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Modelling based Quantitative Assessment of Operational LTE Mobile Broadband Networks Reliability: a Case Study of University Campus Environ

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Abstract: *Reliability is key quality attribute that is of great interest to telecom operators, systems radio frequency engineers and users. Hence, accurate estimation of reliability parameters are useful for modelling, designing and managing of cellular mobile system network resources. In this research, a 2-parameter Weibull distribution model is employed to quantitatively estimate the reliability of LTE mobile broadband networks performance in a typical campus environment using Federal University of Lokoja as a case study.The results obtained across the three indoor and outdoor study locations are reported graphically and quantifiably. For example, whereas 52.91% and 53.26% reliability performance are attained in location 1, location 2 and 3 attained 52.97%, 54.74% and 54.42%, 49.85% respectively, in indoor and outdoor locations. In terms of failure rate, whereas 20.25% and 21.73% reliability performance are attained in location 1, location 2 and 3 attained 19.14%, 23.32% and 24.30%, 18.83% respectively, in indoor and outdoor locations. For mean time to failure, while 20.59 and 19.31 reliability performance are attained in location 1, location 2 and 3 attained 20.47, 24.14 and 20.30, 18.83 respectively, in indoor and outdoor locations.Thehigh variance range of 9.98-38.22 estimates realized across study locations also clearly indicated that the studied LTE system networks needs urgent performance maintenance and optimisation.*

Keywords: *LTE networks, Reliability, Failure rate, Broadband Networks, Weibull distribution.*

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I. Introduction

Reliability is a key engineering indicator for describing the performance of a system or a product by means of probability functions (Isabona and Olayinka, 2013; Isabona, 2014; Isabona and Srivastava, 2017; Igbinovia and Isabona, 2018). The words ‘‘quality’’ and ‘‘reliability’’ are often utilize interchangeably. However, these two terms differ in meaning: quality expresses the performance of a system at a particular point in time, whereas reliability is concerned with the probability that a system is capable of performing its premeditated desired functions through a specified time under certain given conditions. Also, reliability testing procedures are usually more complex compared to quality testing procedures. Nonetheless, reliability testing and quality testing both measure the “goodness” of a system. Besides, system reliability hinge on the initial system quality.

Several works have been carried out in literature regarding reliability study of a product or systems using different statistical probability distributions functions based parameter estimators. For instance, Bartkute and Sakalauskas (2008) explored improved analytical algorithms with a three-parameter Weibull distribution function to estimate the reliability a non-censored sample. However, the author’s procedure lacks information on how to perform reliability analysis using complete data. Singh, et al (2005) studied the point estimators by means of a three-parameters for Exponential Weibull distribution with complete data and type II censored data. Numerical comparative results were achieved for the point estimators.

Luus and Jammer (2005), comparative estimation of Weibull distribution for the errors-in-variables, combined with maximum likelihood and least squares. The authors concluded that MLE provided the most consistent parameter estimates when compared with the results obtained using errors-in-variables approach. Markovic*et al.* (2009) also examined different types of least-squares estimators in comparison with a three parameter Weibull distributions for a complete sample. Nagatsuka (2008) presented a least squares estimation (LSE) study based on double Type-II censored samples. In Cousineau (2009), weighted MLEs which are nearly unbiased estimators is proposed.

Jin et al. (2012) propose an innovative reliability estimation framework by employing physics of failure based approach. The authors concluded by providing the relationship that exist between the physics performance and its failure mechanisms. Also, by means of failure model, Jin et al. (2013) came up with life prediction technique suitable for a momentum wheel in a dynamic covariate environment. Product reliability analysis using Alsalam Cement Factory industry as a case study is contained in (Atta-Elmanan and Mohammed, 2015), using Weibull distribution function.

In (Dumitrascu et al, 2018), the authors conducted a reliability estimation study of Towed Grader Attachment utilizing Weibull distribution, point estimation, Finite Element Analysis and other probability distribution functions.

In this work, a 2-parameter Weibull distribution model is employed to estimate the reliability performance of LTE mobile broadband networks in campus environment using Federal University of Lokoja as a case study.

II. Materials and Method

2.1 Probability Distribution Functions

The fundamental theories of reliability engineering are expressed using probability or probabilistic parameters such as random variables, density functions, and distribution functions.

Probability distributions have been formulated by statisticians, mathematicians, physics and engineers to mathematically model or represent certain behavior. The probability density function (*pdf*) is a mathematical function that describes the distribution. The *pdf* can be represented mathematically or on a plot where the x-axis represents time. There exist a number of probability distribution functions for describing and fitting a statistical distribution to life reliability data. Some of the key ones are presented below

2.2 Normal Distribution Function

The normal distribution possess key two distribution parameters. The first parameter is tagged the mean (μ), and the second one is called the standard deviation (σ) or the variance (σ^2). The normal PDF and PDF can be determine using (Isabona, 2019):

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

$$F(x,\mu,\sigma) = \frac{1}{2}\left[1 + erf\left(\frac{(x-\mu)}{\sigma\sqrt{2}}\right)\right] \quad (2)$$

The maximum likelihood estimators for the normal distribution are the μ and σ; they can be obtained using the expression in (3) and (4):

$$\mu = \frac{1}{N}\sum_{i=1}^{N}(x_i) \quad (3)$$

$$\sigma = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu_i)^2 \quad (4)$$

where x and N indicate the measured sample and the measurement sample number.

2.3 Lognormal Distribution Function

The lognormal distribution, also generally termed Galton or Gaussian distribution, is applicable the desired quantity of interest must be positive. The lognormal PDF and CDF can be defined by (Isabona, 2019)

$$f(x,\mu,\sigma) = \frac{1}{x\omega\sqrt{2\pi}} \exp\left[\frac{-(\ln x-\mu)^2}{2\omega^2}\right] \quad (5)$$

$$F(x,\mu,\sigma) = \frac{1}{2} + \frac{1}{2} erf\left[\frac{-(\ln x-\mu)^2}{\sqrt{2}\omega}\right] \quad (6)$$

In (6), μ and ω maximum likelihood estimators and they represent the shape and scale distribution parameters for the lognormal. The mean and standard deviation for lognormal can be expressed as:

$$\mu = \exp\left(\mu + \frac{\omega^2}{2}\right) \quad (7)$$

$$\sigma = \exp(2\mu + \omega^2)[\exp(\omega^2) - 1] \quad (8)$$

where x stands for the measured sample.

2.4 Rayleigh Distribution Function

The Rayleigh distribution is a continuous probability distribution and also a special (singular) case of the Weibull distribution. The Rayleigh PDF and CDF are given by (Isabona, 2019):

$$f(x,\sigma) = \frac{x}{\sigma}\exp\left[-\left(\frac{-x^2}{2\sigma^2}\right)\right] \quad (9)$$

$$F(x,\sigma) = 1 - \exp\left[-\left(\frac{-x^2}{2\sigma^2}\right)\right] \quad (10)$$

The distribution parameters, μ and σ_m can be obtained the expressions in (11) and (12) respectively:

$$\mu = \sigma\sqrt{\frac{\pi}{2}} \quad (11)$$

$$\sigma_m = \sigma\sqrt{\frac{4-\pi}{2}} \quad (12)$$

where x stands for the measured sample.

2.5Nakagami Distribution Function

The Nakagami distribution, also popularly termed the Nakagami-*m* distribution behave roughly and evenly near its mean value. The Nakagami PDF and CDF can expressed as (Isabona, 2019):

$$f(x,m,a) = \frac{2m^m}{\Gamma(m)a^m}x^{2m-1}\exp\left[-\frac{m}{a}x^2\right] \quad (13)$$

$$F(x,m,\Omega) = \frac{Y\left(m,\frac{m}{a}x^2\right)}{\Gamma(m)} \quad (14)$$

In (15), μ and ω represent the shape and scale distribution parameters for the Nakagami. The mean and standard deviation for Nakagami can be expressed as:

$$\mu = \frac{\Gamma\left(m+\frac{1}{2}\right)}{\Gamma(m)}\left(\frac{a}{m}\right)^{1/2} \quad (15)$$

$$\sigma = \sqrt{a\left(1-\frac{1}{m}\left(\frac{\Gamma\left(m+\frac{1}{2}\right)}{\Gamma(m)}\right)^2\right)} \quad (16)$$

where x stands for the measured sample.

2.6Rician Distribution Function

In communication, the Rician distributions functions are usually employed to study stronger line-of-sight fading channels. The Rician PDF and CDF can expressed as (Isabona, 2019):

$$f(x,v,\sigma) = \frac{x}{\sigma^2}\exp\left[\left(\frac{-x^2+v^2}{2\sigma^2}\right)I_o\left(\frac{xv}{\sigma^2}\right)\right] \quad (17)$$

$$F(x,v,\sigma) = 1 - Q_1\left(\frac{v}{\sigma},\frac{x}{\sigma}\right) \quad (18)$$

In (18), μ and ω represent the shape and scale distribution parameters for the Rician. The mean and standard deviation for Rician can be expressed as:

$$\mu = \sigma\sqrt{\frac{\pi}{2}}L_{1/2}\left(\frac{-v^2}{2\sigma^2}\right) \quad (19)$$

$$\sigma = 2\sigma^2 + v^2 - \frac{\pi\sigma^2}{2} L_{1/2}^2\left(\frac{-v^2}{2\sigma^2}\right) \quad (20)$$

where x stands for the measured sample. $I_o(z)$ and $Q_1(z)$ represent the modified Bessel function and Marcum Q function, respectively.

2.7 Weibull Distribution Function

The choice distribution function for this work is the Weibull distribution. This is due to itsability to provide reasonably accurate failure analysis, and reliability forecasts with extremely small samples (Ng, 2012, Isabona, 2019). This distribution function is named after his discoverer, WaloddiWeibull, a Swedish physicist who utilize it in 1939to perform the modelling of breaking strength distribution of materials (Weibull, 1939). Since that time it was initiated by the author till now, its applications in physics, statistics, mathematics and engineering increased significantly.

In literature, there exist different forms of Weibull distribution functions. In this work, our concern is on 2-parameter weibull distribution function and its parametric features are shown in table 1. The Weibull PDF and CDF can be defined by (Isabona, 2019):

$$f(x,\lambda,c) = \frac{c}{\lambda}\left(\frac{x}{\lambda}\right)^{c-1} \exp\left[-\left(\frac{x}{\lambda}\right)^c\right] \quad (21)$$

$$F(x,\lambda,c) = 1 - \frac{c}{\lambda}\left(\frac{x}{\lambda}\right)^{c-1} \exp\left[-\left(\frac{x}{\lambda}\right)c\right] \quad (22)$$

The distribution parameters, μ and σ can be obtained by the expressions in (23) and (24) respectively:

$$\mu = \lambda\Gamma\left(1 + \frac{1}{c}\right) \quad (23)$$

$$\sigma = \sqrt{\lambda^2\Gamma\left(1 + \frac{2}{c}\right) - \left[\Gamma\left(1 + \frac{1}{c}\right)\right]^2} \quad (24)$$

where x stands for the measured sample.

The shape parameter, *c* is one of the key parameters for interpreting a given system dataset characteristics that has been assumed to follow a Weibull distribution model (Scholz, 2008). For instance, when *c* <1, the part or system has better chance of surviving over a period of time. For *c* >1 the system has lesser chance of surviving over a period of time. It also implies that system has a higher chance of failing over a period of time or during the next small time increment. Rate of system failure therefore increases when *c* >1, decreases when *c*<1 and is constant when *c* =1

Table 1: Specific Life Characteristics for Weibull Distribution

$Weibull: f(x,\lambda,c) = \frac{c}{\lambda}\left(\frac{x}{\lambda}\right)^{c-1} \exp\left[-\left(\frac{x}{\lambda}\right)^c\right]$		
Life Characteristics	Notation	Formula
Proportion of system failing before time	$F(x,\lambda,c)$	$F(x,\beta,\eta) = 1 - \exp\left[-\left(\frac{x}{\lambda}\right)^c\right]$
Reliability	$\Pr = 1 - F(x,\lambda,c)$	$\Pr = \exp\left[-\left(\frac{x}{\lambda}\right)^c\right]$
Mean time to failure (MTTF)	$E(x,\lambda,c)$	$E(x,\lambda,c) = \lambda\Gamma\left(1 + \frac{1}{c}\right)$
Hazard rate function (Failure rate)	$h(x,\lambda,c)$	$h(x,\lambda,c) = \frac{c}{\lambda}\left[\left(\frac{x}{\lambda}\right)^{c-1}\right]$

2.8 Maximum Likelihood Method

Basically, there exist two realistic fitting techniques for parameter estimation in reliability analysis. They are regression estimation (RE) techniques and maximum likelihood estimation (MLE) techniques. The RE technique consist of finding the connection between a dependent variable and independent variable (s). The RE process mostly works best with smaller and complete data sample sizes. . MLE entails using of a likelihood function and looking out for the values of the parameter estimates that robustly maximize the likelihood function based on the available data. MLE is particularly used by researchers for parameter estimation due to its straightforward application procedures and most probable desirable key features (Isabona, 2018).
Accordingly, in this work, the focus is onMLE techniques. The specific aim is to employ the robust parameter estimation techniques of MLE to statically study the reliability of operational LTE network system.

Let $x_1, x_2, x_3,\ldots.. x_n$ be a set of statistically measurable random numbers of trials or failure times of *n* links" connected to a probability distribution function, $f(x,q)$, where q is an undisclosed parameter. The corresponding likelihood function, L of the independent random sample number can be defined as:

$$L = \prod_{i=1}^{n} f_{xi}(x_i, q) \quad (25)$$

In terms Weibull distribution model, the expression in equation (1) can be rewritten as

$$L(\mathrm{x}_1,..x_n;c,\lambda,),,,\ldots..=\prod_{i=1}^{n}\left(\frac{c}{\lambda}\right)\left(\frac{x_i}{\lambda}\right)^{c-1}\exp\left[-\left(\frac{x_i}{\lambda}\right)^{c}\right] \quad (26)$$

where λ and c signify the shape and scale distribution parameters for the Weibull.

III. Location of Study

This study took place inside six locations in Federal University. The Federal University, Lokoja, popularly known as Fulokoja, is a federal university in the confluence city of Lokoja, the capital of Kogi State, North-Central Nigeria. Lokoja lies at the confluence of the Niger and Benue rivers. The section of the map of the university is displayed is figure 1.

The first two locations where data collection place inside the university are inside and outside Physics laboratory. The second two locations are inside and outside university auditorium. The third two locations are inside and outside ASSU building

Figure 1: A Maps showing a snappy section of Federal University Lokoja, Adamkolo Campus

3.1 Method of Data Collection

This research work employsSamsung Galaxy S4 GT-I9505 phone-based walk testing system. It is a TEMS pocket Phone-based testing technique for measuring and analyzing the end-user experience in terms of service quality while using the network (Joseph and Konyeha, 2013, Isabona and Azi, 2013; Isabona and Ojuh, 2014; Isabona and Odion, 2015). Before employing phone-based drive testing systems, two important software, namely, network signal info and cellular Z, were installed inSamsung Galaxy S4 GT-I9505.Thisis this enable one measure and obtain valuable information from LTE cellular network around the measurement location. Such network measurement process is called walking testing. Specially, while the network signal info was used for taking user measurement locations in terms of longitude and latitude, and as well as for obtaining the user measurement distance from the transmitter location, cellular Z was employed for measuring the LTE signal coverage and service quality parameters. These parameters are often called Key Performance Indicators (KPIs). By means of the Cellular Z, the measured signal coverage and quality of service parameters were obtained each measurement location and transferred to an established email for storage. The measured network data were later extracted into Microsoft excel spread sheet and Matlab for further processing. The walk tests were performed in Lokoja over a couple of weeks, during the months of May and June of 2019, and over a range of times. Measurements were taken in three locations in Federal University. The summary of steps employed for the Phone-based walk testing are provided below in section 3.2.Similar process has been employed in (Isabona, 2014).

3.2 Walk Test Procedure

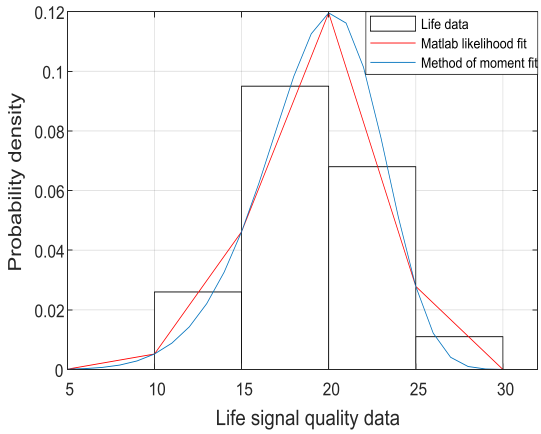
1. Select a test location and measurement route
2. Obtain the longitude and latitude of measurement location.
3. Obtain the serving base station (i.e., eNodeB) distance from the user equipment location
4. Establish an LTE network connection and take measurement.
5. Transfer measurement result to the user established email.
6. Check if the transferred measured data has been transferred successfully to the email before taking the next measurement
7. Complete testing.

IV. Results and Discussion

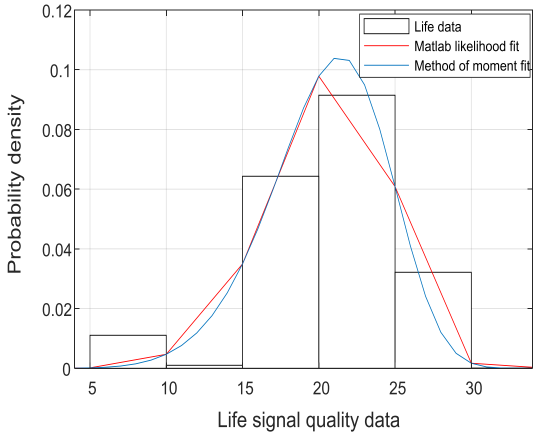
This section present the results and discussion of the work carried out to assess the reliability of an operational commercial LTE network operator transmitting at 800 MHz ultra-high frequency band provision in Federal University, Lokoja. The reliability program scripts, its implementation and graphics were all actualized in Matlab 2018a software/platform. The applied matlab scripts are presented in the appendix section.

4.1 Results

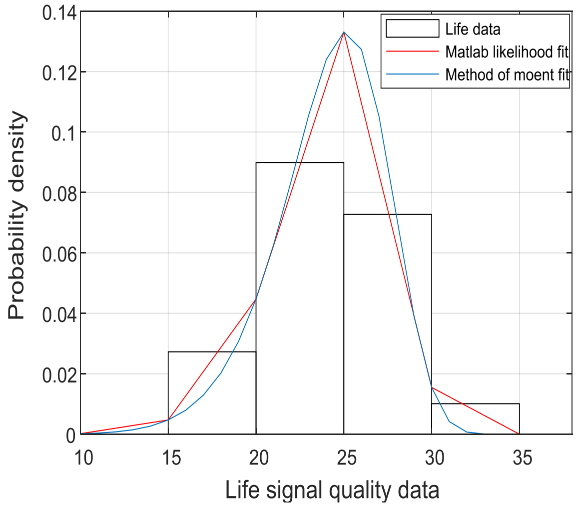
Figures 3 to 5 are displayed to show the probability distribution plots obtained from three location of the studied LTE system network reliability performance using a 2-parameter Weibull distribution function in matlab platform. Table 2 to 4 are displayed to show the results summary obtained using the 2-parameter Weibull distribution.



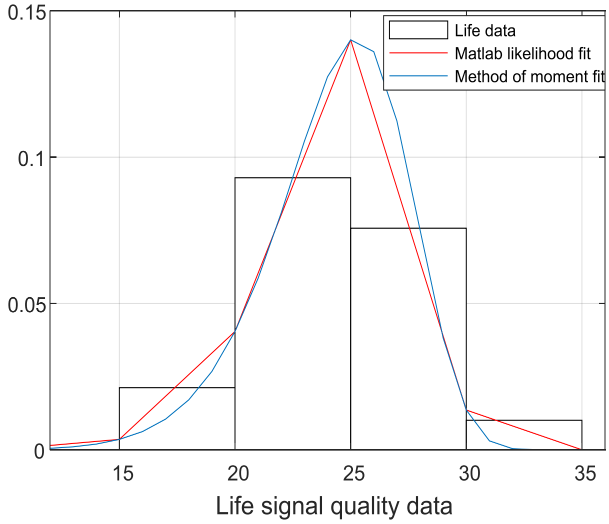
Figures 3 (a): Probability distribution of LTE signal quality data in location 1(indoor)



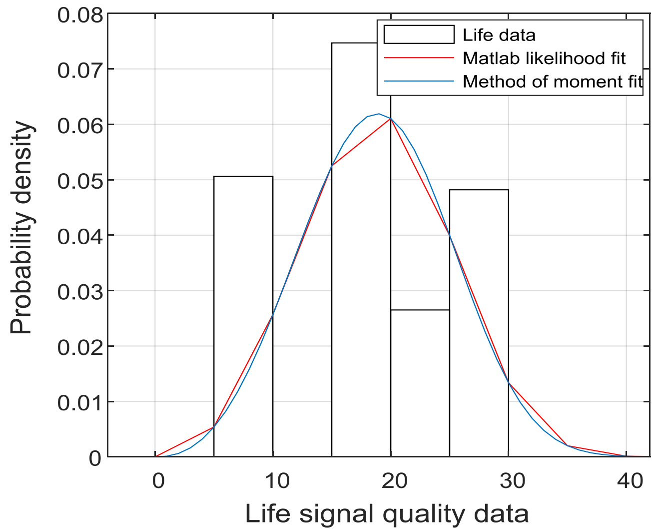
Figures 3(a): Probability distribution of LTE signal quality data in location 1(outdoor)



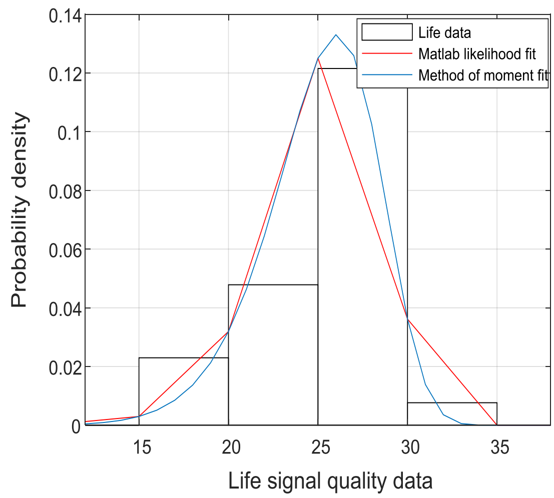
Figures 4(a): Probability distribution of LTE signal quality data in location 2 (indoor)



Figures 4 (b): Probability distribution of LTE signal quality data in location 2 (outdoor)



Figures 5 (a): Probability distribution of LTE signal quality data in location 3 (indoor)



Figures 5 (b): Probability distribution of LTE signal quality data in location 3(outdoor)

Table 2: Reliability parameter estimates using in location 1using Weibull distribution

Life Characteristics	Notation	Result (indoor)	Result (outdoor)
Proportion of system failing before time	$F(x,\lambda,c)$	0.4709	0.4674
Reliability	$\Pr = 1 - F(x,\lambda,c)$	0.5291	0.5326
Failure rate	$h(x,\lambda,c)$	0.2025	0.2173
Mean time to failure (MTTF)	$E(x,\lambda,c)$	19.11	19.31
Beta (Shape parameter)	c	6.08	6.66
Lamda (Scale parameter)	λ	20.59	19.31
Variance	V	11.54	14.96

Table 3: Reliability parameter estimates using in location 2PWeibull distribution

Life Characteristics	Notation	Result (indoor)	Result (outdoor)
Proportion of system failing before time	$F(x,\lambda,c)$	0.4703	0.4526
Reliability	$\Pr = 1 - F(x,\lambda,c)$	0.5297	0.5474

Failure rate	$h(x, \lambda, c)$	0.1914	0.2332
Mean time to failure (MTTF)	$E(x, \lambda, c)$	20.47	24.14
Beta (Shape parameter)	c	6.16	9.16
Lamda (Scale parameter)	λ	20.03	25.47
Variance	V	9.93	8.98

Table 4: Reliability parameter estimates using in location 5 3P Weibull distribution

Life Characteristics	Notation	Result (indoor)	Result (outdoor)
Proportion of system failing before time	$F(x, \lambda, c)$	0.4558	0.5075
Reliability	$\Pr = 1 - F(x, \lambda$	0.5442	0.4985
Failure rate	$h(x, \lambda, c)$	0.2439	0.1442
Mean time to failure (MTTF)	$E(x, \lambda, c)$	20.30	18.83
Beta (Shape parameter)	c	9.74	3.35
Lamda (Scale parameter)	λ	25.27	20.97
Variance	V	38.22	10.01

4.2. Discussion

The results summary in tables 4.1 to 4.4 indicate a poor reliability performance across the three indoor and outdoor study locations. For example, whereas 52.91% and 53.26% reliability performance are attained in location 1, location 2 and 3 attained 52.97%, 54.74% and 54.42%, 49.85% respectively, in indoor and outdoor locations.

In terms of failure rate, whereas 20.25% and 21.73% reliability performance are attained in location 1, location 2 and 3 attained 19.14%, 23.32% and 24.30%, 18.83% respectively, in indoor and outdoor locations.

For mean time to failure, while 20.59 and 19.31 reliability performance are attained in location 1, location 2 and 3 attained 20.47, 24.14 and 20.30, 18.83 respectively, in indoor and outdoor locations.

Another important parameter to about from the results summary in table 4.1 to 4.3 is the shape parameter, *c*. As earlier mentioned, If $c = 1$, there is a constant failure rate and If $c > 1$, there is an increasing failure rate. The results in tables 4.1 to 4.3 clearly indicate increasing failure rates in all the indoor and outdoor study location. For instance, while 6.08 and 6.66 are attained as the estimated shape parameter value in location 1, location 2 and 3 attained 6.16, 9.16 and 9.74, 3.35 respectively, in indoor and outdoor locations. These values of estimated shape parameters (i.e. all greater $c > 1$) clearly implies that the study system broadband LTE network is wearing out greatly, thus calling urgent attention for maintenance and optimisation. High variance range of 9.98-38.22 estimates realized across study locations also clearly indicated that the studied LTE system networks needs urgent performance maintenance and optimisation

V. Conclusion

Most telecom network operators in Nigeria are faced with challenges of achieving robust cellular network design and high service quality provision to subscribers; and all stake holders including the academic research community, the telecom operators and the Nigeria government must be involve in tackling the ugly challenges.

In this work, measurement, modelling and analysis of reliability of the mobile network system contingent on the quality of service provision by a commercial LTE network operator transmitting at 800 MHz ultra-high frequency band is presented using Federal university Lokoja, Kogi State Nigeria as a case study.

This work also explores a 2-parameter Weibull distribution model to estimate the reliability performance of LTE mobile broadband networks in a typical campus environment using Federal University of Lokoja as a case study

The results indicate a poor reliability performance across the three indoor and outdoor study locations. For example, whereas 52.91% and 53.26% reliability performance are attained in location 1, location 2 and 3 attained 52.97%, 54.74% and 54.42%, 49.85% respectively, in indoor and outdoor locations. In terms of failure rate, whereas 20.25% and 21.73% reliability performance are attained in location 1, location 2 and 3 attained

19.14%, 23.32% and 24.30%, 18.83% respectively, in indoor and outdoor locations. For mean time to failure, while 20.59 and 19.31 reliability performance are attained in location 1, location 2 and 3 attained 20.47, 24.14 and 20.30, 18.83 respectively, in indoor and outdoor locations.

The high variance range of 9.98-38.22 estimates realized across study locations also clearly indicated that the studied LTE system networks needs urgent performance maintenance and optimisation

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