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A 4G LTE Evolved packet Core Planning and Deployment in Freetown Sierra Leone

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Abstract: Wireless broadband subscribers have tripled in the past two decades in the world. It subsequently adds more burden on the network traffic, thereby pressuring the current 2G / 3G wireless network infrastructural development in Freetown, Sierra Leone. The existing 2G / 3G network infrastructures in Freetown offer limited resources for download and upload speed of 12.54Mbps and 2.59Mbps, respectively, to active subscribers. The exponential increase in the country's population has adverse effects on the subscriber's database. Therefore, a considerable task is faced by the country's telecommunication network infrastructures to devise an improvement and efficient technologies to augment the current system to handle the numerous issues. Three active private mobile network operators (X, Y, & Z) and one Government-owned operator (W) exist in the country. The only operator that runs across the country is operator X, and it has the highest number of subscribers. The country has just rollout it Long Term Evolution (LTE) by the private MNOs.

The research is to encourage the Sierra Leone National Telecommunication Commission (NATCOM), a telecommunication regulatory body, to mandate all MNOs in the country to roll out the 4G LTE core network infrastructure in Freetown. ARIMA model is used to analyze the throughputs (kbps) prediction to ascertain 4G LTE rollout using the Python programming language is an effective alternative. Statistical data from operator X for ten years for Freetown municipality from January 2010 - November 2019 was collected. The research concludes that 4G LTE deployment or upgrade was necessary for the Freetown municipality.

Keywords: 4G Long Term Evolution (LTE), ARIMA Model, Evolved Packet Core (EPC), Short-Term, and Long-Term Predictions.

Introduction

Long Term Evolution (LTE) is the successor to the third edition (3G), its standard adopted by the "3rd Generation Partnership Project (3GPP)", based on technical specification, eighth edition. Upgrading the "Universal Mobile Telecommunications System (UMTS)" to match the "Advanced International Mobile Telecommunications (IMT-A)" standard recognized by the "International Telecommunication Union (ITU)" is fourth-generation (4G) target (Geography of Sierra Leone, 2018). LTE serves as a new broadband technology implemented in developing African states like Sierra Leone that starts late in 2018 through private telecommunication operators. Freetown was the first place to use the facility, while three provinces and cities used 2G / 3G network infrastructure and technology (Global LTE Deployment Open Signal. 2017).

This research work explores the planning, deployment, and implementation of the LTE Core Network (EPC) in Freetown, Sierra Leone. The Expectation is that the EPC planning and deployment in Freetown will take full advantage of mobile communications, especially in terms of high speed, high bandwidth, low latency, reduced costs, low power consumption, and enhanced data rates. A country found on the west coast of Africa, with approximately eight million people (Bjerke, 2011). Freetown, the capital, accounts for 20% of the country's population. Prior adjacent this, most private and Government-owned operators in Sierra Leone were using 2G / 3G network infrastructure, which had low data flow rates and Internet penetration rates. E-government, e-commerce, e-banking, mobile money, e-learning, and the use of social media applications (WhatsApp, LinkedIn, Facebook, Skype, WeChat) make Freetown a busy city. All these facilities, especially with the introduction of fiber optics, have increased the number of subscribers in the country. The bandwidth directly affects the use of Internet data bundles, VoIP, video streaming, Web browsing, and online banking. These have compelled Broadband operators to seek better and enhanced services that can handle the following factors: data rate, mobility, delay, coverage, capacity, spectrum flexibility. Hence, subscribers and the Internet service provider (ISP) customer's high demand for QoS addressed. Therefore, planning, deploying, and implementing 4G LTE Core Network (EPC) in Freetown is necessary.

Related work

The LTE is a 4th Generation (4G) technology with numerous benefits, and it is the latest technology. The LTE Network planning, which comprises of Evolved Universal Terrestrial Radio Access Networks (E-UTRAN) and the EPC key component in 4G LTE architecture. For efficient LTE core network planning in Sierra Leone, this research focuses on future throughput prediction of active mobile users in Freetown as to make the Government of Sierra Leone see reason as to why 4G LTE upgrade is essential. Therefore, LTE is an efficient network infrastructure providing numerous communication services (benefits) including real-time applications, web browsing, video streaming, VoIP, online transactions, video conferencing, high uploading and downloading speed, high data rate, reduced cost and host of other facilities.

However, with the introduction of big data technology, block-chain technology and informatization from the massive data generated by telecommunication industries in the last decade have raised serious concern for mobile users to receive the utmost network performance, especially on how to manage and transmit these data over the internet. Presently, the massive data generated by social media websites and applications utilized a large share of the bandwidth on the internet. It causes an increase in the volume of the data traffic over the internet and subsequently affects network speed in the bandwidth ingestion (Park, Raza, Thorat and Kim, 2015). It shows that when there is a vast increase in data traffic beyond the capacity of the network, the network will automatically become unstable and ineffective.

Therefore, predicting network bandwidth and downlink throughput for active mobile users in Freetown as a region is essential in developing a 4G Evolved Packet Core network in Sierra Leone. It is evident with more, especially the two leading the MNOs operator X & operator Y, with their "Area code national destination codes (NDCs) increasing continuously for the last five years. For instance, Operator X has about seven NDC codes such as 077, 030, 088, 080, 099, 033, & 034, and Operator Y has about four NDC codes, including 075, 076, 078, & 079 for their subscribers. Even though there is an increase in NDC by MNOs, yet still no additional bandwidths were added to the existing infrastructures, and therefore has resulted in poor performance such as low uplink and downlink, frequent fluctuation in data traffic, and more especially speed. Several researchers have proposed network traffic prediction schemes and engineering mechanisms (Bin Yang and Mingyan Jiang., 2016, Samar Raza Talpur, Tahar Kechadi., 2016, Lun Zhang, Qiuchen Liu, Wenchen Yang, Nai Wei, and Decun Dong., 2013, and Poo Kuan Hoong, Ian, Tan, and Chee-YikKeong., 2012) to predict bandwidth growth requirements in the telecommunication sectors around the world. Similar works carried to get efficient schemes that could predict network traffic of data flow in advance as a way to better provide effective communication services to subscribers without interruption or breakdown. Therefore, an enhanced and efficient scheme for predicting accurate data traffic on a network should be able to capture essential traffic characteristics such as short-range and long-range dependencies.

The ARIMA (Feng Huifang and Yantai Shu., 2013) proposed in 2013, which is a linear times series model for predicting network traffic. They experimented using the Mean Absolute Percentage Error (MAPE) metric to calculate and estimate the result of the ARIMA prediction scheme. The correlation coefficient function real-time to denote time series, and the ARIMA scheme attained a high forecast level. A GSM wireless mobile real data networks using China Mobile at different time scales. The Minimum Mean Square Error (MMSE) was used to estimate and determine the prediction performance of the ARIMA scheme. An analysis was done between the actual data and predicted data. It proves that the ARIMA scheme attained enhanced prediction of network traffic with the relative error between prediction data and the real data less than 0.02. In 2013, a hybrid model two-dimensional corrections and "Single Exponential Smoothing (SES)" for predicting mobile networks for different time interval days and hours (Jian Kuang et al., 2013). The experiment achieved high performance based on a comparative prediction between their scheme and the conventional schemes, and results show excellent prediction efficiency and accuracy attained.

Comparison between 3G and 4G Networks

The four main MNOs operating on 2G/3G network infrastructure and technologies (i.e., GSM/3G HSPA technology standards) are presently active in Sierra Leone (S.L. Teleco Research and Markets., 2018). UMTS family provides the fastest 3G network standards via the HSPA+ standard. The UMTS family and rules offer services to customers downstream of 28Mbits/s and upstream of 22Mbits/s using only one antenna officially commissioned and made available to the public in Sierra Leone in March 2014.

According to (Hanzo, Haas, Imre, O'Brien, Rupp, and Gyongyosi., 2012), these data rates were later increased to 42Mbits/s at peak bit rate downstream where DC-HSPA+ used with two 5MHz UMTS carriers or two by two MIMO. The government-owned operator is operating the fastest 3G-based standard in the CDMA2000 family, EV-DO Rev. B, commissioned and deployed in Sierra Leone around 2013 with a downlink rate of 15.67 Mbit/s. Therefore, in theory, from the customer perspective of bottlenecks, the country's network resources availability is minimal, and internet traffic penetration rate is about 13.6 Mbit / s. For 3G, ITU's IMT-2000 requires 144 Kbps of mobile speed, 384 Kbps of pedestrian speed, and indoor 2 Mbps speed. The leading technologies include CDMA2000 1X / EVDO and UMTS-HSPA.

However, with the increasing number in subscribers and the high demand for better network resources such as fast data rates, high bandwidth, and good QoS rendered when the country now actively involved in online banking and online transactions. Therefore, the data rate provided by these standards and technologies has proven to be incapable of meeting these demands. Because of the high needs, it is essential for the 2G/3G network infrastructure in Sierra Leone to migrate to 4G LTE network System without condemning the existing network infrastructure. Base on that regard, an LTE Core network (EPC) planning, deployment, and implementation is necessary for Freetown to complement subscriber demands. LTE provides up to 300 Mbit/s downlink data rate and 75 Mbit/s uplink data rate, and its improved LTE advancement can support a maximum downlink rate of over 1 Gbit/s. LTE has industrialized to meet the growing demand for broadband communications in the mobile market.

Although LTE as an evolution of 3G / HSPA technology standards, from a design perspective, LTE is a revolution because the wireless interface is brand new, and RAN has a meaningful simplification. LTE is a separate packet-switched network that provides a core service, mobile broadband I.P. access based on its end users. 4G services offer 100 megabits per second, for high-mobility communications such as trains and cars, at speeds of approximately 12.5 megabytes per second, for low-mobility interactions with pedestrians and fixed users, each with the rate of 1 gigabit (Gbit / s). From the analysis of 3G mobile network technology standards, the design speed of 4G LTE, to exceed the quality and speed of 3G networks. Currently, 3G speeds are in the 14 Mbps downlink and 5.8 Mbps uplinks. To be a 4G technology, mobile users must reach 100 Mbps, and fixed users must reach 1 Gbps (Review, 2018). The speed and flow rate provided by the 3G technical standard is much lower than the 4G specification.

Difference between 3G and 4G Networks

Figure 1 below shows a distinct difference between 3G UMTS / HSPA and 4G LTE systems is that RNC does not exist in the LTE architecture living in the conventional UMTS architecture. The RNC's role is to standardize handover and mobility management controls; it also performs functions related to managing the radio resources of the network, such as packet scheduling and control admission. Data packets are always resent when received through the communication medium; to obtain better QoS, the retransmission delay from the mobile device to the RNC to be higher. By causing the eNodeB to perform packet retransmission, the retransmission delay time can be reduced from 80 ms in 3G to 2 ms in 4G. Therefore, the reduced latency allowing the eNodeB to respond more quickly to any differences in communication channel quality (W. P. Review., 2018).

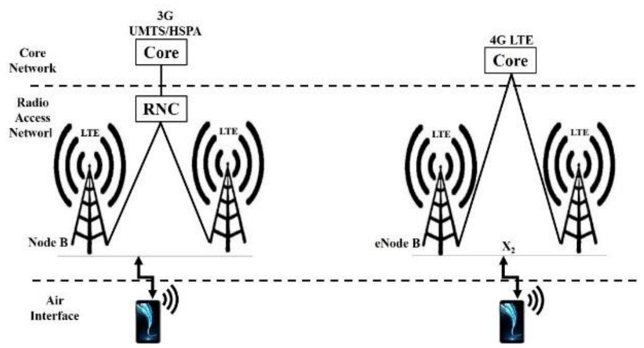

Figure 1. Difference between 3G and 4G (Bharti Kalra and Chauhan, 2014)

The LTE requires to enable a seamless transition from current telecommunications systems. It can be achieved by reusing the existing spectrum, interoperating between the current system and the upcoming system, reusing existing sites, and producing devices at competitive prices. It allows operators to migrate easily. It requires simplified system architecture, strict spectrum constraints, and the use of new radio access technologies with better features. Compared with third-generation systems, LTE is among the new stages in a series of evolving mobile telecommunication systems. It is a further development of functions, speed improvement, and overall performance improvement, as shown in Table 1 below:

Table 1. Difference between 3G and 4G

Attributes	3G	4G
Data Throughput	Up to 3.1 Mbps	10 to 300 Mbps
Upload Rate	5Mbit/s	50Mbit/s
Download Rate	100Mbit/s	1Gbit/s
Techniques for Switching	Packet /Circuit Switching	Packet-Switching
Frequency Band	1.8 – 2.5GHz	2 – 8GHz
Forward Error Correction	Uses Turbo Codes	Concatenated Codes
Application and Services	CDMA 2000, WCDMA	WiMAX and LTE

Research Methodology

4G LTE Core network (EPC) planning and deployment require numerous schemes and challenges that, in turn, increases the difficulty in planning and deploying such infrastructure. The 4G LTE core network (EPC) planning and deployment were adopted using the following methodology.

Planning Problem: Inputs, Outputs, and Objectives

Expecting that the accompanying data and things considered in displaying and arranging issues (Dima Dababneh., 2013):

- Transmission links, interfaces, and potential location of the core network elements, together with their abilities and expenses.
- The eNBs' areas, the total number of active subscribers, covered each cell and the planning parameters
- The connection cost for manual labor, electric fixing, right of the entry floor Spaces, cabling, and grounding, cable runways, power and cooling equipment, and Racks

The yield of the planned issue centers around the accompanying angles to structure the developed bundle center of the LTE organizes. All the more explicitly, it incorporates: Sorting out the topology of the framework, as illustrated in figure 2.

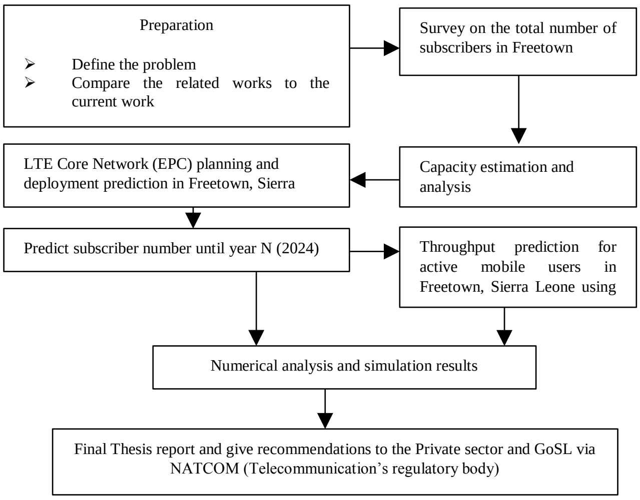

Figure 2. Planning of LTE Network and Mobile Users Throughput (M. Jaber, Z. Dawy, N. Akl, and E. Yaacoub., 2016)

Table 2. Showing statistic data summary (2010-2019)

No	Year	Cell Name	Month	Traffic 1Kbps	Date stamp
1	2010-01-01	FHQWF	January	12206491	2010-01-31
2	2010-01-01	FHQWF	February	24308938	2010-02-28
3	2010-01-01	FHQWF	March	38416369	2010-03-31
4	2010-01-01	FHQWF	April	55610328	2010-04-30
5	2010-01-01	FHQWF	May	60970328	2010-05-31
6	2010-01-01	FHQWF	June	70338156	2010-06-30
7	2010-01-01	FHQWF	July	80844468	2010-07-31
8	2010-01-01	FHQWF	August	74864889	2010-08-31
9	2010-01-01	FHQWF	September	86438163	2010-09-30
10	2010-01-01	FHQWF	October	89187360	2010-10-31

Table 2 shows a statistical dataset head summary for the years and months starting January 2010, October 2010 onto November 2019 with parameters such as cell name, data traffic, and time stamp.

Typical EPC Architecture and Configuration

The EPC is the voice-and information preparing focus of essential administrator framework resources. It connects to the Radio Access Network (RAN), has appeared in the outline beneath. It comprised of the accompanying: association bearers packaged into authorized groups get to edge and inclusion cells. The control plane is ended at the Mobility Management Entity (MME) and afterward, process all the flagging occasions of the client hardware (Figure 3).

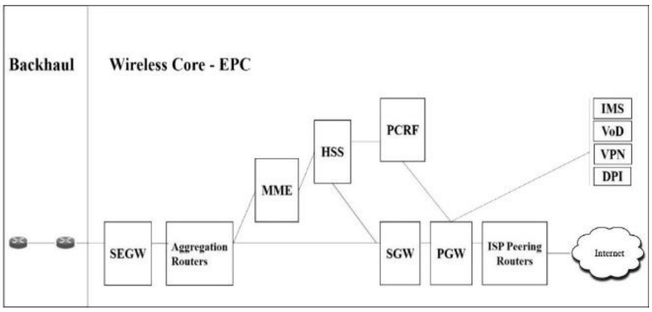

Figure 3. Wireless Core Infrastructure (EPC) Configuration

Non-Access Stratum (NAS) dwells in the middle of the U.E. and the MME in the control plane, and it is liable for call-preparing meeting the executive's capacities. Application traffic relegates via the Packet Gateway (PGW) onto the web utilizing the ISP peering routers. The Communication Service Providers (CSP) may offer extra, administrator facilitated administrations that are not bound to the EPC; application traffic streams that have a place with the administrator facilitated administrations ended at the SGi-LAN. The SGi-LAN further encourages the delicate arrival of new administrations before they further south into the EPC center.

The home Subscription Server (HSS) fills in as a focal database that keeps up a rundown of bought in administrations for U.E.s enrolled with the system. The MME interrogates the HSS for approval of the U.E. carrier foundation demands. The PGW recovers rules to the U.E. application streams from the Policy Control and Rules Function (PCRF), and the U.E. application streams passed via sending routers to the web or the SGi-LAN apparatuses. It is essential to note a remote system framework arranging three principal factors, as most clients today applied them day by day.

Position of evolved NodeBs (eNodeBs) given the potential amount and dissemination of portable supporters. Outstanding burdens for this examination dependent available sizes of generally around 2,000,000 users. The consider model estimates the average number of NAS flagging occasions per endorser in a bustling hour for a specific market plan.

Evolved Packet System (EPS) Traffic

Inspecting and assessing system traffic is indispensable in arranging a system and measuring its introduction or effectiveness. Understanding the various types of connections and interfaces required to carry signals is essential for accurately designing an efficient 4G LTE network in Sierra Leone.

Several traffic parameters to be considered in planning an efficient 4G LTE network, which requires thorough planning such as the following under mentioned below:

The number of attached subscribers in Busy Hour (B.H.)

B.H. is known to be the busiest 60 minute's day, in which the total traffic is extreme throughout the day. B.H. can found using the formula:

$$BH = \frac{m*k*w*b}{W} \quad (1\text{-}1)$$

Where: B.H. = Busy hour, m = monthly usage, w = working days traffic ratio, b = busy hour traffic ratio, k = constant value, and W=working days per month.

Busy Hour Data Session Attempt (BHDSA)

Refers to the number of information meetings endeavored in a working hour and gave the primary strategies to gauge the limit of the system, as in:

$$B = \frac{A*D*3600(sec())}{M(sec())} \quad (1\text{-}2)$$

Where B = BHDSA, A = attached subscribers, D = data traffic intensity, M = mean session time

Busy Hour Voice Session Attempt (BHVSA)

It refers to the number of voice sessions attempted in a working hour, expressed as:

$$Bv = \frac{A*V*3600(\text{sec})}{M\,(\text{sec})} \quad (1\text{-}3)$$

Where Bv = BHVSA, A = attached subscribers, V = voice traffic intensity, M = mean session time

$$A = S * Asr \quad (1\text{-}4)$$

Where A = attached subscribers, S = subscribers, Asr = attached subscribers ratio.

The bandwidth required for bearer sessions (B.W.)

It depicts the measure of throughput required for the clients' administrations.

Simultaneous Evolved Packet System Bearer (EPSB)

It refers to the quantity of EPS carrier meetings co-happening in a bustling hour. The EPSB is a built-up start to finish interface amid the U.E. and the P-GW to offer the clients with the Internet providers they need.

$$Ke = \frac{A * a(\sec) * Ra}{3600(\sec)} \quad (1\text{-}5)$$

Where Ke = eNB-simultaneous-EPSB, A = attached subscribers, a = average-EPSB session-duration, Ra = active-BH-EPSB ratio.

Total Number of Network Users

The total mobile subscribers in Freetown municipality is approximately a million active users, and the population growth factor is 11.3%. For capacity planning, the study estimates active mobile subscribers' growth for 5years to enhance the network to accommodate future subscriber growth of Freetown municipality, and finally, predict the prospective mobile users that the LTE network can operate. The total number of the user is one of the capacity requirement. T (1-6) rmine the mobile subscriber growth in Freetown within the five years, we have to make use of the future mobile subscriber growth by using the exponential growth equation in equation 1-6.

$$\mathbf{F_s} = \mathbf{C_s}[(\mathbf{1} + \mathbf{G_f})]^{n} \quad (1\text{-}6)$$

Where $\mathbf{F_s}$ the future mobile subscriber growth in Freetown is, $\mathbf{C_s}$ is the current mobile subscriber number in Freetown, $\boldsymbol{G_f}$ represent the growth factor rate of Freetown, and n represent the number of years predicted.

Total Network Throughputs

Network throughput viewed as the measurement of data in bits per second. The network can transmit at a given interval (Saleh, Bulakci, Hämäläinen, Redana, and Raaf., 2012). Throughput is an essential metric to determine the performance and quality of the LTE network. The throughput of the system can be affected by several factors, and amongst them is the level of interference in the network. The level of interference will increase as the number of users increases (Qubati, 2014). The total network throughput computed using equation 1-7.

$$\boldsymbol{T_{put}} = \boldsymbol{t_{user}} + \boldsymbol{S_{put}} \quad (1\text{-}7)$$

Where $S_{put}$the throughput of a single user in the network, t_{user} is the total number of user on the web, and $\mathbf{T_{put}}$ Represent the total network throughput.

The service and traffic models are essential parameters to consider when calculating the total performance of the system. Therefore the overall network throughput can be attained by multiplexing the number of subscribers with the single-user performance (Dababneh, St-Hilaire, and Makaya, 2013).

Throughput Model Mathematical Formula

Here, the various mathematical algorithms to determine the bandwidth or throughput of network traffic includes:

ARIMA Model

The Box-Jenkins introduced the ARIMA model (Tao Peng, Zhoujin Tang., 2015). The auto-regression integrated moving average (p, d, and q), a model based on differenced time series data. The original time series data is differenced on the order d to make the data stationary. Furthermore, a stationary time series can be as an ARMA model of order (p, q), where p Represent the order o (1-8) A.R. process the second-generation and q is the order of the M.A. process. ARMA modeled current time series data is given by:

$$\hat{y}_t = a_1 y_{t-1} + a_2 y_{t-2} + \cdots + a_p y_{t-p} + b_1 e_{t-1} + b_2 e_{t-2} + \cdots + b_q e_{t-q} + e_t \quad (1\text{-}8)$$

Where,

$y_{t-1}, y_{t-2}, \cdots, y_{t-p}$ Represent data at past time points

$e_{t-1}, e_{t-2}, e_{t-q}$ Represent errors at past time points

e_t Represent present error

$a_1, a_2, \cdots, a_p$ Represent AR Coefficients

$b_1, b_2, \cdots, b_q$ Represent MA model coefficients

Modelling ARIMA (p, d, and q) involves stabilizing the data, then determining the appropriate values for the model order, and then predicting the time series data from the model.

Model Metrics

The Root-mean-square error (RMSE) and R-squared determine the efficiency of a model. The RMSE represents the squared error statistics of the output model, which distanced between the model's prediction and real values, such as the standard deviation of the residuals.

R-Squared, on the other hand, is the square of the correlation between the measured and predicted values. Note that a high R-square means a better fitting model where the maximum R-square value is 1. The formula for RMSE is given by:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2} \quad (1\text{-}8)$$

Where, y_i Represent real value, $\hat{y}_i$ Represent predicted value

Results and Analysis

Table 3 shows the year subscriber numbers from January 2010 to November 2019 for operator X in Freetown. The researched values tend towards the predicted numbers in the years under review. No total real number of subscriber numbers for the years January 2020 to December 2024 are indicated, but predicted subscriber numbers were given as 3973250.0, 6745250.0, 9999750.0, 13998250.0, and 16276500.0 respectively.

Table 3. Showing yearly subscriber numbers (2010-2019)

No	Year	Date_stamp	Total Subscriber_ Numbers	Predicted Numbers
1	2010-01-01	2010-12-31	592000	N/A
2	2011-01-01	2011-12-31	621000	N/A
3	2012-01-01	2012-12-31	673000	N/A
4	2013-01-01	2013-12-31	844000	N/A
5	2014-01-01	2014-12-31	764000	N/A
6	2015-01-01	2015-12-31	560000	N/A
7	2016-01-01	2016-12-31	972000	N/A
8	2017-01-01	2017-12-31	1472000	N/A
9	2018-01-01	2018-12-31	1742000	NIL
10	2019-01-01	2019-11-30	1864000	N/A
11	2020-01-01	2020-12-31	N/A	3973250.0
12	2021-01-01	2021-12-31	N/A	6745250.0
13	2022-01-01	2022-12-31	N/A	9999750.0
14	2023-01-01	2023-12-31	N/A	13998250.0
15	2024-01-01	2024-12-31	N/A	16276500.0

Computational Results and Visualization

Urbanization has congested Freetown and subsequently has increased the number of active mobile users. It has become the bottleneck for the telecommunication operators who try to maintain QoS standards to meet subscriber demands. The monthly statistical data collected from operator X generated from the system using the equation given below;

$$M_T = HOT_{bs} \times 300 \quad (1\text{-}9)$$

M_T Represents total monthly traffic, HOT_{bs} represent the reference base station. The statistical data interpreted using graphs where Y-axis represents throughputs in Kbps, and the X-axis represents the number of years. Due to the complexity of the data collected from the internal database of operator X, all of it cannot deduce in just one graph. We, therefore, tried to visualize the two-year data for each graph, as shown in figures 3a and 3b below.

The country returns to a healthy life at the end of 2015 for a real situation of the present 4G/2G/3G network infrastructure in Freetown. Government institutions, private companies, as well as return to active operations and from the graph, high increment of data usage occurred in April and December for each year. Its due to high subscriber increment during the two main festive seasons (Easter & Christmas holidays) regularly celebrated in Sierra Leone. Sierra Leone experiences the raining season in July and August month, which most times causes signal degradation due to heavy rains and the heavy wind blowing, which sometimes shifts or changes the antenna positions of the communication towers. It has adverse effects on communication since there will be no line-of-sight existing between the transmitting and the receiving end of the communication system.

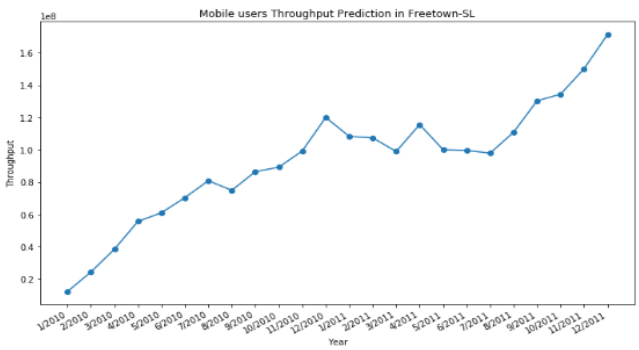

Figure 4a. Showing 2010-2011 data visualization

Everything in the country stabilizes, and figure 4b shows a clear justification for the visualization of 2018-2019 real-time data. We have a high increment of data usage occurring in April and December for each year. Its due to high subscriber increment during the two main festive seasons (Easter & Christmas holidays) regularly celebrated in Sierra Leone. Sierra Leone experiences the raining season in July and August month, which most times causes signal degradation due to heavy rains and the harsh wind blowing, which sometimes shifts or changes the antenna positions of the communication towers. It has adverse effects on communication since there will be no line-of-sight existing between the transmitting and the receiving end of the communication system.

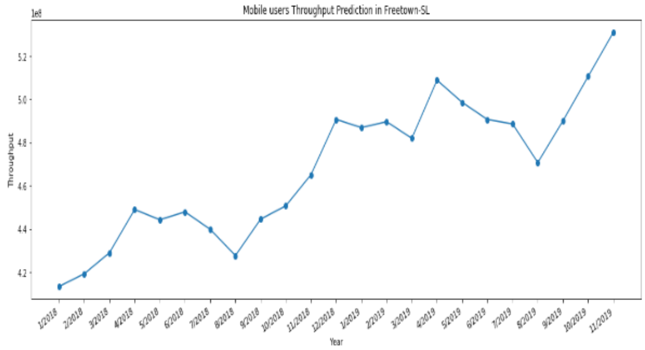

Figure 4b. Showing 2018-2019 data visualization

The second challenge that MNOs faced is the high rise in population growth in Freetown. Unemployment in the provinces has led people to migrate to Freetown, looking out for greener pastors (better living conditions) forcefully, and this situation has inflated mobile subscribers making the capital congested. There is a rapid decrease in active mobile subscriber numbers within the period 2014 to 2015 and shows a real case of a disease outbreak called 'EBOLA' that occurred. The outbreak brought about massive evacuation of both foreigners and many citizens. Private companies (both local &

international) evacuated their employees from the country for fear of the disease, which took the lives of over 4000 people.

ARIMA Model Application

It is among the class of statistical models used for analyzing and forecasting time series data and is widely used. The mode of application of the ARIMA model is summarized as follows:

a. Input and plot the data using the model to check for the trend of data.
b. Check for stationarity.
    - Calculate mean, and Variance
    - Take logs to make Variance equal
    - Apply differencing to make the mean constant (To be at the middle of the graph)
c. Apply Auto-ARIMA function to determine the suitable model
    - Then build the model-It is done using the suitable ARIMA model.
d. Apply the model and perform the prediction

Having gone through the above-listed steps on how to analyze the statistical data gathered from operator X in Freetown, Sierra Leone below shows the different visualization results systematically.

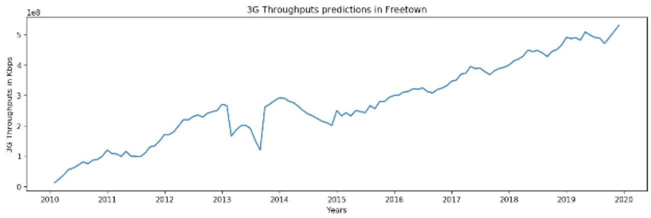

Figure 5. Showing the yearly trend of subscribers

The data trend visualized, as shown in figure 5 above, which even extends to the year 2020. It clearly shows that there are room and high needs to upgrade the present network infrastructure in the country. The trend also clearly indicated the non-stationarity of the data and must be made stationary before the application of the ARIMA model (Alfin Hikmaturokhman et al., 2018) and then use it to perform the short and long term predictions.

In this research work, we use the Auto () _ARIMA method, and base on the data type, the system automatically selects the model with lower AIC and BIC values and P-values. The ARIMA (011) type completes the forecasting process. Figure 5 above shows its initial application to ascertain the Traffic1 in Kbps versus the forecast line graph.

```
                             ARIMA Model Results
==============================================================================
Dep. Variable:            D.Traffic1   No. Observations:                   99
Model:                ARIMA(0, 1, 1)   Log Likelihood              -1811.414
Method:                      css-mle   S.D. of innovations      21383339.292
Date:               Wed, 03 Jun 2020   AIC                          3628.827
Time:                       12:07:27   BIC                          3636.613
Sample:                   02-28-2010   HQIC                         3631.977
                        - 04-30-2018
=================================================================================
                    coef    std err          z      P>|z|      [0.025      0.975]
---------------------------------------------------------------------------------
const          4.413e+06   1.95e+06      2.268      0.026    5.99e+05    8.23e+06
ma.L1.D.Traffic1 -0.0958      0.112     -0.859      0.392      -0.314       0.123
                                    Roots
=============================================================================
                  Real          Imaginary           Modulus         Frequency
-----------------------------------------------------------------------------
MA.1           10.4363           +0.0000j           10.4363            0.0000
-----------------------------------------------------------------------------
```

Figure 6. Shows the model test result

Figure 6 attests to the fact that the ARIMA model type used in this research work ascertain 0.975% (97.5%) performance accuracy with an excellent autoregressive correlation factor (P-value is 0.025). The autoregressive factor, on the other hand, plays a pivotal role in the selection of the model with the scientific policy that whenever the P-value is low, the better will be the performance and accuracy of the model.

Determining the goodness of fit of the model depends on the "Akaike Information Criteria (AIC)" and "Bayesian Information Criteria (BIC)" values, including the P-value. AIC and BIC are the leading measures to consider the accuracy of the model. The AIC is 3628.827, and BIC is 3636.613 and found to be the lowest from all the models tested. Ideally, AIC and BIC with lowest values when the P-value is less one (1) depicts a good model.

Future mobile user throughput prediction in Freetown, Sierra Leone

The focus of this research work is to predict the future throughputs in Kbps of Freetown's active mobile users so that GoSL, through NATCOM as a telecommunications regulator, confirms that government-owned operators start the deployment or rollout of 4G LTE and provided final licenses to all private companies. Industry operators already in the process of 4G LTE rollout. Based on the forecast done on the number of subscribers in co-operated into the system for the coming years, there will be a high increment of subscriber numbers looking at the predicted numbers from table 3 above.

To complement the effort of the GoSL meeting the high demands of internet and communication services, which is the main contribution to this research work, a short-term and long-term prediction of future throughputs in Kbps of active mobile users in Freetown made as shown in figures 7 and 8. Table 2 clearly shows the future throughputs (Kbps) predicted using the ARIMA model through a python programming language.

Short-term Prediction (Three Years-2019-2022)

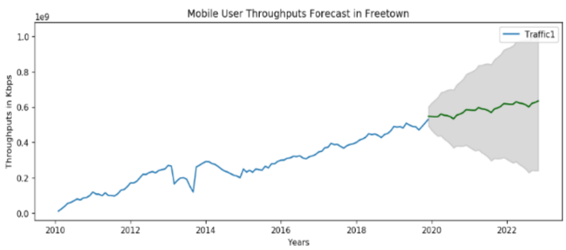

Figure 7. Showing three year's throughputs (Kbps) forecast

Figure 7 above clearly depicts three years forecast of future throughputs (Kbps) of mobile users in Freetown starting November 2019 onto December 2022, as indicated in grey shadow with a green forecast line inside it. The lower outbound downlink throughputs shown in grey color depicts January throughput, and the upper outbound represents December throughput for every year.

Long-term Prediction (Five Years-2019-2024)

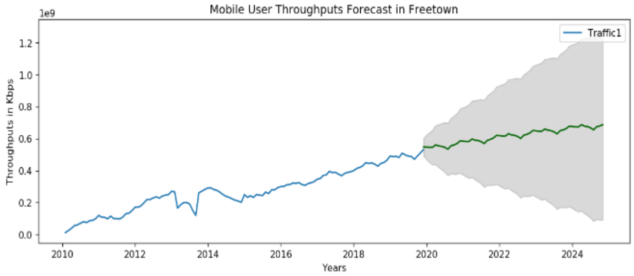

Figure 8. showing five year's throughputs (Kbps) forecast

Similarly, figure 8 above shows five years forecast of future throughputs (Kbps) of mobile users in Freetown starting November 2019 onto December 2024, as indicated in grey shadow with a green forecast line inside it. The lower outbound downlink throughputs shown in grey color depicts January throughput, and the upper outbound represents December throughput for each year.

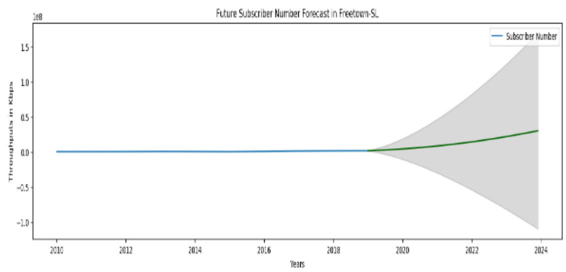

Figure 9. Showing five years subscriber forecast

Figure 9 showcase the prediction of the future number of subscribers for the coming five years (2019-2024) in Freetown, as indicated in the grey shadow with a green line in the middle.

Table 4. Showing the predicted monthly throughputs in Kbps

Year	Month	Predicted Throughputs in Kbps
2019	December	5.475501e+08-----Festive holiday
2020	January	5.465212e+08
	February	5.450428e+08
	March	5.456597e+08
	April	5.5607420e+08-----Festive holiday
	May	5.538348e+08
	June	5.514978e+08
	July	5.455027e+08
	August	5.336118e+08----Bad weather condition
	September	5.541134e+08
	October	5.601472e+08
	November	5.689961e+08
	December	5.8525352e+08-----Festive holiday
2021	January	5.839389e+08
	February	5.821749e+08
	March	5.825061e+08
	April	5.973028e+08-----Festive holiday
	May	5.901099e+08
	June	5.874873e+08
	July	5.812065e+08
	August	5.690300e+08----Bad weather condition
	September	5.892460e+08
	October	5.949941e+08
	November	6.035574e+08
	December	6.195291e+08-----Festive holiday
2022	January	6.179288e+08
	February	6.158792e+08
	March	6.159248e+08
	April	6.304358e+08-----Festive holiday
	May	6.229573e+08
	June	6.200490e+08
	July	6.134826e+08
	August	6.010204e+08----Bad weather condition
	September	6.209508e+08
	October	6.264133e+08
	November	6.346909e+08
	December	6.503769e+08-----Festive holiday
2023	January	6.484910e+08
	February	6.461557e+08
	March	6.459157e+08
	April	6.601411e+08-----Festive holiday
	May	6.523769e+08
	June	6.491830e+08
	July	6.423309e+08
	August	6.295831e+08----Bad weather condition
	September	6.492278e+08
	October	6.544046e+08
	November	6.623966e+08
	December	6.777970e+08-----Festive holiday
2024	January	6.756255e+08
	February	6.730045e+08
	March	6.724788e+08
	April	6.864186e+08-----Festive holiday
	May	6.783688e+08
	June	6.748892e+08
	July	6.677515e+08
	August	6.547180e+08----Bad weather condition
	September	6.740771e+08
	October	6.789683e+08
	November	6.866746e+08
	December	6.976746e+08-----Festive holiday

Table 4 clearly shows the predicted throughputs in Kbps of December 2019 onto January-December 2024. The high increment of data usage as a result of the rapid growth of subscribers that occurred during the festive season (April & December) of every year, as indicated on the table with blue ink color. Similarly, the high signal degradation occurred during July and August as a result of adverse effects on the weather conditions is shown on the table as red ink color.

Comparison of predicted Subscriber numbers versus Throughputs in Kbps

It is mainly to clarify citizen complaints to the GoSL through NATCOM to ascertain, comply, and make MNOs provide better services for them. It is clear that GoSL should start a 4G LTE rollout and complements the effort of other private operators with full support. The predicted number of active subscribers to that of the predicted future throughputs in Kbps plotted. From the result, it is evident that GoSL intervention is highly needed; otherwise, citizens might go out of patient if the complaints about the poor QoS provided by the MNOs in Freetown and the country as a whole rendered to them if not adequately addressed.

Table 5. shows yearly predicted numbers and throughputs in Kbps

No	Year	Predicted Subscriber Numbers	Predicted Throughputs Kbps
1	2020	3973250	6650923000
2	2021	6745250	7081083000
3	2022	9999750	7470109800
4	2023	13998250	7818003400
5	2024	16276500	8120649500

From table 5 above shows the predicted number of active subscribers and the predicted future throughputs (Kbps) for the coming years. The predicted number of active subscribers and the predicted future throughputs (Kbps) increases year by year.

Conclusion

This research represents a specific region of Sierra Leone, and ten years of statistical data was collected from operator X in Freetown for every month (January 2010 - November 2019). However, the emphasis is laid on future throughput prediction of active mobile users in Freetown as that was the only option the GoSL would ascertain clear view to start 4G LTE rollout for Government-owned operator.

The numeric analysis and the throughputs (Kbps) prediction to ascertain 4G LTE rollout with the use of the ARIMA (010) model through a python programming language yields good results. Figure 4.2a and 4.2e show the real-time of yearly numerical visualization of subscriber's downlink throughputs from 2010 onto 2019 in Freetown. Table 4 outlines five years (5) predicted throughputs (Kbps) monthly where blue color row ascertain increment of downlink throughputs (Kbps) and the red color row describe decrement of downlink throughputs. Figure 5 clearly shows the yearly trend graph of the subscriber's downlink throughputs (Kbps), and five (5) subscriber forecast successfully done. The short-term (3Years) and Long-term (5 Years) forecasts of downlink throughputs (Kbps) of subscribers in Freetown were successful, as shown in figures 7 and 8. The model use ascertains a good P-value of 0.025 and 0.975 (97.5%) performance accuracy, as shown in figure 6; hence 4G LTE deployment or upgrade is necessary. In conclusion, the experiment was successful, and the results clearly show that GoSL needs to intervene to combat the problems associated with the low speed provided by the present telecommunication network infrastructure and hence do upgrades.

Recommendations

Based on the results of this study, the following recommendations are also helpful for private and state-owned enterprises:

5.1.1 Government of Sierra Leone (GoSL) through NATCOM

Based on the result of this research work, the following suggestions to the regulatory body for their attention.

Higher Frequency Bandwidth needed by Operators

800MHz bandwidth, which includes uplink and downlink frequencies, is the required 4G LTE bandwidth allocated to West African countries by the ITU body. NATCOM serving as the regulatory body in Sierra Leone should make higher frequency bandwidths available to operators in the country. NATCOM regulatory body is responsible for the allocation of bandwidths in the form of frequency blocks such as 2x5MHz, 2x10MHz, and 2x15MHz to the various telecommunication operators in the country. As the bandwidth has direct proportionality to the throughputs, it means the higher the bandwidth, the better the performance, which increases the throughputs as well.

Auction Price needs to be reduced by the regulatory body

Auction price is the cost of the frequency blocks sales carried out by the NATCOM to the telecommunication operators in the country that emerged as the highest bidders. The regulatory body should reduce the price of the frequency blocks, thereby allowing more operators to bid for the blocks. It will make the telecommunication sector (market) more competitive and affordable, in turn, will forces every operator in the country to be involved in the 4G LTE rollout or upgrade process.

Reduce Taxes Levied on operators

The GoSL through NATCOM should encourage the private sector by reducing taxes levied on their operations so that they will compliment her effort by carrying out their operations within the prescribed standards of communication in the entire country.

Private Telecommunication Operators

Based on the outcome of this research work, the following recommendations to the private operators for their attention.

Reduce Data Tariffs and Internet Service Charges

In Freetown, the data tariffs and internet service charges levied by telecommunication operators to their valid customers are very high that only the rich ones can afford to get better services from them. It has brought about adverse effects on the citizens and severely affects the country's economy. Therefore, private telecommunication operators should reduce the charges levied to customers for data tariffs and internet services so that these services can be affordable even for the last person in the country. It will also encourage more customers to join the network, which will have economic benefits to the operator as well as to the state.

Constant Routine Checks to be Done on the System

Monitoring and system maintenance, like software upgrades (based stations), should continuously be done by the NOC engineers and field engineers (based station engineers) to maintain better QoS. Similarly, NOC engineers must continuously monitor the 2G/3G KPIs and send accurate hourly reports to top-level management for final decision making. Due to the limited number of field engineers, it usually takes two or more days for them to repair some breakdowns/faults, especially when the based stations are far apart. Therefore, for efficient, effective, and un-interrupted telecommunication services, MNOs should employ more field engineers to monitor the various based stations in Freetown, Sierra Leone.

It will be to the advantage to the operator because it will prevent them from getting a penalty or being fined by the telecommunication regulatory body. It will also increase the number of subscribers, in the case where better QoS is maintained.

Government-Owned Operator

Similarly, based on the outcome of this research work, we submit the following recommendations to the Government-Owned operators.

To seek the citizen's interests

As an enterprise sponsored by the GoSL, they should consider what should be the benefit that the citizens can obtain first and foremost, thereby complementing the effort of Government. When this happens, the citizen's complaints to the regulatory body will become a thing of the past.

Reduce Data Tariffs and Internet Service Charges

In Freetown, the data tariffs and internet service charges levied by the Telecommunication operators to their valid customers is so much high that only the rich ones can afford and get better services from them. It brought adverse effects to the citizens and even the country's economy.

Therefore, private telecommunication operators should reduce the charges levied to customers for data tariffs and internet services so that even the least person in the country will afford to get the services rendered. It will also encourage more customers to join the network, which has economic benefits to the operator as well as the state.

Carry out Constant Routine Checks on the System

Monitoring and system maintenance, like software upgrades (base stations), should continuously be done by the NOC engineers and field engineers (based station engineers) to maintain better QoS. Similarly, NOC engineers must continuously monitor the 2G/3G KPIs and send accurate hourly reports to top-level management for decision making. It will be to the advantage to the operator because it will prevent them from getting a penalty or being fined by the telecommunication regulatory body. It will also increase the number of subscribers, in the case where better QoS is maintained.

Future work

The following future research work will be necessary:

- Future throughput prediction of active mobile users involving the main towns in Sierra Leone and not just Freetown when 4G LTE rollout completed in the whole country
- Spectrum regulation for IMT-2020 (5G) in Sierra Leone. Since 5G requires massive bandwidth to operate effectively, control and proper regulation policies of the spectrum for operators is necessary.
- 5G deployment may replace 4G LTE when its bandwidth is over-stretched, and the same research work is useful.

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Conflict of interest

The authors have no conflicts of interest to declare that they are relevant to the content of this article.