Empirical and Statistical Determination of Optimal Distribution Model for Radio Frequency Mobile Networks Using Realistic Weekly Block Call Rates Indicator

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Received: 18 March 2021; Accepted: 10 May 2021; Published: 08 August 2021

Abstract: Mobile phones and handsets enable us to communicate our voice, data and video messages with individuals that are far-off from us. When an active call is initiated by someone using a mobile phone, it is transmitted through a nearby Base Station (BS) transmitter to another BS until the call gets to its intended receiver. Any time a caller initiates and loses a connection to a BS while on conversation, the call is said to be dropped. The initiation and completion of an active call without any form of disconnection or termination is a key service quality parameter in telecommunication system networks. Robust statistical estimation, modelling and characterization of call drop rates is of high importance to the network operators and radio frequency engineers for effective re-planning and performance management process of telecommunication system networks. This work was designed to determine 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. To accomplish the aim, eight probability distributions namely logistic, log-logistic, normal, log-normal, exponential, Rayleigh, rician and Gumbel max were explored and 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 drop call prognostic analysis. The results could be of immense assistance to radio frequency engineers for optimal statistical modelling and design of cellular systems channels.

Index Terms: Block calls, Drop calls, modelling, optimal probability distribution, goodness-of-fit, log-logistic, prognostic analysis

1. Introduction

The telecommunication industrial sector has gone through a remarkable technological growth and advancement over the years, globally. This can be seen in the steady evolution and rolling out of varied cellular radio communication technology such as UMTS (Universal Mobile telecommunication Systems, GSM (Global system for Mobile Communication), LTE (Long Term Evolution) and among others. The deployment and smooth acceptance of these cellular radio communication system networks in our society has also been on the rise daily in the recent years and it keeps rising globally. This has as well been accompanied by large subscription of both personal and commercial subscribers to the various voice, data and video services being offered by the system networks operators or service providers.

As the evolution, deployment and urbane acceptance these different cellular radio communication, systems continuous to grow, complemented with the interminable increase in their service package subscriptions, one important aspect that cannot be overlooked is the level of satisfaction the subscribers obtain from the assorted services network operators to the subscribers. Based on different research studies [1]-[4], it is disclosed that subscribers’ frustration with regard to quality of service (QoS) is the main reason why about 82% of them constantly change network operator or subscribe to more than one operator. One of the foremost problems that leads to mobile subscribers’ complaints and frustration is the problem of call drops while on conversation in cellular radio communication networks. In many
reports, poor network planning, free channels unavailability, high traffic rate, poor antenna engineering configuration, etc., have been identified as the key factors that result to frequent call dropping in cellular communication systems.

2. Literature Review

In literature, different attempts have been adopted to examine and model the rate of call drops in cellular mobile networks, but mostly through theoretical and analytical methods [5]-[14], which are too complex and impracticable to explore during network planning/re-planning phase [15-19]. In [20-29], the authors engaged combined theoretical survey and analytical methods to study wireless network performance using some key performance indicators such as signal quality [20, 21], blocking/dropping probabilities in [22-25], grade of service in [26], traffic delay in [27], outage probability in [28], spectral efficiency in [29], and cell availability in [30], respectively.

The work is proposed to realistically find an optimal reliable statistical distribution model that can characterizes and prognostically analyze the rate of practical drop calls data sample acquired over cellular radio network in the Southern regions of Nigeria.

3. Materials and Methods

Statistical probability distributions are specially formulated distributions by statisticians to mathematically represent or model certain distributional phenomenon. In this work, eight special probability distribution functions (pdfs) and their cumulative distribution functions (cdfs) are explored to model and prognostically characterize the week rate of drop calls acquired over operational cellular mobile radio networks. The eight special probability distributions are logistic, log-logistic, normal, log-normal, exponential, Rayleigh, ician and Gumbel max. The performance of each the eight special probability distributions would be conveyed using goodness of fit (GOF) statistics such as the Kolmogorov Smirnov test, Chi-Square Test and Anderson Test.

3.1 Log-logistic probability Distribution (LLPD)

The LLPD is a robust distribution model whose variables are logistically distributed. The pdf and cdf, mean, mode, variance, skewness and Kurtosis can be expressed by is given by:

\[
f(x) = \frac{\mu x^{\mu-1}}{k^\mu \left(1 + \frac{x}{k}\right)^{\mu+1}}
\]  

(1)

\[
F(x) = \frac{1}{1 + \left[\frac{k}{x}\right]^{\mu}}
\]  

(2)

\[
Mean = k\left(\frac{\pi}{\mu}\right) \csc\left(\frac{\pi}{\mu}\right)
\]  

(3)

\[
Mode = k\left[\frac{\mu - 1}{\mu + 1}\right]^{\frac{1}{\mu}}
\]  

(4)

\[
Variance = k^2\left[\frac{\pi}{\mu}\right] \csc^2\left(\frac{\pi}{\mu}\right) - \frac{\pi}{\mu} \csc^2\left(\frac{\pi}{\mu}\right) - \frac{\pi}{\mu} \csc^2\left(\frac{\pi}{\mu}\right)
\]  

(5)

\[
Skewness = \frac{3 \csc\left(\frac{3\pi}{\mu}\right) - 6 \frac{\pi}{\mu} \csc\left(\frac{2\pi}{\mu}\right) \csc\left(\frac{\pi}{\mu}\right) + 2 \left(\frac{\pi}{\mu}\right)^2 \csc^3\left(\frac{\pi}{\mu}\right)}{\sqrt{2 \csc\left(\frac{2\pi}{\mu}\right) - \frac{\pi}{\mu} \csc^3\left(\frac{\pi}{\mu}\right)}}^{\frac{3}{2}}
\]  

(6)
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Curtosis = \[
\frac{6}{\mu^2} \csc^3 \left( \frac{\pi}{\mu} \right) \sec \left( \frac{\pi}{\mu} \right) + 4 \csc \left( \frac{4\pi}{\mu} \right) - 3 \csc^3 \left( \frac{\pi}{\mu} \right) \csc \left( \frac{3\pi}{\mu} \right) - 12 \csc \left( \frac{\pi}{\mu} \right) \csc \left( \frac{3\pi}{\mu} \right) - 3
\]
\]
where \( \mu \) and \( k \) represent the location and scale parameters.

3.2. Logistic probability Distribution (LPD)

The LPD is a distribution with varied application; it is used for life data analysis, logistic regression analysis and also for growth modeling. The lognormal PDF and CDF can be defined by:

\[
f(x) = \frac{\exp\left(-\frac{x-\mu}{k}\right)}{k \left(1 + \exp\left(-\frac{x-\mu}{k}\right)\right)^2}
\]

\[
F(x) = \frac{1}{1 + \exp\left(-\frac{x-\mu}{k}\right)}
\]

where \( \mu \) and \( k \) represent the location and scale parameters. The variance of the distribution is given by:

\[
\text{Variance} = \frac{k^2 \pi^2}{3}
\]

3.3. Lognormal Distribution Function (LNPD)

The LNPD is also a special distribution is whose random variables with a normally distributed logarithm. The lognormal PDF and CDF can be defined by [31]:

\[
f(x) = \frac{1}{xk\sqrt{2\pi}} \exp\left[-\left(\ln x - \mu\right)^2\right]
\]

\[
F(x) = \frac{1}{2} + \frac{1}{2} \text{erf}\left[\frac{-\left(\ln x - \mu\right)^2}{\sqrt{2k}}\right]
\]

where \( \mu \) and \( k \) represent the location and scale parameters.

3.4. Normal Distribution

The normal distribution remain one of the most applied distribution for data analysis. The normal PDF and PDF can be determine using [31]:

\[
f(x) = \frac{1}{k\sqrt{2\pi}} \exp\left[-\left(x - \mu\right)^2\right]
\]

\[
F(x) = \frac{1}{2} \left[1 + \text{erf}\left(\frac{x - \mu}{k\sqrt{2}}\right)\right]
\]

where \( \mu \) and \( k \) represent the location and scale parameters.

3.5. Gumbel Distribution

The Gumbel distribution, also generally termed the Extreme Value Type I (EV I) distribution, is named in honor of Emil Gumbel. The lognormal pdf and cdf of this distribution can be defined by (Isabona, 2019).
\[ f(x) = \frac{1}{k} \exp\left[\frac{-\left(x - \mu\right)}{k} - \exp\left(-\frac{x - \mu}{k}\right)\right] \]  
\[ F(x) = \exp\left(-\exp\left(-\frac{x - \mu}{k}\right)\right) \]

where \( \mu \) and \( k \) represent the location and scale parameters.

### 3.6. Exponential Distribution

This is one of the most extensively explored continuous distributions, especially for modeling the elapse time between events. The pdf and cdf of exponential distribution can be determined using:

\[ f(x) = \frac{1}{k} \exp\left[-\left(\frac{x - \mu}{k}\right)\right] \]  
\[ F(x) = 1 - \exp\left[-\left(\frac{x - \mu}{k}\right)\right] \]

where \( \mu \) and \( k \) represent the location and scale parameters.

### 3.7. Rayleigh Distribution

The Rayleigh distribution is a popularly used continuous probability distribution and also a special (singular) case of the Weibull distribution. The Rayleigh pdf and cdf are given by [31,32]:

\[ f(x) = \frac{x}{k} \exp\left[-\left(\frac{x^2}{2k^2}\right)\right] \]  
\[ F(x, \sigma) = 1 - \exp\left[-\left(\frac{x^2}{2\sigma^2}\right)\right] \]

where \( \mu \) and \( k \) represent the location and scale parameters.

### 3.8. Nakagami Distribution Function

The Nakagami distribution, another well-known distribution termed the Nakagami-\( m \) distribution, behaves roughly and evenly near its mean value. The Nakagami pdf and cdf can be expressed as [31]:

\[ f(x) = \frac{2^m m^m}{\Gamma(m) \Omega^m} x^{2m-1} \exp\left[-\frac{m}{\Omega} x^2\right] \]  
\[ F(x, m, \Omega) = \frac{Y\left(m, \frac{m}{\Omega} x^2\right)}{\Gamma(m)} \]

In (21), \( \mu \) and \( \sigma \) represent the location and scale distribution parameters for the Nakagami.

### 3.9. Rician Distribution Function

In communication, the Rician distribution functions are usually employed to study stronger line-of-sight fading channels. The Rician PDF and CDF can be expressed as [31]:

\[ f(x) = \frac{x}{k^2} \exp\left[-\frac{x^2 + \nu^2}{2k^2}\right] I_0\left(\frac{x\nu}{k^2}\right) \]
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\[ F(x) = 1 - Q_1\left(\frac{v}{k}, \frac{x}{k}\right) \]  

(24)

In (23), \( \mu \) and \( k \) represent the location and scale distribution parameters for the Rician, where \( I_v(z) \) and \( Q_1(z) \) represent the modified Bessel function and Marcum Q function, respectively.

4. Results and Analysis

The five weeks drop call rate data explored for this study was obtained from the Radio network controller (RNC) stations of an operative GSM/UMTS system networks service provider operating Southern Nigeria. The number of NodeBs transceivers engaged in the data collection were 120.

The results in Table 1 contain the weekly call drop statistics at a glance using EasyFit 5.6 Software. The graphics were also done using the EasyFit 5.6 Software. The results reveal that the table that the mean drop call rates ranges from 0.75 to 0.33 values, which are all within the 5% (0.02) threshold for GSM/UMTS networks.

To determine the optimal probability distribution model for weekly drop call rates data, we explored three goodness of fit (GOF) statistical tools such as the Kolmogorov Smirnov test, Chi-Square Test and Anderson Test. Tables 2 (a) - 6 (a), show the goodness of fit results using Kolmogorov Smirnov test, Anderson test and Chi-square test.

The results in Tables 2 (b) - 6 (b), the log-logistic distribution was found to be the optimal probability distribution for the weekly rate of drop call prognostic analysis. For the purpose of visibility, the respective plotted pdf and cdf graphs using the log-logistic distribution are shown in Figs. 1 (a)-5(a) and Figs.1 (b)-5(b).

Table 1. Results of the weekly call drop rate statistics at a glance

| Statistic       | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 |
|-----------------|--------|--------|--------|--------|--------|
| Mean            | 0.46   | 0.33   | 0.37   | 0.73   | 0.72   |
| Variance        | 0.85   | 0.61   | 0.88   | 5.07   | 2.98   |
| Std. Deviation  | 0.92   | 0.78   | 0.94   | 2.25   | 1.72   |
| Range           | 4.75   | 3.30   | 5.34   | 14.08  | 9.55   |
| Coef. of Variation | 1.97 | 2.33   | 2.52   | 3.07   | 2.39   |
| Std. Error      | 0.13   | 0.11   | 0.13   | 0.32   | 0.24   |
| Skewness        | 3.11   | 3.17   | 3.89   | 4.99   | 3.51   |
| Excess Kurtosis | 10.63  | 9.38   | 17.25  | 27.59  | 14.35  |

Table 2 (a): Goodness of Fit tests on week 1 call drop rates

| Week 1              | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|---------------------|-------------------------|---------------|-----------------|
| Logistic            | 0.28484                 | 7.4128        | 15.744          |
| Log-logistic        | 0.12245                 | 9.0142        | 1.252           |
| Normal              | 0.30588                 | 7.7838        | 13.744          |
| Log-normal          | 0.15962                 | 10.445        | 9.2907          |
| Gumbel              | 0.34077                 | 6.1854        | 7.5814          |
| Exponential         | 0.35526                 | 40.125        | 38.002          |
| Rayleigh            | 0.5252                  | 83.414        | 76.755          |
| Rician              | 0.62478                 | 132.83        | 122.31          |

Table 2 (b): Goodness of Fit tests score on week 1 call drop rates

| Week 1           | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|------------------|-------------------------|---------------|-----------------|
| Logistic         | 33                      | 7             | 35              |
| Log-logistic     | 1                       | 13            | 3               |
| Normal           | 35                      | 10            | 32              |
| Log-normal       | 7                       | 26            | 28              |
| Gumbel           | 38                      | 5             | 22              |
| Exponential      | 42                      | 44            | 41              |
| Rayleigh         | 46                      | 46            | 43              |
| Rician           | 48                      | 48            | 45              |
Table 3 (a): Goodness of Fit tests on week 2 call drop rates

| Week 2          | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|-----------------|-------------------------|---------------|-----------------|
| Logistic        | 0.33418                 | 9.9241        | 19.314          |
| Log-logistic    | 0.06508                 | 5.1312        | 1.2203          |
| Normal          | 0.3343                  | 10.378        | 19.63           |
| Log-normal      | 0.10735                 | 5.4515        | 1.8956          |
| Gumbel          | 0.37833                 | 0.37833       | 12.543          |
| Exponential     | 0.42531                 | 30.46         | 60.754          |
| Rayleigh        | 0.5986                  | 95.112        | 93.75           |
| Rician          | 0.70252                 | 153.21        | 153.6           |

Table 3 (b): Goodness of Fit tests score on week 2 call drop rates

| Week 2          | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|-----------------|-------------------------|---------------|-----------------|
| Logistic        | 33                      | 29            | 30              |
| Log-logistic    | 1                       | 4             | 4               |
| Normal          | 32                      | 32            | 21              |
| Log-normal      | 15                      | 11            | 9               |
| Gumbel          | 37                      | 27            | 27              |
| Exponential     | 41                      | 40            | 37              |
| Rayleigh        | 44                      | 44            | 39              |
| Rician          | 45                      | 45            | 40              |

Table 4 (a): Goodness of Fit tests on week 3 call drop rates

| Week 3          | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|-----------------|-------------------------|---------------|-----------------|
| Logistic        | 0.3613                  | 9.7808        | 18.942          |
| Log-logistic    | 0.20945                 | 12.255        | 13.424          |
| Normal          | 0.34836                 | 10.016        | 19.914          |
| Log-normal      | 0.21815                 | 12.772        | 13.081          |
| Gumbel          | 0.39366                 | 8.7466        | 12.774          |
| Exponential     | 0.48273                 | 75.936        | 60.40           |
| Rayleigh        | 0.66823                 | 140.72        | 119.63          |
| Rician          | 0.73453                 | 217.86        | 153.6           |

Table 4 (b): Goodness of Fit tests score on week 3 call drop rates

| Week 3          | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|-----------------|-------------------------|---------------|-----------------|
| Logistic        | 31                      | 7             | 32              |
| Log-logistic    | 6                       | 13            | 20              |
| Normal          | 30                      | 9             | 34              |
| Log-normal      | 20                      | 21            | 17              |
| Gumbel          | 36                      | 5             | 14              |
| Exponential     | 42                      | 1             | 44              |
| Rayleigh        | 47                      | 48            | 44              |
| Rician          | 48                      | 49            | 45              |

Table 5 (a): Goodness of Fit tests on week 4 call drop rates

| Week 4          | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|-----------------|-------------------------|---------------|-----------------|
| Logistic        | 0.36322                 | 11.101        | 23.456          |
| Log-logistic    | 0.2500                  | 13.027        | 10.555          |
| Normal          | 0.37251                 | 11.492        | 21.645          |
| Log-normal      | 0.29769                 | 17.443        | 19.756          |
| Gumbel          | 0.42655                 | 10.36         | 13.982          |
| Exponential     | 0.49057                 | 118.68        | 72.938          |
| Rayleigh        | 0.66207                 | 134.12        | 118.1           |
| Rician          | 0.78421                 | 245.16        | 173.4           |
Table 5 (b): Goodness of Fit tests score on week 4 call drop rates

| Distribution  | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|----------------|-------------------------|---------------|-----------------|
| Logistic       | 31                      | 6             | 34              |
| Log-logistic   | 6                       | 14            | 22              |
| Normal         | 34                      | 10            | 29              |
| Log-normal     | 12                      | 22            | 22              |
| Gumbel         | 40                      | 4             | 10              |
| Exponential    | 41                      | 46            | 39              |
| Rayleigh       | 47                      | 44            | 43              |
| Rician         | 48                      | 48            | 42              |

Table 6 (a): Goodness of Fit tests on week 5 call drop rates

| Distribution  | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|----------------|-------------------------|---------------|-----------------|
| Logistic       | 0.34596                 | 9.7407        | 18.87           |
| Log-logistic   | 0.30612                 | 14.559        | 15.011          |
| Normal         | 0.3536                  | 10.011        | 19.52           |
| Log-normal     | 0.35748                 | 20.942        | 34.39           |
| Gumbel         | 0.40295                 | 8.9953        | 12.523          |
| Exponential    | 0.52399                 | 167.23        | 90.816          |
| Rayleigh       | 0.73547                 | 249.21        | 158.4           |
| Rician         | 0.73547                 | 249.21        | 158.4           |

Table 6 (b): Goodness of Fit tests score on week 5 call drop rates

| Distribution  | Kolmogorov Smirnov test | Anderson Test | Chi-Square Test |
|----------------|-------------------------|---------------|-----------------|
| Logistic       | 13                      | 5             | 11              |
| Log-logistic   | 6                       | 13            | 9               |
| Normal         | 15                      | 7             | 12              |
| Log-normal     | 17                      | 30            | 21              |
| Gumbel         | 33                      | 3             | 7               |
| Exponential    | 43                      | 45            | 37              |
| Rayleigh       | 48                      | 48            | 41              |
| Rician         | 49                      | 49            | 40              |

Fig.1. Pdf of drop call rates in week 1
Fig. 2. Pdf of drop call rates in week 2.

Fig. 3. Pdf of drop call rates in week 3.

Fig. 4. Pdf of drop call rates in week 4.
Fig. 5. Pdf of drop call rates in week 5.

Fig. 6. cdf of drop call rates in week 1.

Fig. 7. cdf of drop call rates in week 2.
Fig. 8. cdf of drop call rates in week 3.

Fig. 9. cdf of drop call rates in week 4.

Fig. 10. cdf of drop call rates in week 5.

5. Conclusion

The design, analysis and characterization of operational cellular communication system networks performance via realistic modeling and evaluation, also aid their effective network re-planning and performance management process.

This work was designed to determine the optimal probability distribution model for effective drop call rates analysis and characterization based on a five week acquired rate of drop calls data sample in the Southern regions of Nigeria. To accomplish the aim, eight different probability distributions namely logistic, log-logistic, normal, log-normal, exponential, Rayleigh, rician and Gumbel max were explored for drop call rates analysis and characterization. From the results, the profound performance of the log-logistic probability distribution over others is clearly shown. The results are conveyed using goodness of fit (GOF) statistics, after applying these distributions to a week call drop rates data obtained over GMS/WCDA cellular radio networks.
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How to cite this paper: Divine O. Ojuh, Joseph Isabona,” Empirical and Statistical Determination of Optimal Distribution Model for Radio Frequency Mobile Networks Using Realistic Weekly Block Call Rates Indicator ’’, International Journal of Mathematical Sciences and Computing(IJMSC), Vol.7, No.3, pp. 12-23, 2021. DOI: 10.5815/ijmsc.2021.03.02