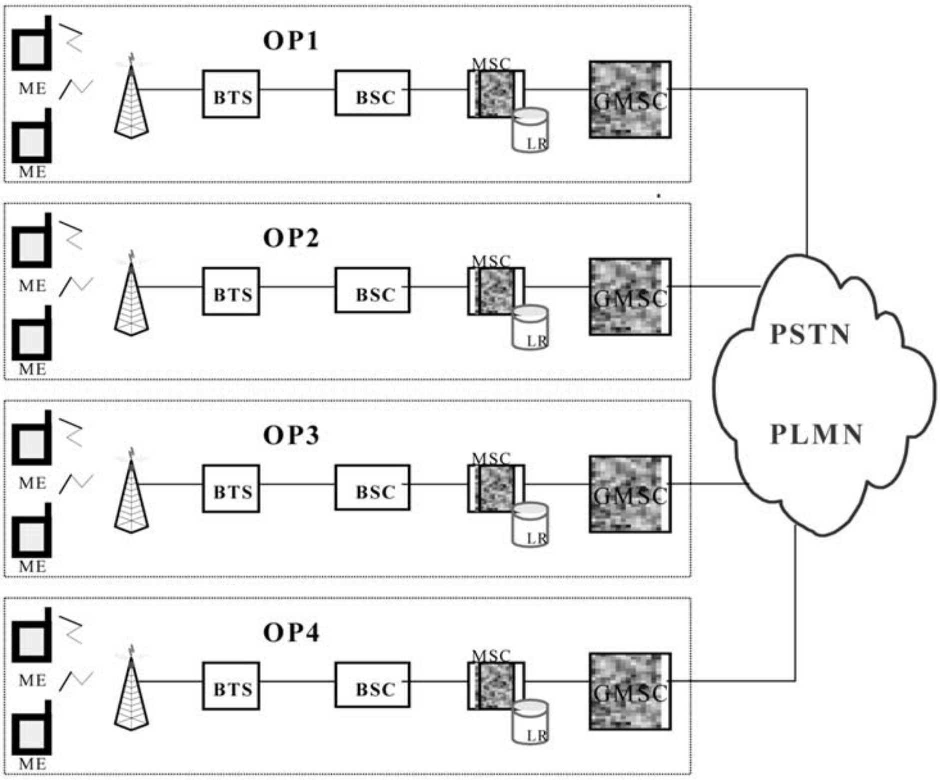
TABLE 1

Average Connectivity Call Failures

City	Op1	Op2	Op3	Op4
Ikeja	14	0	71	1
Abuja	20	10	70	14

FIGURE 7

Interconnectivity Call Failure Test Architecture



the time of this test. In *Table 2*, the test results of APCFs are presented. We observe that all the GSM networks are heavily congested with respect to their ability to interconnect with subscribers from other operators.

Analyses of Test Results

In *Table 1*, apart from the test result for OP2, the APCF for OP1, OP3, and P4 for Abuja are considerably higher than the outcomes for the non-rocky city, Ikeja. This can also be observed from the chart in *Figure 8*. Since the test scenario was chosen such that no call failure was expected, the operators, except OP2, are heavily internally congested.

Similarly, we find that the interconnectivity test outcomes for Abuja are also higher than those from Ikeja. *Figures 9* and *10* give the charts for Ikeja and Abuja, respectively. *Figure 11* presents a graphical comparison of the APCF for Ikeja and Abuja. Each operator in *Figure 11* consists of two charts, the first for Abuja and the second for Ikeja. The figure shows that although the test outcomes from Abuja are higher than those from Ikeja, it may not necessarily be very significantly different. If we can conclusively show that the difference between the APCF is significantly higher in Abuja, we would have shown that the rocky environment is contributing significantly to the levels of dropped calls and crosstalk observed from Abuja. So, we statistically test the outcomes in *Tables 1* and *2* to see if the observed test data is significantly different.

TABLE 2

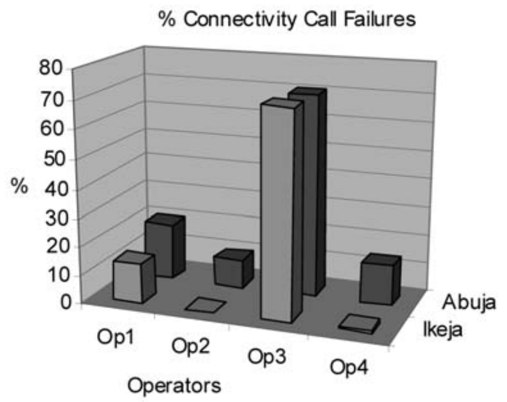
Average Interconnected Failures

From	To	Ikeja	Abuja
OP1	OP3	35	40
OP1	OP2	10	14
OP1	OP4	10	15
OP2	OP3	76	75
OP2	OP1	33	44
OP2	OP4	46	54
OP3	OP1	88	90
OP3	OP2	96	95
OP3	OP4	94	95
OP4	OP1	49	55
OP4	OP2	61	60
OP4	OP3	64	68

(Note: OP3 reported network problems during the test period)

FIGURE 8

Comparing Connectivity in Abuja and Ikeja



Statistical Comparison of Test Results

Statistical testing of the data is inevitable, since we could not conclusively say from the charts that the data outcome for Abuja is significantly different for those from Ikeja. So, if we let X and Y to represent Ikeja and Abuja, respectively, X and Y are independent random variables and thus, from *Tables 1* and *2*, we get the following:

} Case 1: Connectivity APCF

1 X = 14, 0, 71, 1 ⌉

2 Y = 20, 10, 70, 14 ⌋

3 X = 35, 10, 10, 76, 33, 46, 88, 96, 94, 49, 61, 64 ⌉

4 Y = 40, 14, 15, 75, 44, 54, 90, 95, 95, 55, 60, 68 ⌋

5 Matched-pairs test, *T* -Statistic given in [18] can be used to carry out the statistical testing of the difference between the Ikeja and Abuja data in case 1 and case 2.

FIGURE 9

Interconnectivity APCF for Ikeja

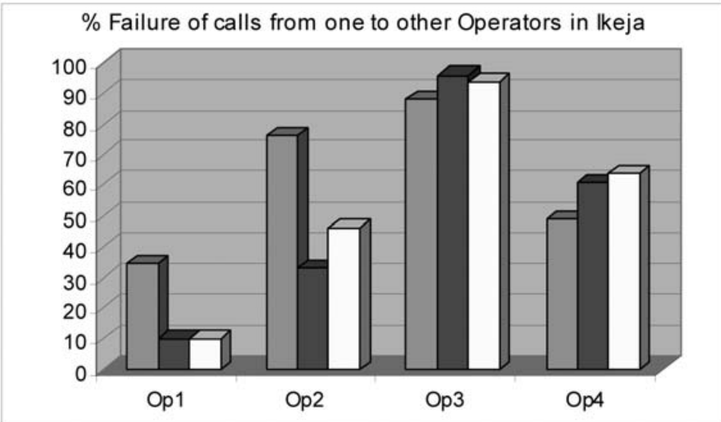


FIGURE 10

Interconnectivity APCF for Abuja

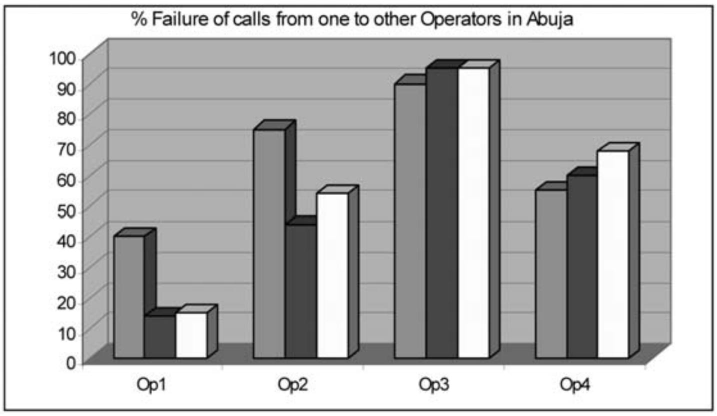
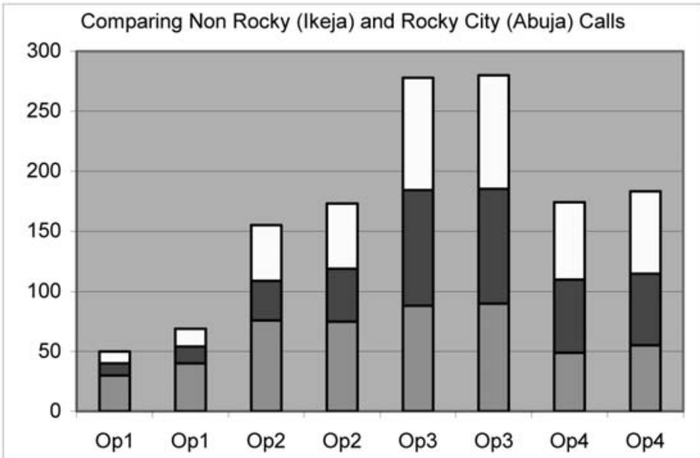


FIGURE 11

Comparing Ikeja and Abuja Interconnectivity



Put d = X – Y, then T = (E(d) √N)/S(d) , where S(d) = Standard deviation of d and E(d) = Expected value of d

6 N

7 $S2\ (d) = \sum_{n=1} (\text{Observed} - \text{Expected})2/(N-1)$

$\lambda = t_{a,N-1}$ is given in a table [19], where a is the critical significant level and N-1 is the degree of freedom.

So, if $T \geq \lambda$ then the test is critically significant at α.

LEMMA. Given that X and Y are values from independent random variables of two possible outcomes. Since t in $T \in (-\infty, \infty)$, apply Logit transform to X and Y such that x_i = Ln((X+1)/(101-X)) and y_i = Ln((Y+1)/(101-Y)), then set $d_i = x_i - y_i$ and

8 $$S^2 = \sum_{n=1}^{N} (E(d_i) - E(d_{ij}))^2/N - 1$$

Thus, the data for X and Y can be compared for goodness of fit such that if

9 $T = ((E(d_i)\sqrt{N})/S(d_i)) \geq \lambda$, then X and Y are significantly different at α, with N-1 degree of freedom.

So, applying this to the Ikeja and Abuja data in *Tables 1* and *2*, for the
Case 1, T = 1.9883, l = 1.638 and for
Case 2, T = 3.26238, l = 1.363 at α = 0.10.

Since $T \geq \lambda$ for cases 1 and 2, the difference between the call failures from Ikeja and Abuja for the connectivity and interconnectivity test calls is critically significant. We note that it suffices to test for case 2, which has more sample data and indeed, for case 2 at α = 0.005, λ = 3.106, which is also less than T = 3.26238. In other words, as expected, the rocky surrounding has contributed to the additional observed APCFs of the operators in Abuja.

Observation and Conclusions

Abuja, the capital city of Nigeria, experiences unprecedented crosstalk and dropped calls more than Lagos and some other urban cities in Nigeria. One would have expected the reverse to be the case, which was the reason the authors embarked upon this research. First, this paper addresses the various interferences that the operators would have to exploit and optimize in order to ensure a reasonable level of service to the consumers. Primarily, this paper includes results from test runs for the four mobile operators in Nigeria, which were carried out in Ikeja and Abuja in order to isolate the reason for the comparatively high number of dropped calls and crosstalk observed in Abuja. The test scenarios were chosen such that the only significant difference between Abuja and Ikeja test scenarios is the terrain—the rocky environment.

The test scenarios and parameters were further chosen such that there would be no call failures observed during the test run. However, the test results in *Table 1* and *Figure 8* show that except for operator OP2, the operators were congested internally for Ikeja and all the operators very congested in the case of Abuja. The level of average percentage call failures observed can only point to inadequate planning and design issues. Though it has been observed elsewhere [16, 17] that when each of the operators embark on a promotion, that network would show considerable degradation in service due to inadequate infrastructure, but the test runs were carried out when the operators, except OP3, were not running any promotion. It is therefore our belief that the poor quality of mobile services in Abuja and most cities could be more of a design issue. The frequency reuse distance and the cell radius need proper examination and re-engineering by the operators. We pointed out earlier that the frequency reuse design should take into consideration the power of the transmitted signal, the terrain over which the mobile signal is sent, the height of mobile antenna, the type of antenna used, the weather condition, and the frequency used.

Furthermore, we discovered from the connectivity and interconnectivity test result and statistical testing of the observed outcomes that there are considerable differences between Abuja and Ikeja observed data. The relatively higher average percentage call failures observed in Abuja in comparison with that from Ikeja can therefore only point to the impact of the rocky environment in Abuja. So, in this paper we show that the poor quality of mobile service is Nigeria is caused by poor design and rocky environment. However, it is our contention that the operators could exploit multipath caused by the rocky environment in Abuja for better communication services. There are now optimization techniques to compute the cell distance and radius, along with other variables in mind, and it is also recommended that the operators should exploit the optimization techniques.

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