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Estimating Call-Drop Probability Rates among Wireless Cellular Networks in Ghana

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Abstract:
The increasing rate of call-drop among wireless cellular networks has become a headache for subscribers of mobile voice networks in Ghana. Despite the many studies that have been carried out on call-drop, most of them have failed to examine call-drop probability rates, a key metric of tackling the issue of call-drop. This study combines the probability distribution function of call-drop and maximum likelihood estimator to estimate call-drop probability rates among the wireless cellular networks in Ghana. The call-drop of the networks was, first of all, fitted to a probability distribution. The call-drop probability rate was then estimated using the maximum likelihood estimator of the fitted distribution. The call-drop probability distribution of Airtel-Tigo, Vodafone, and Glo follow the Geometric probability distribution, while that of MNT follows the Negative Binomial probability distribution. The call-drop probability rate of MTN is 7.6%, Vodafone is 3.3%, Airtel-Tigo, and Glo is 3.0%. These call-drop rates are found to be outside the prescribed NCA's acceptable limit of less than 3 %.

Keywords: *Call-Drop rate, call-drop probability, wireless cellular networks, Poisson probability, geometric distribution, negative binomial distribution, maximum likelihood estimate*

1. Background

Mobile subscribers worldwide are grappling with the issue of call-drops (Singh et al., 2017; Tarkaa & Pahalson, 2019; Gaur, 2016). Mobile subscribers cited call-drop as the most common complaint in a recent Pew Internet and American Life Project study (Jan & Lee, 2012). According to the study, seventy-two percent of cellphone owners have experienced call-drops at least once a week, and thirty-two percent have experienced them several times a week (Jan & Lee, 2012). Quality of service, particularly call-drop rate, has become an issue to consider as a result of the enormous growth in the number of subscribers over time (Singh & Pandey, 2016; Akanbasiam & Ngala, 2017). The failure of a service provider to sustain a call after it has been established properly is referred to as a call-drop (Patil, 2016; Li et al., 2015; Tarkaa & Pahalson, 2019). Such an event's probability is called drop probability (Tarkaa & Pahalson, 2019; Li et al., 2015). The call is lost or abruptly disengaged before the user can finish it normally, and the reason for this is mostly due to a problem with the service provider's network (Tarkaa & Pahalson, 2019; Erunkulu et al., 2019; Tarkaa & Mom, 2018).

In addition to the discomfort that the user may experience, call-drops to result in the user incurring extra costs as a result of the user's repeated attempts to call in order to continue the communication (Kumar, 2015; Pattaramalai et al., 2007; Khare & Sudhakar, 2019). Hence call-drops lead to an unwarranted financial burden on the user. Consumers are required to pay even if they maintain a connection for only one or few seconds before the call is disconnected. The user is, therefore, seriously disadvantaged (Kumar, 2015; Khare & Sudhakar, 2019). Not only does call-drop result in monetary losses to the user, but also a time-wasting experience for the user and negatively impacts the production and efficiency of subscribers in the long run (Kumar, 2015).

Call-drop arises due to a variety of technical issues and challenges, including inadequate infrastructure; area coverage; signal quality & strength; interference level; network congestion; and network failure (Li et al., 2015; Levin, 2020; Shrivastava & Sinha, 2016; Chandler, 2020; Jeff, 2017; Khare & Sudhakar, 2019; Erunkulu et al., 2019; Singh & Pandey, 2016). The remote area subscribers primarily face call-drops because of a lack of coverage (Li et al., 2015; Levin, 2020; Shrivastava & Sinha, 2016; Chandler, 2020; Jeff, 2017; Khare & Sudhakar, 2019; Erunkulu et al., 2019; Singh & Pandey, 2016). However, in urban and metro areas, this arises due to the increasing gap between the increasing growth of the mobile subscriber base and the lack of investment in building network infrastructure to support the growing demand, including setting up additional base transceiver stations in given geographical areas and establishment of in-building larger coverage (Li et al., 2015; Levin, 2020; Shrivastava & Sinha, 2016; Chandler, 2020; Jeff, 2017; Khare & Sudhakar, 2019; Erunkulu et al., 2019; Singh & Pandey, 2016).

Call-drop probability is a critical metric for monitoring the performance of wireless cellular networks. It indicates the likelihood that a call will be dropped due to a failed handoff or technical issues (Tarkaa & Pahalson, 2019; Erunkulu et al., 2019). The objective of all wireless cellular networks is to keep the probability of call-drop to a specified value while maintaining higher bandwidth utilization or lower call blocking rates for new calls (Kumar, 2015; Erunkulu et al., 2019; Iraqi & Boutaba, 2005). Call-drop probability has been a subject of concern in both academia and practice (Aalo & Efthymoglou, 2010; Madan et al., 2008; NCA, 2020; Jan & Lee, 2012; Iraqi & Boutaba, 2005; Akanbasiam & Ngala, 2017; Khare & Sudhakar, 2019; Tarkaa et al., 2011; Li et al., 2015; Levin, 2020; Shrivastava & Sinha, 2016; Chandler, 2020; Jeff, 2017; Khare & Sudhakar, 2019; Erunkulu et al., 2019; Singh & Pandey, 2016).

Generally, it is not possible to compute call-drop probability when there is no specific probability distribution function (Erunkulu et al., 2019; Tarkaa & Pahalson, 2019; Ohaneme et al., 2016; Iraqi & Boutaba, 2005). As a result, several probability distributions have been proposed to determine the call-drop probability of wireless cellular networks both in developed and developing countries (Aalo & Efthymoglou, 2010; Madan et al., 2008; NCA, 2020; Jan & Lee, 2012; Iraqi & Boutaba, 2005; Akanbasiam & Ngala, 2017; Khare & Sudhakar, 2019; Tarkaa et al., 2011; Tarkaa & Mom, 2018; Boggia et al., 2007; Ohaneme et al., 2016; Calistus et al., 2018; Tarkaa & Pahalson, 2019; Al-Tarawneh & Taebi, 2017; Kocevska et al., 2020; Erunkulu et al., 2019; Siddiqui et al., 2015). Theoretically, call-drop probability is said to follow the Poisson probability distribution (Khare & Sudhakar, 2019; Tarkaa et al., 2011; Tarkaa & Mom, 2018). However, several authors have found that call-drop probability follows other probability distribution functions (Aalo & Efthymoglou, 2010; Boggia et al., 2005; Boggia et al.,2007; Fang et al., 1997; Pattaramalai et al., 2007; Erunkulu et al.,2019; Ojuh & Isabona, 2021; Patil, 2016).

These and other research results from the literature reveal that there is inconclusive evidence on the best probability distribution for estimating call-drop (Erunkulu et al., 2019; Tarkaa & Mom, 2018). Moreover, call-drop estimates in the literature were computed based on different socio-economic and technological characteristics, which are key determinants of call-drop rate estimates and their probability distributions. This study adds to the debate by estimating call-drop rates among wireless cellular networks in Ghana. In Ghana, there are a total of four (4) mobile network operators. According to the National Communication Authority's (NCA) Telecom Subscription Survey, Ghana had a total wireless cellular network user base of 26,469,963 in 2020, with various mobile operators (NCA, 2020). Ghana's mobile network industry is undoubtedly one of the most competitive (Ngala & Akanbasiam, 2018; NCA, 2020). Scancom (MTN) owns 55.95 percent of the market share as of January 2020, followed by Vodafone Mobile with 21.93 percent, Airtel-Tigo with 20.37 percent, and Glo with 1.75 percent (NCA, 2020). Call-drop among these mobile network operators is a common occurrence that makes the news almost daily. Numerous subscribers of these wireless cellular networks have complained about it several times (Ngala & Akanbasiam, 2018; Chronicle, 2021).

Estimating the call-drop probability rate among the wireless cellular networks in a developing country, such as Ghana, with different technological and network issues is interesting for policy, practice, and theory. In terms of practice, it is envisaged that the knowledge of call-drop probability distribution will especially be beneficial to the network operators in Ghana to optimize their performance and improve their quality of service. With regard to policy, it is anticipated that the results from this study will assist policymakers in making informed decisions on the quality of service of network operators and help the regulators monitor the performance of the network operators. From a theoretical perspective, the results of the study will contribute to the literature on estimating call-drop probability among cellular networks. The rest of the paper is organized as follows:

- Section 2 presents the problem statement.
- This is followed by the review of previous related work in section 3.
- In section 4, the proposed method for the study is presented.
- In section 5, the experimental results of the study are presented.
- In section 6, the results of the findings of the study are discussed.
- In section 7, the conclusion and recommendations of the study are presented.
- Finally, the potential future work and limitations of the study are presented in Section 8.

2. Statement of the Problem

Call-drop among wireless cellular networks is a major cause for concern in Ghana (Ngala & Akanbasiam, 2018); Akanbasiam & Ngala, 2017). According to the Chronicle (2021), the call-drop problem in Ghana appears to be a result of the over-subscription of wireless cellular networks, thus making it impossible to render quality services. The call-drop rate among the wireless cellular networks has gone up recently, creating inconveniences not only for individual users but also for the business communities in Ghana, thus, affecting the smooth running of businesses in the country (Akanbasiam & Ngala, 2017; Chronicle, 2021; Ngala & Akanbasiam, 2018). For instance, the issue of call-drop is gradually creeping into the mobile money transfer sector, making it very difficult to transfer and receive money from subscribers of the various networks. The problem is so alarming that if not properly addressed, it could bring chaos to the subscribers.

Despite several confirmations by the National Communication Authority (NCA) that call-drop among the wireless cellular networks in Ghana is within the acceptable range, the problem continues to persist. The magnitude, occurrence, and consequences of the problem call for a new approach to estimating call-drop among the wireless cellular networks in Ghana **h**ence this study. Unlike the NCA, which usually relies on the sample survey method in estimating call-drop rates, this study contributes to the problem's solution by using a new approach of combining the probability distribution function of the call-drop and the maximum likelihood estimator in estimating call-drop rates.

3. Literature Review

Many research works have been carried out on call-drop. Aalo and Efthymoglou (2010) examined call-drop probability and call completion probability for a cellular network. The authors reported that call-drop and call completion probabilities in a heterogeneous wireless network, where the handoff failure in each cell is not constant, follow a uniform probability distribution. Boggia et al. (2005), through an investigation of drop call probability in an established Vodafone network in Italy, found that the call-drop follows a log-normal probability distribution. Using field data, Boggia et al. (2007), in modelling call-drop in well-established cellular networks, found that call-drop probability is exponentially distributed rather than log-normally distributed.

Erunkulu et al. (2019) used an artificial neural network to predict call-drop in the GSM network in Nigeria. The authors found that their model has an accuracy of almost 88 percent call-drop prediction. They revealed that call-drop in Nigeria is likely to follow an exponential probability distribution. Calistus et al. (2018) proposed an efficient call acceptance probability principle for mitigating call failures in a wireless network system in Nigeria. The authors found that their new scheme could admit new calls provided the relative probability factor (δ) was less than 0.7. Tarkaa and Pahalson (2019) analyzed call-drop probability among Mobile Telecommunication Network (MTN) in Apapa Lagos, Nigeria. The authors confirmed that the call-drop probability of the network was within the acceptable region.

Ojuh and Isabona (2021) examined the optimal probability distribution model for drop call rates based on a five-week acquired rate of drop calls data sample in the Southern regions of Nigeria. The authors fitted eight probability distributions, namely: logistic, log-logistic, normal, log-normal, exponential, Rayleigh, Rician, and Gumbel max, to the data. Based on the combined scores of three goodness of fit statistical tests, the log-logistic distribution was found to be the optimal probability distribution for the weekly rate of call-drop. Nasser (2006) estimated call-drop probability in a multimedia wireless network using an adaptive bandwidth allocation algorithm. The authors claimed their algorithm improved system performance and reduced, in particular, handover blocking probability and call-drop. Chao and Li (2005) studied handover and call-drop considering a cellular mobile communication network with multiple cells and different classes of calls. The authors revealed that each cell and class of call has different call holding, cell residence times, and call-drop rates.

Patil (2016) examined the call-drop rate in a 4G network using a vertical Handoff algorithm in India. Based on the comparison of the call-drop rate from the existing and the proposed research work, the author found that the call-drop rate was lower than the existing rate. The call-drop rate among the wireless cellular network in India was assumed by the author to follow an exponential probability distribution instead of the theoretical distribution of Poisson. In an experimental study, Fang et al. (1997) found that call-drop probability has Gamma, (staged) Erlang, hyper-exponential, and hyper-Erlang probability distributions. In a study of call completion probability, Pattaramalai et al. (2007) found that call-drop probability follows a Weibull probability distribution.

Li et al. (2015) analyzed call-drop probability in a relay-based high-speed railway environment through a handoff probability algorithm in China. Based on the simulation and comparison of the call-drop model, the authors found that putting a relay between the base stations can significantly improve the call-drop problem. The authors, however, failed to consider the Doppler Effect in their model. Using an artificial intelligence-based handover scheme, Singh et al. (2017) examined call-drops in cellular networks in India. The authors reported that their proposed scheme was able to achieve a satisfactory level of call-drop minimization.

Ugege et al. (2021), through a flexible handoff prioritization scheme, examined call-drop probability in mobile networks in Nigeria. The authors used traffic intensity and call-drop probability to decide whether new calls could use reserved channels or not. In their proposed model, the authors kept the number of reserved channels fixed rather than calculating the numbers to reserve per time, thereby reducing the computational complexity of the scheme. The simulation results showed an improved quality of service for the handoff calls while producing a commensurate improvement for the new calls through a reduced call-drop probability and call block probability.

Ojesanmi et al. (2021), through the performance evaluation of an adaptive guard channel scheme in a wireless network, measured the call-drop rate of wireless cellular networks in Nigeria. The model used two schemes: guard channel with fuzzy logic; and guard channel without fuzzy logic. The authors revealed from their model that the guard channel with fuzzy logic has call-drop rate values ranging from 12.0 to 18.9 percent, while the guard channel without fuzzy logic has call-drop rate values ranging from 28.2 percent to 75.7 percent. The author found the model to be more efficient in predicting call-drops in a wireless network.

Iraqi and Boutaba (2005) studied handoff and call-dropping probabilities in wireless cellular networks. The authors reported that it is not clear how to compute call-drop probability based on local information when there is no specific distribution model for handoffs. Tarkaa and Mom (2018) considered a comparative analysis of call-drop probability due to handover and other factors in Nigeria. The authors reported that the cellular networks needed further optimization as the handover call-drop probability surpassed the call-drop probability due to other factors.

Despite the many studies that have been carried out on call-drop probability rate estimates, few have examined call-drop probability rates using the probability distribution function of call-drop. As reviewed in the literature, most of these studies have estimated call-drop probability rates through various vertical handover algorithms, artificial intelligence, and other proposed algorithm methods. Although most authors claim that their models are efficient in estimating call-drop probability rates, there are inconclusive findings as to which method is best in estimating call-drop probability rates. To combine the probability distribution function of call-drop and the maximum likelihood estimation method, this study proposes a new approach to estimating call-drop probability rates among wireless cellular networks.

4. Proposed Method

The Poisson probability distribution function is, first of all, used to estimate the call-drop probability rates among wireless cellular networks. This is to verify whether the theoretical viewpoint of call-drop probability distribution of Poisson holds for call-drop in Ghana. The measured call-drop data is then fitted to a probability distribution using EasyFit, a probability distribution fit software, to determine the exact probability distribution function of call-drop among the wireless cellular networks. The call-drop probability rate among the wireless cellular networks is then estimated using the maximum likelihood estimator of the exact fitted probability distribution. The various equations of the proposed method are presented as follows:

4.1. Call-Drop Probability (CDP)

Call-drop is one of the important indicators of the performance of wireless cellular networks in any given country. Since wireless cellular network operators seek to maximize both customer satisfaction and revenue, it is critical that mobile communication networks be designed, maintained, and operated in a way that lowers both call-drop rate and operator expenses. Call-drop probability is defined to be

$$P(X = n) = \frac{(v_d t)^n}{n!} e^{-v_d t}, n \geq 0 \qquad (1)$$

where, v_d is the call-drop rate, t *is* the call duration, while X is a random variable that counts the number of drops and n is the confirmed calls dropped. As indicated in equation (1), the probability distribution is a Poisson probability distribution function with a discrete variable that counts the number of dropped calls (Tarkaa et al., 2011; Tarkaa & Mom, 2018; Boggia et al., 2007; Boggia et al., 2005).

4.2. Call-Drop Rate (CDR)

Call-drop rate is defined as the number of dropped calls divided by the total number of call attempts into percentage terms as indicated in equation (2)

$$CDR = \frac{Number\ of\ calls\ dropped}{Total\ number\ of\ call\ attempts} \times 100\% \qquad (2)$$

A critical look at equation (2) reveals that the rate at which call-drops is the average of the call-drop multiplied by 100. Therefore, one can use the maximum likelihood estimation approach to achieve a similar result. Hence, this study uses the maximum likelihood estimation approach in computing the CDR of wireless cellular networks in Ghana.

4.3. Maximum Likelihood Estimation (MLE)

Let $X_{1,}\ X_{2,} \cdots,\ X_n$ denote a random sample whose assumed probability distribution depends on some unknown parameterθ. The main objective here is to find a point estimator$\mu(X_{1,}X_{2,}\ \cdots, X_n)$, such that: $u(x_{1,}x_{2,}\ \cdots, x_3)$ is a 'good' point estimate of θ, where $x_{1,}x_{2,}\ \cdots, x_n$ are the observed values of the random sample. For instance, one plans to take a random sample $X_{1,}\ X_{2,} \cdots,\ X_n$ for which the X_i are assumed to be normally distributed with mean μ and variance σ^2. Then the goal will be to find a good estimate of μ, using the data $x_{1,}x_{2,}\ \cdots, x_n$ that are obtained from a specific random sample.

Let $X_{1,}\ X_{2,} \cdots,\ X_n$ be a random sample from a distribution that depends on at least one unknown parameter $\theta_{1,}\theta_2, \cdots, \theta_m$ with probability density function $f(x_{i;}\theta_1, \theta_2, \cdots \theta_m)$. Let's say that $(\theta_1, \theta_2, \cdots,\ \theta_m)$ is restricted to a given parameter space Ω. Then when regarded as a function of $\theta 1, \theta_2, \cdots, \theta_m$, the joint probability density function of $X_{1,}\ X_{2,} \cdots, X_n$ is given by

$$L(\theta_1, \theta_2, \cdots, \theta_m) = \prod_{i=1}^{n} f(x_{i;}\theta_1, \theta_2, \cdots \theta_m) \qquad (3)$$

where $((\theta_1, \theta_2, \cdots, \theta_m)\ in\ \Omega)$ is the likelihood function. If $[u_1(x_1, x_{2,}\ \cdots, x_n), u_2(x_1, x_{2,}\ \cdots, x_n), \cdots\ u_m(x_1, x_{2,}\ \cdots, x_n)]$ is the $m - tuple$ that maximizes the likelihood function, then $\hat{\theta}_i =\ u_i(X_{1,}X_{2,} \cdots, X_n)$is the maximum likelihood estimator of θ_i, for i = 1,2,$\cdots, m$. The corresponding observed values $[u_1(x_1, x_{2,}\ \cdots, x_n), \cdots\ u_m(x_1, x_{2,}\ \cdots, x_n)]$ are called the maximum likelihood estimates of θ_i, for i = 1,2,$\cdots, m$. Let's take a look at the MLE of Poisson probability distribution, the theoretical probability distribution of call-drop rate.

4.4. Poisson Probability Distribution Function

Poisson distribution is a probability distribution that shows how often an event can happen within a certain period of time. The distribution is often used to understand independent events that occur at a constant rate over a given time interval (Kissell & Poserina, 2017). The distribution is a count distribution. In other words, it is a distribution used to model a count of data. Poisson probability distribution has been used as the theoretical probability distribution to model call-drop probability of wireless cellular networks because call-drops are measured as count data within a given time period (Tarkaa et al., 2011; Ahmed, 2015). We let the random variable Y denotes the number of call-drops within a given time interval. The Poisson probability distribution associated with this random variable is defined as

$$P(Y = y) = \frac{\mu^y e^{-\mu}}{y!}, \qquad (4)$$

where $y =$ 0, 1,... represents the number of call-drop of a wireless cellular network at a given time interval and $\mu > 0$ is the mean. Figure 1 depicts the shape of the Poisson probability distribution with different means.

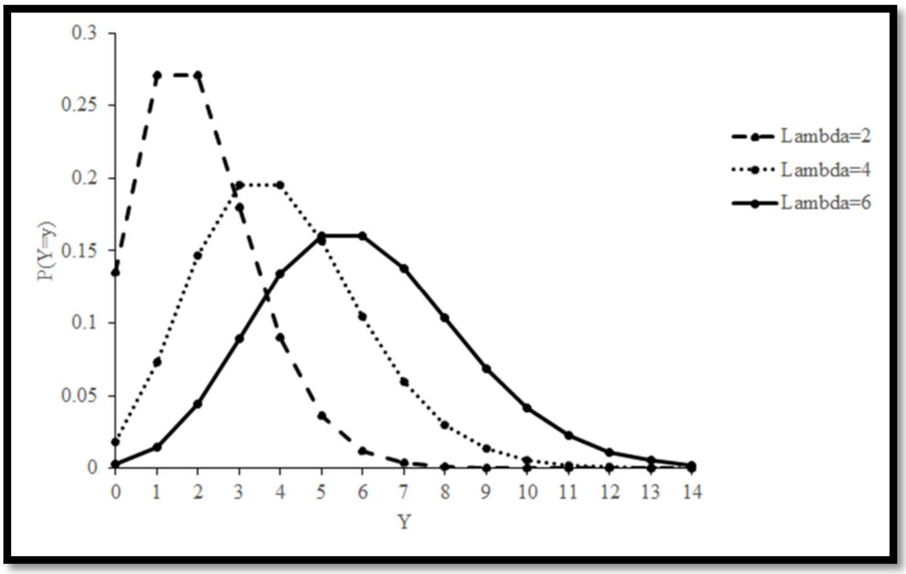

Figure 1: Poisson Probability Distribution with Different Means (Lambda)

4.4.1. Maximum Likelihood Estimate of Poisson Probability Distribution

The mean is the most useful result of the Poisson probability distribution. Here the authors use the maximum likelihood method of estimation to show that this parameter is the most useful of the Poisson probability distribution. Since Poisson distribution is a discrete probability distribution, its likelihood function for a set of n measurements can be written as

$$L(\mu)=\prod_{i=1}^{n}P(Y=y)\ =\prod_{i=1}^{n}\left[\frac{\mu^{y_i}e^{-\mu}}{y_i\,!}\right] \tag{5}$$

$$=\frac{\mu\sum y_i e^{-n\mu}}{y_1!y_2!...y_n!} \tag{6}$$

The log-likelihood function of $L(\mu)$ is

$$l\equiv\ln(L)=\left(\sum_{i=1}^{n}y_i\right)\ln(\mu)-n\mu-\ln(y_1!y_2!...y_n!). \tag{7}$$

We differentiate with respect to the parameter μ and set it equal to zero to obtain

$$\frac{\delta l}{\delta\mu}=-n+\frac{1}{\mu}\sum_{i=1}^{n}y_i=0 \tag{8}$$

We finally solve equation (5) to get

$$\mu=\frac{1}{n}\sum_{i=1}^{n}y_i \tag{9}$$

This result indicates that once call-drops of the wireless cellular networks are shown to be Poisson distributed, the average call-drop probability rates can be obtained using the sample average or mean.

4.5. Goodness of Fit Test

4.5.1. Anderson Darling Test

The Anderson-Darling test is used to test if a sample of data came from a population with a specific distribution (Stephens, 1974; Anderson & Darling, 1954). It is a modification of the Kolmogorov-Smirnov (K-S) test and gives more weight to the tails than the K-S test. The K-S test is distribution-free in the sense that the critical values do not depend on the specific distribution being tested. The Anderson-Darling test uses the specific distribution to calculate critical values (Anderson & Darling, 1954). The Anderson-Darling test is defined as:

- Ho: The data follows a specified distribution
- H_1: The data do not follow the specified distribution

The Anderson–Darling statistic, denoted by A^2, is given by the weighted sum of the squared deviations $F_X(x;\theta) - F_n(x)$:

$$A^2 = \frac{1}{n}\left(\sum_{i=1}^{n}(F_X(x;\theta) - F_n(x))^2\right) \quad (10)$$

Starting from the fact that A^2 is a random variable that follows a certain distribution over the interval $[0;+\infty[$, it is possible to test, for a significance level that is fixed a prior, whether $F_n(x)$ is the realization of the random variable $F_X(X;\theta)$; that is, whether X follows the probability distribution with the distribution function $F_X(x;\theta)$. In simple terms, the Anderson-Darling test statistic.

$$A^2 = -N - S \quad (11)$$

where

$$S = \sum_{i=1}^{N}\frac{(2i-1)}{N}[\ln F(X_i) + \ln(1 - F(X_{N+1-i}))] \quad (12)$$

F is the cumulative distribution function of the specified distribution, and X_i are the ordered data. The critical values for the Anderson-Darling test depend on the specific distribution being tested. The test is one-sided, and the hypothesis that the distribution is of a specific form is rejected if the test statistic A^2 is greater than the critical value.

4.5.2. Kolmogorov Smirnov Test

The Kolmogorov-Smirnov test is used to test if a sample comes from a population with a specific distribution. The Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (ECDF). Given the N ordered data points $X_1, X_2, ..., X_N$, the ECDF is defined as:

$$E_N = n(i)/N \quad (13)$$

where $n(i)$ is the number of points less than X_i and they X_i are ordered from smallest to largest value. This is a step function that increases by $1/N$ at the value of each ordered data point. The Kolmogorov-Smirnov test is given by:

Ho: The data follow a specified distribution

H_1: The data do not follow the specified distribution

The test statistic for Kolmogorov-Smirnov test is defined as:

$$D = \max_{1\le i\le N}\left(F(X_i) - \frac{i-1}{N}, \frac{i}{N} - F(X_i)\right) \quad (14)$$

where F is the theoretical cumulative distribution of the distribution being tested. The hypothesis regarding the distributional form is rejected if the test statistic, D is greater than the critical value obtained.

5. Data Collection Procedure

A call-drop test was conducted to collect the required data to estimate the call-drop probability rates among Ghana's wireless cellular networks and to measure the number of call-drops among the wireless cellular networks. The Drive Test (DT) method was used to collect the information about the call-drops of the wireless cellular networks and was conducted at key locations in Accra during the busy hours of 6:00 am-10:00 am in the morning; and 2:00 pm-9:00 pm in the evening for one month. The Drive Test was performed among the wireless cellular networks regardless of the technology. Typically, the wireless cellular network is quantified in terms of average activity during the busy hour of the day. The busy hour of the day happens during the given period of time which has the greatest amount of traffic. The number of call-drops was measured during heavy hour traffic because this period usually has the highest amount of blocked or lost calls. This implies that if the number of call-drops of the wireless cellular networks during this period is less, call-drops in all other non-busy hour traffic should be less. The data collection took place in the month of April 2021. Voice calls were made in a series of two attempts with a 5-second delay between each call. A successful call was limited to 60 seconds in duration.

The raw data was cleaned and organized prior to the data analysis. Before beginning the raw data analysis, the data was thoroughly checked for any errors. The purpose of this step was to eliminate any undesirable data points (redundant, incomplete, or incorrect data points) to ensure high-quality data for analysis. After cleaning the data, it was exported to EasyFit Professional for analysis. A statistical analysis of the observed data is conducted, which enables the estimation of the mean and standard deviation using the well-known estimators for these parameters (Kissell & Poserina, 2017). Additionally, the coefficient of variation, which is defined as the ratio of the standard deviation to the mean, is computed. This parameter indicates the degree to which data is dispersed around the mean value. After estimating these parameters, the data was then fitted to a Poisson probability distribution to confirm whether the theoretical view that a call-drop follows a Poisson probability distribution holds for call-drops among wireless cellular networks in Ghana. Following that, the measured call-drop data were fitted to the appropriate or exact probability distribution. The call-drop probability rate was then determined using the probability distribution's maximum likelihood estimator.

6. Results

Table 1 shows the estimated parameters of the experimental sampled data. It is observed that the call-drops among the wireless cellular networks show values of coefficient of variation (CV) less than 1. This result indicates that the dispersion of the data around the mean is lower, suggesting reliable data points for further analysis. It is evident from the results that the dispersion is lower in the MTN data points compared to the rest of the networks. Meanwhile, on average, the MTN's call-drop was higher than the rest of the wireless cellular networks.

Networks	Morning	Evening	Overall
	M±SD (CV)*	M±SD (CV)*	M±SD (CV)*
MTN	24.8±11.35 (0.46)	47.7±22.33(0.47)	36.3±21.01(0.58)
Vodafone	25.4±11.34(0.45)	35.1±22.83(0.65)	30.3±18.53(0.61)
Airtel-Tigo	24.1±11.77(0.49)	42.6±23.94(0.56)	33.42±0.88(0.63)
Glo	22.3±9.95(0.45)	43.5±22.56(0.52)	32.9±20.34(0.62)

Table 1: Estimated Statistical Parameters

** M=Mean, SD=Standard Deviation, CV = Coefficient of Variation*

6.1. Poisson Fitted Distribution of Call-Drops

Figures 2 to 5 show the fitted Poisson probability distribution of call-drops among the wireless cellular networks in Ghana. The figures show that the call-drops of the wireless cellular networks do not follow the Poisson probability distribution. This is confirmed by the results of the Kolmogorov Smirnov and Anderson Darling Goodness of Fit tests, as shown in table 2. The results of the Kolmogorov Smirnov test (KS-test) show that the call-drops of MTN (D=0.31838), Vodafone (D=0.3846), Airtel-Tigo (D=0.30172), and Glo (D=0.36703) does not come from a Poisson probability distribution. Similarly, the results of the Anderson Darling test indicate that the call-drops of MTN (A^2=67.936), Vodafone (A^2=59.998), Airtel-Tigo (A^2=73.768), and Glo (A^2=68.298) does not come from a Poisson probability distribution.

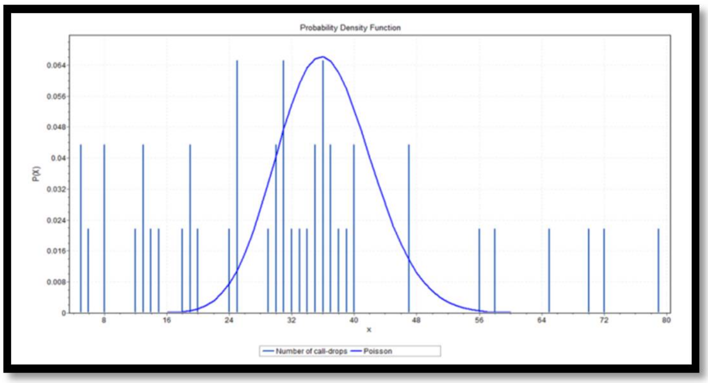

Figure 2: Poisson Probability Density Function of Call-Drops of MTN

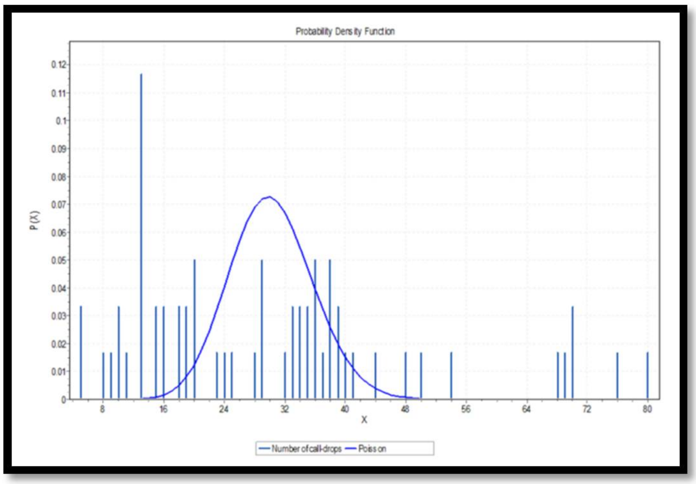

Figure 3: Poisson Probability Density Function of Call-Drops of Vodafone

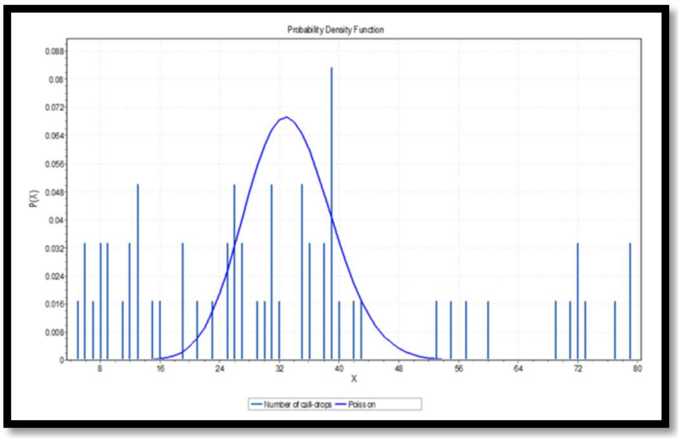

Figure 4: Poisson Probability Density Function of Call-Drops of Airtel-Tigo

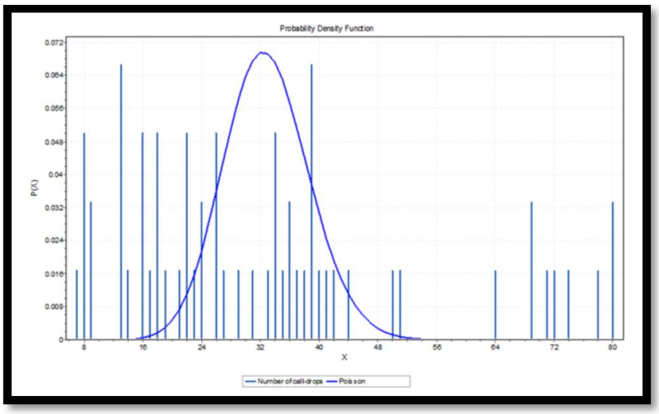

Figure 5: Poisson Probability Density Function of Call-Drops of Gio

Networks	Parameter	Goodness of Fit Test	
		Kolmogorov Smirnov Test (D)[a]	Anderson Darling Test (A²)[b]
MTN	$\lambda = 36.3$	0.31838	67.936
Vodafone	$\lambda = 30.3$	0.3846	59.998
Airtel-Tigo	$\lambda = 33.4$	0.30172	73.768
Glo	$\lambda = 32.9$	0.36703	68.298

Table 2: Poisson Fitted Distribution of Call-Drops among Wireless Cellular Networks

[a]$D_{critical}$ = 1.36/$\sqrt{n}$ = 0.0203 $at\ \alpha - level\ of$ 5%; [b]$A^2_{critical}$ = 0.752 $at\ \alpha - level\ of$ 5%

6.2. Call-Drop Probability Distribution of Wireless Cellular Networks

Table 3 shows the call-drop probability distribution of Airtel-Tigo. The results, as indicated in the table, reveal that the call-drop of Airtel-Tigo follows a Geometric probability distribution. Among the five probability distributions that were fitted to the call-drops of the Airtel-Tigo network, Geometric probability distribution was ranked first. The distribution was found to be statistically significant in fitting the call-drops of the network, as indicated by the results of the Goodness of Fit tests. The results of the calculated Kolmogorov Smirnov test (D=0.01803) are less than the critical value of 0.0203 at a 5% level of significance, supporting the claim that the call-drops of the Airtel-Tigo network follows a Geometric probability distribution. Similar results were obtained with respect to the Anderson Darling Goodness of Fit test. The test results also revealed that the calculated value (A^2=0.2897) is less than the critical value of 0.752 at a 5% significance level, also supporting the claim that the call-drops of the Airtel-Tigo network come from a Geometric probability distribution.

Distribution	Kolmogorov Smirnov Test (D)[a]	Anderson Darling Test (A²)[b]
	Statistic (Rank)	Statistic (Rank)
Uniform Distribution	0.16944 (2)	26.812 (4)
Geometric	0.01803 (1)	0.2897 (1)
Logarithmic	0.45216 (5)	21.828 (3)
Negative Binomial	0.29818 (3)	9.4014 (2)
Poisson	0.30172 (4)	73.768 (5)

Table 3: Call-Drop Probability Distribution of Airtel-Tigo

$^{a}D_{critical}$ = 1.36/$\sqrt{n}$ = 0.0203 $at\ \alpha - level\ of$ 5%; $^{b}A^{2}_{critical}$ = 0.752 $at\ \alpha - level\ of$ 5%

Table 4 depicts the call-drop probability distribution of Glo. The probability distribution of the call-drops of Glo telecommunication network is also found to follow a Geometric probability distribution. As indicated in the table, among the five probability distributions that were fitted to the call-drops of the network, Geometric distribution is ranked first. Geometric probability distribution is found to be the only distribution that is statistically significant, as indicated by the results of the Kolmogorov Smirnov and Anderson Darling Goodness of Fit tests.

Distribution	**Kolmogorov Smirnov Test (D)[a]**	**Anderson Darling Test(A^2)[b]**
	Statistic (Rank)	**Statistic (Rank)**
Uniform Distribution	0.15714 (2)	29.471 (4)
Geometric	0.01242 (1)	0.0938 (1)
Logarithmic	0.5046 (5)	23.266 (3)
Negative Binomial	0.25549 (3)	10.985 (2)
Poisson	0.36703 (4)	68.298 (5)

Table 4: Call-Drop Probability Distribution of Glo

$^{a}D_{critical}$ = 1.36/$\sqrt{n}$ = 0.0203 $at\ \alpha - level\ of$ 5%; $^{b}A^{2}_{critical}$ = 0.752 $at\ \alpha - level\ of$ 5%

Table 5 shows the call-drop probability of Vodafone mobile telecommunication. The results of both the Kolmogorov Smirnov and Anderson Darling Goodness of Fit tests reveal that Geometric probability distribution best fits the call-drops of the network. As indicated in the table, Geometric probability distribution is ranked the first among the five distributions that fit the call-drops of the network. On the other hand, the Geometric probability distribution is the only fitted distribution that is found to be statistically significant at the level of 5%. The rest of the fitted distributions are not statistically significant.

Distribution	**Kolmogorov Smirnov Test (D)[a]**	**Anderson Darling Test (A^2)[b]**
	Statistic (Rank)	**Statistic (Rank)**
Uniform Distribution	0.16146 (2)	22.941 (4)
Geometric	0.00909 (1)	0.254 (1)
Logarithmic	0.50264 (5)	22.904 (3)
Negative Binomial	0.29681 (3)	12.879 (2)
Poisson	0.3846 (4)	59.998 (5)

Table 5: Call-Drop Probability Distribution of Vodafone.

$^{a}D_{critical}$ = 1.36/$\sqrt{n}$ = 0.0203 $at\ \alpha - level\ of$ 5%; $^{b}A^{2}_{critical}$ = 0.752 $at\ \alpha - level\ of$ 5%

Table 6 shows the results of the probability distribution of the call-drops of MTN. The results indicate that the call-drop of MTN, unlike the other previous wireless cellular networks, follows a Negative Binomial probability distribution. Among the five probability distributions that were fitted to the call-drops of MTN, the Negative Binomial probability distribution was ranked first. The distribution was also found to be statistically significant in fitting the call-drops of MTN, as indicated by the results of the Kolmogorov Smirnov and Anderson Darling Goodness of Fit tests. The results of the calculated Kolmogorov Smirnov test (D=0.00162) are less than the critical value of 0.0203 at a 5% level of significance, supporting the claim that the call-drops of the MTN network follows a Negative Binomial probability distribution. Similarly, the results of the calculated Anderson Darling Goodness of Fit test (A^2=0.724) are less than the critical value of 0.752 at a 5% level of significance, also supporting the claim that the call-drops of MTN follow a Negative Binomial probability distribution.

Distribution	**Kolmogorov Smirnov Test (D)[a]**	**Anderson Darling Test (A^2)[b]**
	Statistic (Rank)	Statistic (Rank)
Uniform Distribution	0.16111 (2)	18.754 (3)
Geometric	0.2129(3)	5.0916 (2)
Logarithmic	0.47879 (5)	23.349 (4)
Negative Binomial	0.00162 (1)	0.724 (1)
Poisson	0.31838 (4)	59.998 (5)

Table 6: Call-Drop Probability Distribution of MTN.

$^{a}D_{critical}$ = 1.36/$\sqrt{n}$ = 0.0203 $at\ \alpha - level\ of$ 5%; $^{b}A^{2}_{critical}$ = 0.752 $at\ \alpha - level\ of$ 5%

6.3. Call-Drop Probability Rates of Wireless Cellular Networks

Table 7 shows the call-drop probability rates among the wireless cellular networks in Ghana. With respect to Vodafone network, the results show that with identically independently distributed call attempts, the number of call-drops follows a Geometric probability distribution with a probability of call-drop, p=0.032. Similarly, regarding Airtel-Tigo, the results indicate that with identically independently distributed call attempts, the number of call-drops follows a Geometric probability distribution with a probability of call-drop, p=0.02911. Likewise, the results of Glo indicate that with identically independently distributed call attempts, the number of call-drops follows a Geometric probability distribution with a probability of call-drop, p=0.0295. Meanwhile, the results of MTN show that with identically independently distributed call attempts, the number of call-drops follows a Negative Binomial probability distribution with the probability of three call-drops per successful call-up, p=0.083.

Networks	Distribution	Parameter	MLE*
MTN	Neg. Binomial	n=3;p=0.083	$\hat{p}$ = 0.076
Vodafone	Geometric	p=0.035	$\hat{\theta}$ = 0.033
Airtel-Tigo	Geometric	p=0.02911	$\hat{\theta}$ = 0.030
Glo	Geometric	p=0.0295	$\hat{\theta}$ = 0.030

Table 7: Call-Drop Probability Rates of Wireless Cellular Networks.
**MLE= Maximum likelihood estimates; $\hat{p} = r/r + \bar{X}$; $\hat{\theta} = 1/\bar{X}$*

The results of maximum likelihood estimates indicate that the call-drop rate of MTN for every three dropped calls is 7.6%. The call-drop probability rate of Vodafone is 3.3% for every call attempt. The call-drop probability rate of Airtel-Tigo is found to be 3.0% for every call attempt, while the call-drop probability rate of Glo is estimated to be 3.0% for every call attempt.

7. Discussions

The results of the study revealed that although on average, call-drop among the wireless cellular network within the period of the study is high, the call-drop of MTN is found to be higher than the rest of the network. This is not surprising as MTN owns almost 56 percent of the market share of mobile voice (NCA, 2020). Therefore, it is not unexpected that the majority of the call-drops will occur with the network since it has the largest share of subscribers. These results also confirm the findings of (Ngala & Akanbasiam, 2018), who found in their quality of service study among the major mobile network operators (MTN, Vodafone, Tigo, and Airtel) that the average call-drop rate among the MTN network is higher than the rest of the networks. This result could also be one of the reasons for the several complaints against the MTN network by their subscribers.

The results of the Goodness of fit tests – Anderson Darling and Kolmogorov-Smirnov tests have revealed that the call-drop rate of the four major networks (MTN, Vodafone, Airtel-Tigo, and Glo) does not come from a Poisson probability distribution. These results dispute the theoretical claim that call-drop rate follows a Poisson probability distribution function (Tarkaa et al., 2011; Tarkaa & Mom, 2018; Boggia et al., 2005; Boggia et al., 2007). This, therefore, suggests that the probability distribution of call-drop is rather a dynamic one depending on a number of parameters and factors, such as the location or the country of operation of the network, the technological infrastructure of the network, and other network issues. These results also underscore the need for network regulators to ensure that the networks operate within the network policies to provide a better quality of service.

Iraqi and Boutaba (2005) claimed that it is not possible to compute call-drop probability rates based on local information without knowing the specific probability distribution of the call-drop. Hence, one of the objectives of the study was to determine the call-drop probability distribution of the wireless cellular network. The result has indicated that the call-drop rates of the four major networks (MTN, Vodafone, Airtel-Tigo, and Glo) in the country have different probability distributions, confirming the findings of other authors that call-drops have different probability distributions (Aalo & Efthymoglou, 2010; Boggia et al., 2005; Boggia et al.,2007; Fang et al., 1997; Pattaramalai et al., 2007; Erunkulu et al.,2019; Ojuh & Isabona, 2021; Patil, 2016), and that the probability distribution of call-drop is inconclusive (Erunkulu et al., 2019; Tarkaa & Mom, 2018).

The findings of the study revealed that the call-drops of Glo mobile network, Vodafone mobile network, and Airtel-Tigo mobile network follow Geometric probability distribution, suggesting that the subscribers of these wireless cellular networks may have experienced several call-drops within a call-up (Akanbasiam & Ngala, 2017). On the other hand, the findings of the study revealed that the call-drop of the MTN network follows Negative Binomial probability distribution. This indicates that, unlike the other network subscribers, MTN network subscribers may experience several call-drops within several call-ups (Akanbasiam & Ngala, 2017). The Negative Binomial distribution is the generalization of the Geometric probability distribution. Hence, it can be said that the call-drop probability distribution of the MTN network gives a general picture of the problem of call-drop among the wireless cellular networks in Ghana. This claim is supported by the fact that MTN is the most subscribed mobile voice network in Ghana (NCA, 2020).

In terms of the call-drop probability rates among the wireless cellular networks in Ghana, the findings of the study revealed that the call-drop probability rates of all the networks do not fall within the NCA's acceptable call-drop rate of less than 3% (NCA, 2020), hence confirming the findings of Ngala and Akanbasiam (2018). They also found in their study on quality of service among the major mobile network operators that the call-drop of MTN, Vodafone, Tigo, and Airtel, in one of the big cities in Ghana, falls outside the acceptable value of less than 3 percent. Although not in Ghana, Tarkaa and Mom (2018), considering a comparative analysis of call-drop probability due to handover and other factors in Nigeria, also found that the call-drop probability rates of MTN and Glo surpassed the acceptable values. Thus, this result confirms that call-drop is a serious issue among mobile networks in Ghana and other parts of the world.

8. Conclusion and Recommendations

8.1. Conclusion

The authors have been able to estimate the call-drop probability rates of wireless cellular networks in Ghana by using the maximum likelihood estimation method. By finding the call-drop probability distributions of the mobile networks and then finding the maximum likelihood estimates of the probability distributions, the authors have been able to establish that the call-drop probability rates of the wireless cellular networks in Ghana are high, contrary to the NCA's claims (NCA, 2020). The result has therefore confirmed the several complaints by the majority of the subscribers of these networks in Ghana. This approach is found to be another effective method of estimating call-drop probabilities. Contrary to the theoretical claim that call-drop rates follow a Poisson probability distribution, this approach has helped to find out that the call-drop probability distributions of three mobile networks in Ghana – Airtel-Tigo, Vodafone, and Glo, follow a Geometric probability distribution. In contrast, MTN follows a Negative Binomial probability distribution. The results have shown that call-drop probability is sensitive to a number of factors, such as the mobile cellular network.

The results of this study are significant, especially in this era of 3G, 4G, and yet-to-be-implemented 5G networks, where a large number of services that were previously unavailable have been made possible today. This rapid and consistent growth in the cellular industry has profoundly impacted almost every aspect of human (day-to-day) life, including social networking, healthcare, education, transportation, and national security. Hence excessive call-drops with these networks, if not properly determined, will be very detrimental not only to individual Ghanaians but the nation as a whole, including businesses and other essential areas of the economy. This makes the study of this topic very significant in helping to address the issue of call-drop among the wireless cellular networks in Ghana.

8.2. Recommendations

Call-drop probability distributions of the wireless cellular networks have been found in this study to be very important in determining the call-drop rate of wireless cellular networks. The critical role call-drop plays in the performance metrics of wireless cellular networks and user satisfaction with the networks call for more attention to be paid to the findings of this study. Hence the recommendations of this study are crucial for improving the services of wireless cellular networks. To the regulators of the wireless cellular networks, that is, NCA, the findings of the study have indicated that more work needs to be done when it comes to monitoring and evaluating the performance of the networks, as the study has revealed that the call-drop rates of all the wireless cellular networks are above the cut-off points. NCA must task the wireless cellular networks to improve upon their network services. The NCA should apply appropriate sanctions to any network that fails to comply with quality standards. This will help to ensure that call-drops of these are within acceptable standards.

To policymakers, as part of finding a lasting solution to the problem, the network algorithm of wireless cellular networks should be critically examined to ensure that the algorithms do not have these call-drop failures and ping-pong effects. Policymakers should set up an independent body whose job is to review the algorithms of these networks regularly. This will help to deal with the problem of call-drops, and ensure that customers get value for their money. It will also help to ensure that the wireless cellular networks do not take advantage of the system and make a lot of money from providing bad services to customers. They should also find possible means to assist the network operators with enough funds for the state-of-the-art technologies and expansion of their services.

To the wireless cellular network providers, it is recommended that, as a matter of urgency, attention is paid to the improvement of their system, as the degree of switching intent among cellular network users rises proportionately to the frequency of network quality issues experienced. This could even mean reducing the number of subscribers on the network to ensure that existing subscribers are well-catered for and that the system is improved before new ones are enrolled in an expanded system.

9. Potential Future Work and Study Limitations

9.1. Potential Future Work

This is the first time this approach has been used to estimate the call-drop probability rate. Therefore, it is recommended that further research in academia be conducted to explore this approach in estimating call-drop probability rates of wireless cellular networks. Meanwhile, follow-up work is also recommended to determine the effectiveness and efficiency of this approach in estimating call-drop and compare it to the conventional approach of calculating call-drops among wireless cellular networks. The results of the study have given the indication that several factors may be influencing call-drop probability rates among the wireless cellular networks in Ghana. It is recommended that a future study be carried out to examine the potential factors influencing call-drop among wireless cellular networks in Ghana.

9.2. Study Limitations

This study was limited to subscribers of wireless mobile network users in the Greater Accra Region of Ghana. Hence the generalization and interpolation of the findings of the study should be made with caution.

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