Modeling the Effect of Dropped Calls on Cell Traffic in Established 3G-Based Cellular Networks

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ABSTRACT
One most important parameter for assessing the quality of service (QoS) in a network is the probability of dropped calls, which has so far not been deeply studied within the context of established cellular networks. This paper therefore studies the effect of call dropping on cell traffic parameters. First, it derives an analytical model for multiple cells and discusses how the various cell parameters affect the system’s performance. Second, a qualitative (GIS) solution showing the distribution of cells traffic over the study area is presented to verify the state of the system. Third, the effectiveness of our methodology is validated by simulating the proposed model. Simulation results revealed a fifty percent (50%) reduction in dropped calls, and an improved system performance.

Keywords- CDMA, forced termination, quality of service, teletraffic behaviour, call handover

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1. INTRODUCTION

Dropped call is the common term for describing the unexpected termination of a wireless mobile user call due to technical reasons, including its presence in a dead zone. One reason for dropped calls is when the mobile user moves out of a wireless network range. An active call cannot usually be sustained across a different company’s network (as it is impossible for calls to re-route themselves over the traditional network system while in progress). This scenario results in the termination of the call due to inability to sustain the signal between the mobile user and the original network. Another common reason is when a mobile user enters an area that has no wireless signal presence, interrupted, interfered with, or jammed. From a network perspective, this is similar to leaving the coverage area. Occasionally calls are dropped upon handoff – between cells, within the same provider’s network [1-5]. One possible reason is a traffic imbalance between two cell sites when the new cell site is at capacity and cannot accept additional traffic from the call trying to “hand in”.

Another reason is wrong network configuration, which renders one cell site “unaware” of the cell the mobile user is attempting to hand off to. If the mobile phone cannot find an alternative cell to provide the handshake, then the call is lost. Co-channel and adjacent channel interference can also be responsible for dropped calls in a wireless network [6-7]. Neighbouring cells with same frequencies may interfere with each other to deteriorate the quality of service and cause dropped calls. However, the reduction in co-channel interference depends on the amount of sectoring a cell uses. A cell is usually partitioned into three 120° sectors or six 60° sectors and as many as six sectors per cell have been used in practical network services. Transmission problems are also a common cause of dropped calls – resulting from a faulty transceiver (TRX) within the base station. At the receivers’ end, calls may be dropped if a mobile phone loses battery power and abruptly stops transmitting. Sun spots and solar flares are rarely blamed for causing interference that leads to dropped calls. The increasing demand of cellular network services constitutes another source of dropped calls.

This capacity related issue has forced network operators to provide stringent QoS. Experiencing frequent dropped calls is one of the most common customer complaints received by wireless service providers. These providers have attempted to address the complaint in various ways, including expansion of the customers’ network coverage, increased cell capacity, offering compensations to individual dropped calls, etc.
The classification of what causes dropped calls in a single cell is reported in [8] (see Table 1). They show that call dropping is mainly due to electromagnetic causes (e.g. power attenuation, deep fading, etc.). At the users level, calls are dropped due to irregular user behaviour (e.g. mobile equipment failure, phone switched off after ringing and subscriber charging capacity – the probability that a call does not find an available communication channel), but this is negligible for any data set. However, calls can also be dropped by a load control algorithm (typically located in the radio network controller in WCDMA) to preserve system quality.

Table 1. Occurrence of Call Dropping in a Reference cell

<table>
<thead>
<tr>
<th>Drop call causes</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic causes</td>
<td>51.4</td>
</tr>
<tr>
<td>Irregular User behaviour</td>
<td>36.9</td>
</tr>
<tr>
<td>Abnormal Network response</td>
<td>7.6</td>
</tr>
<tr>
<td>Others</td>
<td>4.1</td>
</tr>
</tbody>
</table>

2. PROBLEM STATEMENT

In March, 2007, the Nigerian communication commission (NCC) awarded 3G mobile telephony spectrum licenses to four communication companies namely, Airtel communication limited, Mobile Telecommunication Network (MTN), Global Communications Limited (GLO) and Ashteri Engineering Limited, after a tender and pre-qualification process [9]. The license authorized these companies to operate the CDMA 2000 IX-EV-D0 technology. Recently, the NCC has licensed other communication companies namely Starcomms, Multilink, Visafone and Zoom communications Limited, to operate the 3G-based CDMA 2001 X-EV-D0 technology. Although there exist a monopoly of telecommunication companies in Nigeria, the consumers’ satisfaction and quality service delivery in some part of the country is far from expectation. Specifically, there has been serious complaints by mobile users on poor service quality, frequent call drops, echo during radio conversation, poor interconnectivity to and from licensed networks, distortions, network congestions, among other factors. These factors have left many mobile subscribers with no other alternative than to subscribe to more than one network and patronage of dual SIM phone manufacturers in order to maintain seamless connectivity. Call interruptions are perceived negatively by end-users (more negatively than call blocking) and therefore calls for the effective management of their probability using suitable resource management techniques.

Although various signal boosters have been manufactured to reduce dropped calls and dead zones related problems with many options such as wireless units and antennae intended to aid in strengthening weak signals, the main issue causing call droppings has not been treated. With the poor planning and deployment of network infrastructure (in Nigeria, for instance) without adherence to standards, network optimization remains the last resort.

3. RELATED WORKS

The teletraffic behaviour of code division multiple access (CDMA) networks have been the subject of research ever since CDMA started gaining popularity in the military and commercial applications. In [10] for instance, the Erlang capacity of CDMA networks is well covered. In [11], the M/G/∞ queueing model is used to assess the uplink capacity of CDMA networks. The authors [11] also present a technique for computing the outage probability of the network. These classical papers have focused on “rigid” traffic models that do not consider elastic or best effort traffic, whose bit rate dynamically changes. The importance of modeling call dropping and its impact on the Erlang capacity in cellular networks in general has been emphasized by several authors [1, 11-13] and more recently in [8, 14-16]. In [8], an analytical approach to modeling single cell (including single cell clusters) is presented. The authors use statistical estimates from the Visafone telecommunication company operating in Italy to predict call dropping. They also show numerically (without simulation) how the traffic parameters affect the system’s performance.

In this paper, a dropped call probability model, derived in an experimental context is proposed. We improve on the traffic model in [8] and extend the model to capture the impact of multicells on CDMA networks. We also perform a simulation of the proposed model to carefully examine the behaviour of the traffic behaviour and how they affect the system’s performance. The traffic data is exploited in two ways. First, a study (and collection) of daily call drop statistics, including the cell index base station and dropped call rate is carried out. Second, a formulation of an analytical model from a theoretical and practical point of view is made. Furthermore, studying call dropping behaviours as a function of other network parameters (e.g. traffic load, call duration, etc.) would aid the optimization of the system’s performance and guarantee excellent quality of service delivery as well as improved revenue.

4. SYSTEM MODEL DESIGN

4.1 Experimental Test Bed/Empirical Data Analysis

A field survey of dropped call data from an operational telecommunications limited in Nigeria was carried out. These data, which covered the east region of Nigeria, were observed over a period of three months at the various base station controllers (BSCs) from a handheld communication monitoring device. The aim of this survey was to analyze and predict the trend of dropped calls, as well as its effect on the network performance. Table 2 shows the average dropped call rate obtained for the three months period. We observed from this data that on the average, dropped calls occurred at a rate of 1.32% (i.e. at a probability of 0.0132).
Table 2. Observed drop rate data obtained from our test bed system

<table>
<thead>
<tr>
<th>BSC</th>
<th>Number of BS</th>
<th>Drop rate (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL1</td>
<td>22</td>
<td>1.091729 ± 0.26877</td>
</tr>
<tr>
<td>CELL2</td>
<td>26</td>
<td>1.358634 ± 0.34083</td>
</tr>
<tr>
<td>CELL3</td>
<td>25</td>
<td>1.542237 ± 0.50397</td>
</tr>
<tr>
<td>CELL4</td>
<td>27</td>
<td>1.945080 ± 0.55811</td>
</tr>
<tr>
<td>CELL5</td>
<td>24</td>
<td>0.687215 ± 0.12309</td>
</tr>
<tr>
<td>CELL6</td>
<td>24</td>
<td>1.304929 ± 0.33127</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1.321637</td>
</tr>
</tbody>
</table>

In Figure 1, we analyze the dropped call data in Table 1, by relating the observed call dropping probabilities with the number of base stations. We observed from the graph that on the average, the rate of dropped calls increases as the number of base stations increases. This increase is most likely due to the sudden rise in mobile subscribers, which ultimately could result in cell congestion thereby necessitating call dropping. Fitting a linear trend equation with a two year moving average to the scatter plot, we noticed that there exist a significant linear relationship \((r=0.35)\) between call dropping probability and number of base stations. Although our test bed is presently dealing with her network capacity problem, the quality of equipment used should be carefully chosen, since this may likely contribute to the poor network quality experienced by mobile users in recent times. The degree of contribution \((r^2=0.1225)\), indicates that other factors contribute more to dropped calls rather than the number of BSs and therefore requires efficient radio resource management techniques, such as network optimization and robust queue management.

4.2 Analytical modelling of dropped calls

We derive an analytical model that predicts the dropped calls probability as a function of other traffic parameters. We commence by making some basic assumptions and then progress to obtain the model.

Let \(\lambda_i\) represent the total traffic entering a generic cell. Based on the experimental results obtained in Table 2, we assume that call blocking probability is roughly negligible (i.e. the system can be considered as non-blocking), \(\lambda_i\) is also the total traffic acceptable in the cell. The dropped call probability \(P_d\) is the same as the fraction of traffic dropped due to other causes. \(P_d\), can be related to the probability of normally terminated calls \(P_{nt}\), thus,

\[
P_d = 1 - P_{nt} \tag{1}
\]

A call request is served by a randomly selected channel, and completes if correctly terminated after a duration time \(T\). We define \(T\) as a sum of two variables: \(T_{cr}\) and \(T_c\), which models the ringing and conversation time respectively. The random variable \(T_{cr}\), models the ringing duration with a weighted sum of an exponential and lognormal pdfs, \(f_{T_{cr}}(t)\) as [8]:

\[
f_{T_{cr}}(t) = \alpha e^{-\lambda t} + \frac{(1-\alpha)}{\sqrt{2\pi}} e^{\frac{-\left(\log(t) - \theta\right)^2}{2\varphi^2}}, t \geq 0, \alpha \in [0,1] \tag{2}
\]

where \(\alpha\) is a weight coefficient

The r.v \(T_c\) models the conversation duration with a lognormal pdf \(f_{T_c}(t)\) and is given as [17]:

\[
f_{T_c}(t) = \frac{1}{\varphi \sqrt{2\pi}} e^{\frac{-(\log(t) - \theta)^2}{2\varphi^2}}, \varphi, \theta > 0, t \geq 0 \tag{3}
\]

Suppose \(T_{cr}\) and \(T_c\) are independent, the pdf \(f_T(t)\) of the call duration for a normally terminated call can be obtained as a product of the pdfs in equations (2) and (3), thus:

\[
f_{T}(t) = f_{T_{cr}}(t) f_{T_c}(t) = \int_{0}^{t} f_{T_{cr}}(t - \tau) f_{T_c}(\tau) d\tau \tag{4}
\]

The probability that a call, among \(k\) active calls is not involved by a single drop event, during the duration time \(T=t\) is \(P_{nd}(1) = \frac{(k-1)}{k}\). Hence, given that drop events are assumed to be independent, with \(n\) drop events, this probability becomes
\[ P_{\text{nd}}(n) = \left( \frac{k - 1}{k} \right)^n \]  
(5)

On the other hand, drop events also constitute a Poisson process. Hence, if \( Y \) is a random variable that enumerates the number of drops, the probability that there are \( n \) drops in the interval \( T=t \) is:

\[ P(Y = n) = \left( \frac{v_d t}{n!} \right)^n e^{-v_d t}, \quad n \geq 0 \]  
(6)

where \( v_d \) is the traffic intensity and is defined as

\[ v_d = m \lambda t + b \]  
(7)

where \( \lambda t = \text{traffic in call/hr} \)
\( m \) and \( b \) are evaluation constants and could be obtained with a least square regression technique.

From equations (5) and (6), the probability that a call with duration \( T = t, k, n \) is normally terminated in the presence of \( k \) existing calls and \( n \) drop events, \( P_{\text{nt}}(T = t, k, n) \), is the same as the probability that a drop event does not affect the considered call. Thus,

\[ P_{\text{nt}}(T = t, k, n) = P_{\text{nt}}(n) P(Y = n) = \left( \frac{k - 1}{k} \right)^n \left( \frac{v_d t}{n!} \right)^n e^{-v_d t} \]  
(8)

Applying the total probability theorem to the drop events, the probability that a call with duration \( T = t \) is normally terminated in the presence of \( k \) contemporary calls (i.e. the calls are not dropped), can be estimated as

\[ P_{\text{nt}}(T = t, k) = \sum_{n=0}^{\infty} P_{\text{nt}}(T = t, k, n) \]

\[ = \sum_{n=0}^{\infty} \left( \frac{k - 1}{k} \right)^n \left( \frac{v_d t}{n!} \right)^n e^{-v_d t} \]  
(9)

\[ = e^{-v_d t} \sum_{n=0}^{\infty} \left( \frac{1}{k} \right)^n \left( \frac{v_d t}{n!} \right)^n \]

\[ = e^{-v_d t} \cdot e^{\left( \frac{k-1}{k} \right) v_d t} = e^{rac{v_d t}{k}} \]

Again, using the total probability theorem and summing over all the possible numbers of contemporary active calls, the probability that a call is normally terminated with duration \( t \) is

\[ P_{\text{nt}}(T = t) = \sum_{k=1}^{\infty} P_{\text{nt}}(T = t, k) \cdot P_s(k) \]  
(10)

where \( P_s(k) \) is the probability that there are \( k \) active users (i.e. \( k \) calls in progress) and is given as [18].

\[ P_s(k) = C_n \cdot \frac{\rho^k}{k!}, \quad k \geq 1 \]  
(11)

Here, \( \rho \) is the utilization factor and is given as the product of the total traffic \( \lambda t \) and the mean service time \( E[T] \). \( C_n \) is a normalization coefficient which considers that there is at least one ongoing call. Applying the normalization condition, the coefficient \( C_n \) evaluates to

\[ C_n = \frac{1}{e^\rho - 1} \]  
(12)

Note that by exploiting the utilization factor \( \rho \), we can also evaluate the mean number of active users \( E[N] \) as:

\[ E[N] = \sum_{k=1}^{\infty} k \cdot C_n \cdot \frac{\rho^k}{k!} = \frac{e^\rho - 1}{e^\rho - 1} \cdot \frac{1}{k!} \]  
(13)

Substituting \( C_n \) (in equation (12)) into equation (11), we have

\[ P_{nt}(T=t) = \sum_{k=1}^{\infty} \left( \frac{1}{e^\rho - 1} \right) \cdot \frac{\rho^k}{k!}, \quad k \geq 1 \]  
(14)

Also, substituting equations (14) and (9) into equation (10), we obtain

\[ P_{\text{nt}}(T = t) = \sum_{k=1}^{\infty} e^{-v_d t} \cdot \frac{1}{e^\rho - 1} \cdot \frac{\rho^k}{k!} \]  
(15)

It now seems trivial to evaluate the probability of a normally terminated call \( P_{nt} \), by considering all possible calls duration, thus:

\[ P_{\text{nt}} = \int_0^\infty P_{\text{nt}}(T = t) \cdot f_T(t) dt \]

\[ = \frac{1}{e^\rho - 1} \sum_{k=1}^{\infty} \frac{\rho^k}{k!} \int_0^\infty f_T(t) e^{-v_d t} dt \]  
(16)

where \( f_T(t) \) is the pdf, and is defined by equation (4).

Finally, from equation (1), the drop call probability can be rewritten as

\[ P_d = 1 - P_{\text{nt}} = 1 - \frac{1}{e^\rho - 1} \sum_{k=1}^{\infty} \frac{\rho^k}{k!} \int_0^\infty f_T(t) e^{-v_d t} dt \]  
(17)

Equation (17) is simulated in the next section to study the effect of the traffic parameters on the system performance. We simulate the derived model using the C++ programming language and predict the dropped call probability for the network system.

5. MODEL SIMULATION AND DISCUSSION

5.1 Simulation Input

The derived model was simulated using ideal traffic parameters and dropped calls data from the test bed system as shown in Table 3. However the program is generic and can be used to simulate other environments. The traffic data collected covered both low and peak periods.
Table 3. Simulation input parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilization factor ($\rho$)</td>
<td>5 – 30</td>
</tr>
<tr>
<td>Active users (k)</td>
<td>10 – 100</td>
</tr>
<tr>
<td>Average drop calls rate from Airtel ($d_{rate}$)</td>
<td>0.0132</td>
</tr>
<tr>
<td>Time (T)</td>
<td>5s</td>
</tr>
<tr>
<td>Weight coefficient ($\alpha$)</td>
<td>0.05</td>
</tr>
<tr>
<td>Evaluation constant ($\theta$)</td>
<td>0.5</td>
</tr>
<tr>
<td>Evaluation constant ($\varphi$)</td>
<td>0.9</td>
</tr>
<tr>
<td>Traffic ($\lambda$)</td>
<td>(5 – 35) Erlang/s</td>
</tr>
</tbody>
</table>

5.2 Simulation Results

To evaluate the performance of the model, a simulation of the dropped call probabilities for all the base stations (BSs) in the study area was carried out. We discovered from the simulation summary in Table 4 that our model has minimized dropped calls rate by 50%.

Table 4. Summary of simulated dropped call probabilities

<table>
<thead>
<tr>
<th>BSC</th>
<th>Number of BS</th>
<th>Drop rate</th>
<th>Confidence interval (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL1</td>
<td>22</td>
<td>0.543942</td>
<td>0.543942 ± 0.133394</td>
</tr>
<tr>
<td>CELL2</td>
<td>26</td>
<td>0.676166</td>
<td>0.676166 ± 0.168985</td>
</tr>
<tr>
<td>CELL3</td>
<td>25</td>
<td>0.766375</td>
<td>0.766375 ± 0.249226</td>
</tr>
<tr>
<td>CELL4</td>
<td>27</td>
<td>0.965476</td>
<td>0.965476 ± 0.274143</td>
</tr>
<tr>
<td>CELL5</td>
<td>24</td>
<td>0.342917</td>
<td>0.342917 ± 0.061273</td>
</tr>
<tr>
<td>CELL6</td>
<td>24</td>
<td>0.649610</td>
<td>0.649610 ± 0.164144</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.657414</td>
<td></td>
</tr>
</tbody>
</table>

Qualitative representations (a GIS solution) of the distribution of the experimental (empirical) and simulated dropped calls are shown in Figure 2 and Figure 3, respectively. The maps in Figures 2 and 3 were digitized using the digital elevation map (DEM) software and the data distribution done with Arc GIS 9.1 software. We observed from Figure 2 that users experienced frequent degrees of dropped calls (i.e., low, medium and high rates). We also noticed a remarkable improvement in Figure 3 as dropped calls were properly controlled by the proposed model. Also, the overall dropped calls have reduced. In Figure 4, dropped call probability is plotted against the number of active users (network capacity) for normal traffic. It is observed that there is a sudden rise in call dropping as the network capacity increases from 10 to 20 users. We attribute this rise to type one error, which occurs when the number of admissible users exceeds the maximum number which the call maintenance stage is able to control due to traffic congestion.

Call dropping is plotted in Figures 5 and 6, taking the carried traffic and network utilization, respectively as parameters for performance evaluation. An interesting observation from these Figures is that there is almost a zero call dropping until a certain point is reached when the system’s performance starts degrading. This occurs when the traffic grows or becomes bursty and available resources equate the network traffic (reaches a certain threshold). Put differently, when the various radio resources are available during a call maintenance stage, the network becomes stable, thereby providing the required QoS to users accessing the system. Figure 7 shows the effect of dropped calls on network traffic. As expected, there is a strong correlation between the call dropping rate and offered traffic. That is, as the network traffic grows, the rate of...
dropped calls also increases. This calls for appropriate load control measures especially during bursty periods. Generally, these results (Figures 4-7) allow us to assess the sensitivity of call dropping rate with respect to the offered and carried traffic loads.

Figure 4. A graph of drop call probability vs. number of users

Figure 5. A graph of drop call probability vs. network traffic

Figure 6. A graph of drop call probability vs. utilization factor

Figure 7. A graph of drop call rate vs. network traffic

Traffic control has a weak-positive effect on the area spectral efficiency [19]. This forms an interesting future research
direction. In practice, the use of directive antennas with realistic pattern has been found to strongly impact the spectral efficiency for systems using the dynamic channel assignment strategy, but this strategy could also incur to its advantage, heavier system loading. Hence, an efficient resource management technique to keep the spectral efficiency at the barest minimum while gaining increased network capacity (in the presence of heavy traffic) should be adopted.

6. CONCLUSION AND FUTURE WORK

This paper has explored the teletraffic modeling of dropped calls performance in an established cellular network. We used the call dropping probability to provide a measure of performance for failed calls in progress. An analysis of empirical data observed from an operating network in Nigeria is used as test bed for data capturing and a simulation implementing the derived analytical model was carried out with the system’s performance evaluated by comparing the simulation results with the observed data. Concerning the tradeoff between call dropping and the network traffic, the traffic demand in the network exceeded the available network capacity and this phenomenon occurs when the network at capacity or nearly full.

A future direction of this research is to investigate the application of cell sectorization as a means of improving the current size of cellular networks.

REFERENCES


AUTHORS’ BRIEF

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