Ibrahim Alhassan Gedel (1), Nnamdi I. Nwulu (2)

University of Johannesburg, South Africa

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A techno-economic comparison of 5G centralized wireless network architectures

***Abstract**.. The key drawback of 5G technology implementation is the high total cost of ownership (TCO) of the architecture design and TCO of a suitable technology that will meet the 5G base station (BS) requrement. Requirements include low latency, high capacity and dense coverage and simultaneous support for applications such as machine-to-machine communication (M2M), device-to-device communication (D2D) and the internet of things (IoT). This study designs the most economical centralized wireless network architecture by modifying the existing macrocell, picocell and femtocell technologies. A mathematical model for capital expenditure (Capex) operational expenditure (Opex) and TCO for modified macrocell, modified gNodeB picocell (mpgNodeB) and femtocell is presented. A mathematical model for centralized wireless network architecture is also presented. The model has been tested and the results show that the Opex, Capex and TCO of the modified macrocell and picocell were found to be directly proportional to the number of gNodeBs. Sensitivity analysis (SA) also shows that the TCO of the mpgNodeB is one fourth of the gNodeB. SA further shows that the interest rate variation has a significant effect on the Capex, Opex and TCO of the gNodeB and mpgNodeB.*

***Streszczenie.** Główną wadą wdrożenia technologii 5G jest wysoki całkowity koszt (TCO) projektu architektury oraz odpowiedniej technologii, która spełni wymagania stacji bazowej 5G (BS). Wymagania obejmują małe opóźnienia, dużą pojemność i gęsty zasięg oraz jednoczesną obsługę aplikacji, takich jak komunikacja maszyna-maszyna (M2M), komunikacja urządzenie-urządzenie (D2D) i Internet rzeczy (IoT). W ramach tego artykułu zaprojektowano najbardziej ekonomiczną architekturę scentralizowanej sieci bezprzewodowej poprzez modyfikację istniejących technologii makrokomórek, pikokomórek i femtokomórek. Przedstawiono matematyczny model wydatków kapitałowych (Capex), wydatków operacyjnych (Opex) i TCO dla zmodyfikowanej makrokomórki, zmodyfikowanej pikokomórki i femtokomórki. Przedstawiono również model matematyczny scentralizowanej architektury sieci bezprzewodowej. (**Techniczno-ekonomiczne porównanie scentralizowanych architektur sieci bezprzewodowych 5G**)*

Keywords: 5G technology; Centralized Wireless Network Architectures: Total Cost of Ownership:
Słowa kluczowe: technologia 5G, sieć bezprzewodowa, TCO

1. Introduction

According to a study by CISCO, [1] the global mobile data traffic demand will increase at an annual compound index of 66.32% and will reach 11.42 exabyte per month by 2024. To meet this explosive data traffic demand, there is a need to enhance capacity, including the introduction of new spectrum (mmWave), deployment of advanced wireless technology such as multiple input multiple output (MIMO) and deployment of a heterogenous network (small cells with macro- or microcell).

The current conventional network architecture is fully based on distributed base stations (BS), were each BS has its own baseband unit (BBU), frequencies and logical resources, resulting in high capital cost due to infrastructure building, high operational cost due to energy and cooling and maintenance cost, high intercell interference and low network utilization.

5G mobile technology is designed to connect millions of devices and run on thousands of applications at a latency of 1 millisecond[2]. These services have necessitated the implementation of the design of low-latency, dense coverage and economically cheaper 5G centralized network architecture by modifying the existing network, to aid mobile network operators (MNO) to increase data transmission speed and capacity.

Technology such as MIMO and massive MIMO will be integrated with the existing technology to improve network coverage, capacity [3] and the data rate at the macrocell level in the implementation of 5G architecture.

Implementing a hyperdense cellular network on the existing independent BS is not suitable for 5G technology because of the numerous setbacks of this network architecture. To achieve dense coverage, lower latency, higher capacity and lower cost of implementation, a centralized mobile network architecture has been proposed in a study by China Mobile. Light Radio by Alcatel-Lucent, project P-CRAN is set up by NGMN, wireless network cloud (WNC) [1] [4] [5] and super BS based centralized network architecture [6]. The implementation of centralized mobile network architecture (CMNA) is achieved by introducing baseband pool processing with distributed antennas equipped with remote radio heads (RRHs) to save energy and reduce carbon dioxide emission, reduce capital expenditure (Capex) by up to 68% and operational expenditure (Opex) by 57%. CMNA will significantly improve resource utilization by sharing, easy upgrading and network capacity expansion. Software defined radio (SDR) can be implemented easily, making operations and maintenance cheaper. CMNA makes it easy to adopt virtualization technology; physical BS are represented as virtual BS to mitigate inter-cell interference and improve spectral efficiency.

One of the most frequently used technologies for the implementation of the 5G is network is the RRH. The RRH is a radio technology that has the capability to improve the rate at which data are transferred, with negligible losses between the BBU Central Unit - Distributed Unit (CU-BU), through fronthaul to RRH and to the antenna. The RRH uses the common public radio interface protocol in communication.

Ultra-broadband backhaul links can be achieved using mmWave technology to carry traffic to or from either the small BSs or the relay stations. Coverage and capacity upgrades are very flexible and cheaper to implement with mmWave but very complex and expensive with a fiber optics backhaul link. mmWave technology will change the mobile industry owing to the available spectrum at this band. The mmWave will help to reduce antenna sizes, enabling the fabrication of hundreds or thousands of antenna elements, even at the user equipment (UE.) This study proposes a centralized wireless network architecture where all the layers, 1, 2 and 3, will be at the BBU, and a distributed antenna equipped with an RRH and MIMO. The RRH is connected to the BBU through a fiber-optic cable. The architecture will be the most economical for the implementation of 5G technology, high utilization efficiency and low inter-cell interference technology and architecture.

According to reference [7] MNO will require augmentation of 5G new ratio (NR) or gNodeB to be able to satisfy the requirements of modern services such as IoT, D2D and M2M communications. This will require better and cost-effective planning. In reference [8], analysis of 5G deployment through a mathematical approach is used to develop volume elasticity, price elasticity and a model to predict the future number of subscribers. An increase in the population is directly proportional to subscriber growth. Reference [9] presented an analysis of Capex, Opex, total cost of ownership (TCO), and network capacity based on antenna augmentation, intercell interference and energy efficiency for a distributed antenna system (DAS) and femtocell. Reference [10] performed a techno-economic analysis of small cell and DAS, various financial models, Capex and Opex. The paper also presented an expenditure model based on net present value (NPV) and the cell area model. Reference [11] defined the TCO for DAS as the sum of Capex and Opex and a sensitivity analysis (SA) was done on the bandwidth, running cost and interest rate. Reference [12] presented a techno-economic analysis for 5G architecture for DAS and MIMO. Reference [13] uses an ordinary annuity model to predict the future annual repeating payment of the principal amount invested for Capex, Opex and TCO. Reference [14] states that the principal cost for operations includes the running cost and backhaul cost, whereas the principal invested capital amount is made up of the eNodeB, the evolved packet core (EPC) and the transmit and receive antenna.

Although a lot of work on the techno-economic model and SA of essential variables was reported in literature, the authors did not consider the evaluation of 5G centralized wireless network architecture and a techno-economic model for centralized network architecture in 5G.

References [9], [10], [13], [8], [13], [10] present techno-economic models and sensitivity analysis for DAS, MIMO, macrocell and small cell, but the models presented do not take into account the effects of inflation and interest rate on investments in 5G coupled with centralized wireless network architecture.

No study has concurrently assessed the effect on interest rate and inflation on the proposed economic model for 5G centralized wireless network architecture. The key contributions of this study are highlighted below:

a) The proposed 5G LTE centralized wireless network architecture is designed with macrocell, small cell and femtocell.

b) A mathematical model for Capex, Opex and TCO will be presented for 5G centralized macrocell, picocell, femtocell and the model for centralized wireless network architectures.

c) An SA is performed on macrocell, modified picocell (small cell) and femtocell in a 50 meters square area. SA is performed on the effect of inflation and interest rate on the Capex, Opex and TCO of the macrocell, picocell, and femtocell.

2. 5G LTE Centralized Wireless Network Architectures

The proposed architecture in figure 1 is a centralized wireless network architecture made up of a modified gNodB macrocell (gNodB) connected to the main core through a fiber backhaul, from the BBU to the core; the gNodB is equipped with massive MIMO technology, which uses a very large array of antenna elements, up to 128, with the same number of transceivers. The massive MIMO streams are sent from all the antennas to the picocell and femtocell through mmWave. These transmissions are done at a reduced interference between signals going to different users and cell sites. The proposed architecture will allow various radio resources to operate together dynamically when needed, using the synchronization of several cell or antenna ports and processing of the radio signal together.

In the proposed centralized heterogamous network architecture all the traffic is aggregated and forwarded to the centralized radio access network (C-RAN) through fiber. The heterogamous network architecture has five or more modified picocells with RRH and femtocell offloading to a macrocell. The architecture will reduce maintenance cost by 50%, since maintenance will be done only on the macrocell and when the radio is faulty on the picocells. Energy consumption will be very low, since there will be no cooling and backup power will be reduced on all the picocells. The networks' architecture that is presented has some drawbacks, which include the cost of the spectrum license, integration of fronthaul and backhaul, network traffic control and interaction among cloud edge design mobile operators and private C-RANs. The most cost-effective way to deploy 5G in Ghana and the rest of Africa is upgrading the existing 4G LTE macrocell with massive MIMO technology, modified picocell (high-power picocell with RRH) and femtocell, as shown in figure 1 below. The macrocell houses the BBU and connects all traffic to the C-RAN through an internet protocol network. Traffic offloading is done between the picocell, the femtocell and the macrocell through an mmWave.

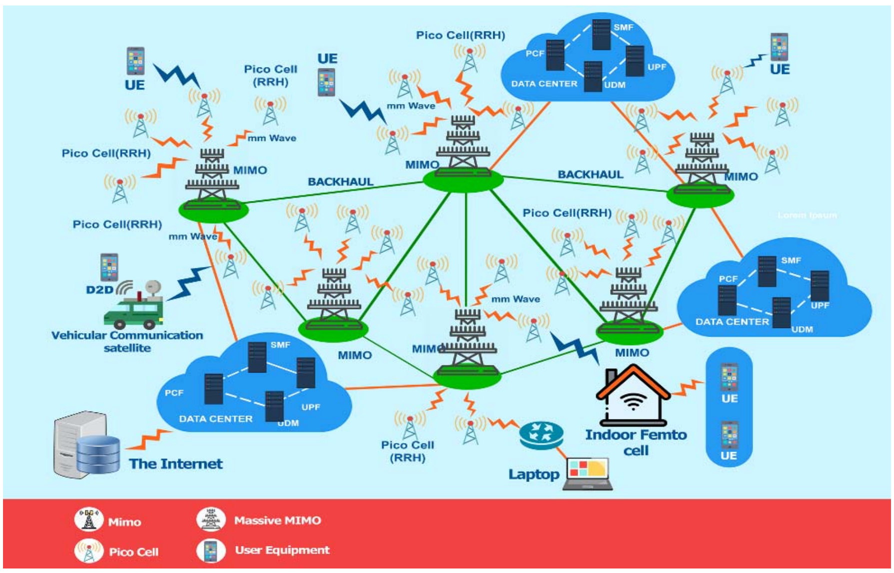

Fig.1: Proposed 5G centralized wireless network architecture.

3. Techno-economic Model Formulation

In this section, we based our research on the work of [7][9][12][42][9] [15] to develop an improved economic model for an annual repeating payment for the telecom infrastructure and the TCO. We will improve the models in the reference above and present models for 5G to calculate TCO for 5G centralized wireless network architectures.

(1) $$A = P\frac{r(1+r)^n}{(1+r)^n - 1}$$

(2) $$A = \frac{i}{1-(1+i)^{-n}}C$$

(3) $$\varepsilon_i = \sum_{k=0}^{K-1}\frac{\alpha_{k,i}}{(1+\beta)^k}$$

(4) $$C_{\text{macro}}^{TCO} = (1+f_m)N(C_{eNB}+C_{EPC})\frac{r(1+r)^n}{(1+r)^{n-1}} + NC_{st} + f_{BW}BW$$

(5) $$C_{\text{macro}} = \frac{i}{1-(1+i)^{-n}}N(C_{eNB}+C_{EPC}) + f_{\text{site}}\frac{i}{1-(1+i)^{-n}}N(C_{eNB}+C_{EPC}) + N_{C_{\text{site}}} + f_{BW}BW$$

(6) $$C_{\text{small}} = (1+f_{\text{site}})\frac{i}{1-(1+i)^{-n}}NC_{i/f}$$

Equation (1) is a repeating payment model where A is the repeating payment, n the years of the payment, P denotes the individual present value and r symbolizes the periodical interest rate. The parameters n in equation (1) and (2) and k in equation (3) represent the repayment plan in years. Again, equations (2) and (3) are the same as

$C = P = \varepsilon_i$, $r = I = \beta$ and $n = n = k$.

Equation (4) is the TCO for a macrocell with parameters including N is the number of eNodeB, C_{eNB} in the capital cost for a single Bs, C_{EPC} is the capital cost for the core network for deploying a single eNB, f_{BW} is the backaul bandwidth — expressed in €/Gbps — C_{st} site other cost apart from maintenance cost, Bw the cost of site interconnection, and f_m site maintenance costs. Equations (4) and (5) are the same but equation (6) is for a small cell.

Equations (1), (2) and (3) all have a limitation; payment is always made at the end of the investment and this can affect the agreed payment plan or attract a penalty if the MNO defaults on payment. The calculation does not take into account the time value for money (TVM), making the model unattractive to investors. The fluctuation in the interest rate and inflation affect the amount to be paid. Equations (4), (5) and (6) are the TCO for a macrocell and small cell; they do not take into consideration whether infrastructure is owned by the MNO or a tower company. The TCO does not take into account whether the tower infrastructure is owned by the MNO or rented, nor does it consider the height of the tower, which is a principal cost element in tower building. The performance analysis was between the Opex and logical MIMO antenna, Capex and logical MIMO antenna and TCO and logical MIMO antenna. Analysis of network capacity and network capacity density. which are essential for 5G based on a specific intersite distance (ISD), was not performed. The analysis did not consider network capacity for all the BS including macrocell, DAS and RRH, and the total network capacity based on the ISD used.

3.1. Techno-economic Conventional Model Formulation

The purpose of the study is to develop a risk-free, economical model that will mitigate all the limitations of the models used in [15][9][10][16][8][11][17][12][13][18].

The new model will have investment paid at the beginning of the financial year instead of the end. The effect of TVM, which was a major drawback of the models in 1, 2 and 3, is dealt with. A drop in interest rate and increase in inflation will not have any effect on this investment model. The model TCO or value will be (1+M) times that of the previous model. This makes the developed model more robust and good for MNO, resulting in a good NPV. The most significant metric the represent the difference between the present value of cash inflow and outflow is the NPV[19].

Since the present value will be greater than the initial cost of the investment, the profitability index will be greater than one. The initial capital investment for a centralized 5G network architecture will be proposed, as will the initial operational investment for a centralized 5G network architecture. The TCO or the initial cost of investment and finally, an NPV model will be developed for the MNO. The model for the total network capacity in a centralized architecture will be proposed and the cell area will be presented based on the ISD. The performance analysis between the Capex and network capacity TCO or total cost of investment (TCI) and network capacity will be presented in an area for macrocell, DAS, RRH and femtocell. Capex and NPV as well as Capex and network capacity density will be presented for MNO.

(7) $$C_p = C_i(1+m)\left(\frac{m(1+m)^n}{(1+m)-1}\right)$$

3.2. Capex for Telecom 5G Technology Deployment of Backbone (eNodeB)

Capex is the cash used in acquiring new telecommunication equipment, including installation, configuration and commissioning. Examples are eNodB, femtocell, picocell, core element and transmission backhauling. It also includes infrastructure, buildings (housing and offices) and the interest charges on the capital or the cost of capital. Suppose $C_{\text{Im}vMNO}$ is the initial capital of investments, m is the interest for the cost of capital and C_{cxmc} is the repayment amount, then based on equation (6),

(8) $$C_{cx\text{Macro}} = C_{\text{Im}vBB}(1+m)\left(\frac{m(1+m)^n}{(1+m)-1}\right).$$

The main advantages of this model over what is being used are that the TCI value will be (1+M) times that of the previous model, making this kind of investment more profitable, the risk level is very low and any increase in the interest rate will have no effect on the return value of the investment.

Assuming that the MNO owns the (mast) telecom tower, then

(9) $$C_{\text{Im}v\text{ Macro}} = (Bs+Ue)\begin{pmatrix}C_{CXMCT}+C_{ENB}+C_{EPC}\\ +C_{BH}+C_{ord}\end{pmatrix}.$$

For N number of eNodeB

(10) $$C_{\text{Im}v\text{ Macro}} = C_{CXMCT} + N\begin{pmatrix}C_{ENB}+C_{EPC}\\ +C_{BH}+C_{ord}+C_{bwm}\end{pmatrix}(Bs+Ue).$$

By substituting equation (10) in to (8)

(11) $$C_{\text{cx Macro}} = C_{CXMCT} + N\begin{pmatrix} C_{ENB} + C_{EPC} + \\ C_{BH} + C_{ord} + C_{bwm} \end{pmatrix}(Bs + Ue)\times (1+m)\left(\frac{m(1+m)^n}{(1+m)-1}\right)$$

3.3. Opex for Telecom 5G Technology for Backbone Site (eNodeB)

The Opex is the amount of money set aside to manage the day-to-day activities, which include the cost of rent, vehicle maintenance cost, salaries and wages, etc.

Where C_{ENB} is the cost of the eNodeB , C_{EPC} the cost of the evolved packet and C_{BH} the cost of backhauling or transmission networks, C_{ord} is the cost of installation and *Ms* and *Md* are the number of antennas at the source and destination. If $C_{InvoMNO}$ is the Opex expenditure for an MNO,

$$C_{InvoMacro} = C_{sm} + C_{me},$$

where C_{sm} is the site management cost and C_{me} is the site material cost.

For N number of sites

(12) $$C_{InvoMacro} = N\left(C_{sm} + C_{me}\right)\left(Bs + Ue\right).$$

For equation 7,

(13) $$C_{oxMacro} = \frac{C_{Invo\ \text{Macro}}}{1}(1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right).$$

By substituting equation (11) into (12),

(14) $$C_{oxMacro} = N\left(C_{sm} + C_{me} + C_{\text{Rent}}\right)\left(Bs + Ue\right)\times \left((1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)\right)$$

(15) $$C_{oxMacro} = C_{oxMC} + N\left(C_{sm} + C_{me}\right)\left(Bs + Ue\right)\times (1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)$$

If the tower is owned by the $\text{MNO} \rightarrow C_{net} = 0$ and C_{oxMC} the Opex of the telecom (mast) tower will be added to the equation.

3.4. Total Cost of Investments for Backbone Site (eNodeB)

TCO or TCI is a single value that represents the lifespan of a capital purchase. It is a financial estimate that helps in determining the direct and indirect costs of a product or services. It is the sum of the operational cost and the capital cost that helps in making critical agreement vs. buy comparisons. It includes vendor selection, prioritization of capital acquisition, and overall corporate budgeting.

(16) $$TCI_{BB} = C_{cxMC} + C_{ox\text{Macro}}$$

(17) $$TCI_{BB} N\begin{pmatrix} C_{ENB} + C_{EPC} \\ + C_{BH} + C_{ord} + C_{bwm} \end{pmatrix}(Bs + Ue)\times (1+m)\left(\frac{m(1+m)^n}{(1+m)-1}\right) + N\left(C_{sm} + C_{me}\right)\left(Bs + Ue\right)\times (1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)$$

factorization equation (17)

(18) $$TCI_{\text{Macro}} = \left((1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)\right)\times N\begin{pmatrix} C_{ENB} + C_{EPC} + C_{BH} + C_{ord} \\ + C_{bwm} + C_{sm} + C_{me} \end{pmatrix}(Bs + Ue)$$

If the MNO is renting the tower then C_{cxMCT} , C_{oxMCT} and equal to zero (0) and C_{Rent} will be added to the Opex of the MNO. Equation (17) will therefore become

(19) $$TCI_{BB} = (1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)(Bs + Ue)\times N\begin{pmatrix} C_{ENB} + C_{EPC} + C_{BH} + C_{ord} + C_{bwm} \\ + C_{sm} + C_{me} + C_{\text{Rent}} + C_{bwm} \end{pmatrix}.$$

Equation (18) will be used to determine the NPV of an investment in the mobile network operators over a period of time. $C_{\text{Traffic/Data}}$ is the revenue or data traffic generated over this period from traffic/data of a number of eNodeB.

3.5. Capex for Telecom 5G Technology Deployment of Picocell (RHH)

CAPEX involves the cost of purchasing new infrastructure and the action to integrate new items when existing equipment is updated. In picocell (RHH) BS costs are given by the following equation: $\left(C_{ENB} + C_{EPC} + C_{BH} + C_{ord}\right)$. If there are N BS then $N\left(C_{ENB} + C_{EPC} + C_{BH} + C_{ord}\right)$ is the cost of all the BS. The total capital cost for a year will then be given by

(20) $$C_{cxRRH} = (1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)\times N\left(C_{ENB} + C_{EPC} + C_{BH} + C_{ord}\right).\text{T}$$

3.6. Opex for Telecom 5G Technology for Picocell (RRH)

The Opex for a picocell (small cell) will be the cost of operation and maintenance of the network and site rental, if C_{sm} and C_r are the site rental cost then for N BS, the sum of the Opex variable will be $N\left(C_{sm} + C_r\right)$.

(21) $$C_{oxRRH} = (1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)N\left(C_{sm} + C_r\right).$$

The TCO or cost of investment for the picocell (RRH) is the sum of the total Capex and the total Opex.

(22) $$TCI_{RRH} = C_{cxRRH} + C_{oxRRH}$$

(23) $$TCI_{RRH} = N(1+m)\left(\frac{m(1+m)^n}{(1+m)^n - 1}\right)\times \begin{pmatrix} C_{ENB} + C_{BH} \\ + C_{ord} + C_{sm} + C_r \end{pmatrix}$$

3.7. Centralized Indoor Solution with Femtocell

LTE femtocell technology is used in the indoor environment. The introduction of femtocells brings about a reduction in the deployment of macrocell sites and reduces the millions of dollars operators spend on building macrosites. Femtocells provide exceptional improved coverage and capacity, resulting in revenue generation from services such as internet service, video and data service. When femtocell technology is used, electricity bills are no longer the responsibility of the operators. The ability of a femtocell to do automatic configuration, self-organization, synchronization and timing, eliminates the cost of operation and maintenance. Compared to macrocell, microcell and picocell, the deployment of femtocell technology will reduce capital and operating expenditure, thus reducing the TCI or cost of ownership to the MNO, as shown in equation (25).

$$TCI_{\text{Femto}} = N(1+m)\left(\frac{m(1+m)^n}{(1+m)^n-1}\right)(C_{ENB}+C_{BH}) \quad (24)$$

3.8. Total Cost of Investment or Cost of Ownership for Centralized Wireless Network

The TCI for centralized wireless network architecture is defined as the sum of all the TCI for the number of BS deployed.

$$TCI_{CWN} = TCI_{BB} + TCI_{RRH} + TCI_{\text{Femto}} \quad (25)$$

Substituting equations (19), (23) and (25) into equation (26) yields

$$\begin{aligned} TCI_{CWN} = {} & (1+m)\left(\frac{m(1+m)^n}{(1+m)^n-1}\right)(Bs+Ue)\times \\ & N\begin{pmatrix} C_{ENB}+C_{EPC}+C_{BH} \\ +C_{ord}+C_{bwm}+C_{sm} \\ +C_{me}+C_{\text{Rent}}+C_{bwm} \end{pmatrix}+ \\ & N(1+m)\left(\frac{m(1+m)^n}{(1+m)^n-1}\right)\begin{pmatrix} C_{ENB}+C_{BH} \\ +C_{ord}+C_{sm}+C_r \end{pmatrix}+ \\ & N(1+m)\left(\frac{m(1+m)^n}{(1+m)^n-1}\right)(C_{ENB}+C_{BH}) \end{aligned} \quad (26)$$

Factorizing equation (26)

$$TCI_{CWN} = (1+m)\left(\frac{m(1+m)^n}{(1+m)^n-1}\right)\times N\left\{\begin{matrix} (Bs+Ue)\begin{pmatrix} C_{ENB}+C_{EPC}+C_{BH} \\ +C_{ord}+C_{bwm}+C_{sm} \\ +C_{me}+C_{\text{Rent}}+C_{bwm} \end{pmatrix}+ \\ p(C_{ENB}+C_{BH}+C_{ord}+C_{sm}+C_r) \\ +f(C_{ENB}+C_{BH}) \end{matrix}\right\} \quad (27)$$

4. Model Verification

5G technology will required many NR to be deployed to achieve dense coverage, high capacity, high throughput and ultra-reliable low-latency communication. 5G will required shorter ISD, meaning that MNO will deploy many more sites than 4G. Both old 4G and 3G of 1 GHz to 2.6 GHz for high coverage, and a new high band spectrum between 3.5 GHz to 40 GHz for high capacity will be required. The deployment will require the installation of RRH (4T4R, 8T8R, 16T16R, 16T16R, 32T32R), with massive MIMO antenna and fronthaul (fiber optics) on the tower (see the centralized architecture in figure 1). Based on the needs of 5G technology, the cheaper and easier way of deploying 5G technology in Ghana and the rest of Africa would be the implementation of centralized architecture in collaboration with network sharing to enable MNO to meet the ISD of 5G technology. In this section the researchers will report on testing of the model using the MTN network in the Tema metropolitan area. Tema has an area of 565 km^2 [20][21][22] and a population of about 292 700 living in 40 956 houses. The test was performed on 50 km^2, 1.3 km ISD for the macrocell, 0.698 km for the modified picocell and 0.354 km for the femtocell. The test considered 25 368 people in 3 624 houses. The size of each home is 13.8 m^2, and each home has seven occupants. We will verify the economic performance of the models for macrocell, modified picocell (small cell) and femtocell [23] [24]. An SA will be performed on macrocell, modified picocell (small cell) and femtocell in a 50 m^2 area. Finally, an SA [25] is used to assess the effect of a key variable on the Capex, Opex and TCO of the macrocell, picocell, and femtocell.

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4.1. Data Analysis

Table 1: TCO Cost Parameters and System Variables

General Costs			
Parameter	**Description**	**Value**	**Range of Analysis**
	Macrocell		
C_{eNB} or gNB	Capital cost of eNB or gNB	$1,250.00	[400, 1600]
C_{EPC}	Cost of core for deploying single gNB	$137.50	[50, 175]
Nm	Number of eNB or gNB or NR deployed	120	[10,130]
n	Instalment plan per year	$6.00	[2, 20]
m	Annual interest rate	$0.08	[2.5, 9.5]
C_{sm}	Cost of site maintenance/ year	$3,800.00	[1150, 5550]
C_{oxmct}	Cost of running the operation (passive, active and others)	$1,115.63	[446.25, 1338.75]
C_{cxmct}	Cost of investment of the passive infrastructure/ year	$17,727.95	
C_{BHm}	Annual cost of front- and backhaul	$6,000.00	[2400, 7200]
bwm	Cost of site interconnection	10	[5, 15]
C_{me}	Cost of installation material	$980	
C_{ord}	Cost of installation	$650	
Lbw	Yearly backhaul cost per Gbps	1300	[585, 1755]

Bs	Built-in antennas for MIMO at the BS for macrocell	64	[2, 4, 8, 16, 64, 128, 256, 512]
Ue	Built-in antennas for MIMO at the UE for macrocell	4	[2, 4, 8, 16, 64, 128, 256, 512]
	Picocell (RRH)		
C_{eNB}	Capital cost for a single small cell (modified picocell)	$850.00	[5950, 17850]
C_{epcp}	Cost of core for deploying single gNB	$80.00	
Np	Number of picocell eNB	120	[10, 130]
C_{sp}	Cost of site maintennace	$270.00	[78.84, 236.54] €
Bsp	Built-in antennas for MIMO at the BS for picocell	64	[2, 4, 8, 16, 64, 128, 256, 512]
Uep	Built-in antennas for MIMO at the UE for picocell	4	[2, 4, 8, 16, 64, 128, 256, 512]
C_{BHp}	Fronthaul cost for optical fibre	$6,900.00	
$Cbhp$	Yearly backhaul cost per Gbps for picocell	790	
$Csit$	Cost of site interconnection	10	[5, 15]
		7900	
Parameter	Femtocell	**Value**	**Range of Analysis**
C_{enbf}	Capital cost for a single BS	$110.00	
Bhf	Yearly backhaul cost per Gbps for femtocell	$544.00	
Nf	Number of femtocells deployed	120	[1, 120]
C_{EPCf}	Core network cost for installing a single femtocell	$80.00	
Bsf	Built-in antennas for MIMO at the BS for femtocell	64	[2, 4, 8, 16, 64, 128, 256, 512]
Uef	Built-in antennas for MIMO at the UE for femtocell	4	[2, 4, 8, 16, 64, 128, 256, 512]
$Bhfc$	Backhauling cost	$38.50	

4.2. Result

Table 2: ISD of 1.3 km, 50 km^2, Macrocell (RRH), 7.5% Interest Rate

Sites	Capex k$	Opex k$	TCO k$
1	593.6	76.6	670.1
10	5 935.9	765.5	6 701.5
20	11 871.9	1 531.1	13 403.0
30	17 807.8	2 296.6	20 104.4
40	23 743.8	3 062.2	26 805.9
50	29,679.7	3 827.7	33 507.4
60	35 615.6	4 593.2	40 208.9
80	7 487.5	6 124.3	53 611.8
100	59,359.4	7 655.4	67 014.8
120	71 231.3	9 186.5	80 417.8

Table 3: ISD of 0.698 km, 50 km^2, Modified Picocell (RRH), 7.5% Interest Rate

Sites	Capex k$	Opex k$	TCO k$
1	140.94	4.20	145.14
10	1 409.41	42.05	1 451.46
20	2 818.82	84.10	2 902.92
30	4 228.23	110.88	4 339.11
40	5 637.64	143.11	5 780.75
50	7 047.05	172.39	7 219.44
60	8 456.45	196.78	8 652.45
80	11 275.27	257.0	11 532.27
100	14 094.09	321.67	14 415.76
120	16 912.91	378.435	17291.345

Table 4: ISD of 0.354 km, 50 km^2, Femtocell, 7.5%s Interest rate

Sites	Capex k$	Opex k$	TCO k$
1	11.12	0.60	11.72
10	114.31	6.00	120.31
20	228.62	11.99	240.61
30	342.93	17.99	360.92
40	457.24	23.98	481.22
50	571.55	29.98	601.53
60	685.86	35.97	721.84
80	914.48	47.97	962.45
100	1 143.10	59.96	1,203.06
120	1 371.72	71.95	1,443.67

4.3. Discussion of Result

The paper tested the model using the cost parameters in table 1 to compute the Capex, Opex, and TCO for macrocell (gNodeB), modified picocell and femtocell using the standard interest rate of 7.5%. The test result in table 2 for the gNodeB shows that the relationship between the Capex, Opex and TCO are directly proportional to the number of gNodeB deployed notwithstanding the total number of gNodeB deployed at a time. The cost of ownership for deploying one gNodeB is the same even if 10, 20, 30 or 40 etc. gNodeB are deployed at a time. This means that MNO can implement any number of gNodeB at any time with no increase or reduction in TCO.

Table 3 also shows the modified picocell with 0.698 km ISD. The results show that the Capex is directly proportional to the number of modified Picocells (mpgNodeB) deployed, irrespective of the total number of mpgNodeB deployed at a time. However, the Opex and TCO look different for this technology; a higher number of installations will reduce the Opex and TCO to an average of 15.32%. The result for femtocells in Table 4 is not any different from the gNodeB; the relationship between the Capex, Opex and TCO are directly proportional to the number of femtocells deployed. The TCO for femtocells is

100% of the cost of the subscriber's. This can be an open user or a closed user group and is capable of supporting up to 32 uses when deployed.

4.4. Sensitivity Analysis

Sensitivity analysis for macrocell, modified picocell and femtocell with variable interest rate

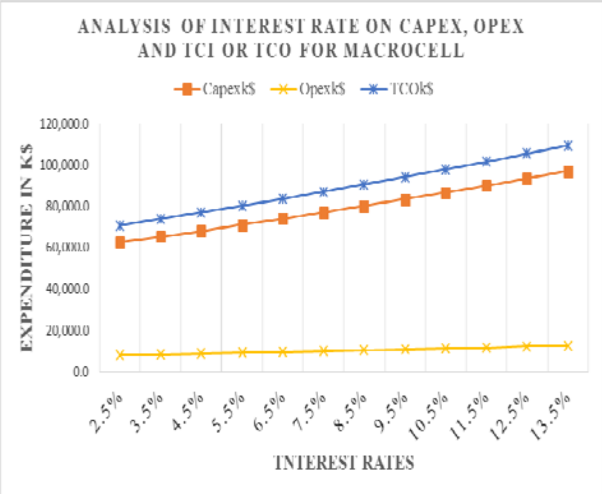

Fig 2: Effect of Interest Rate on Capex, Opex, TCO for Macrocell

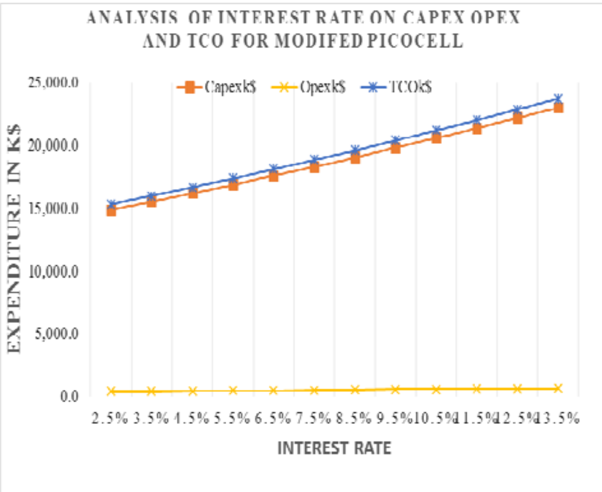

Fig. 3: Effect of Interest Rate on Capex, Opex, TCO for Modified Picocell

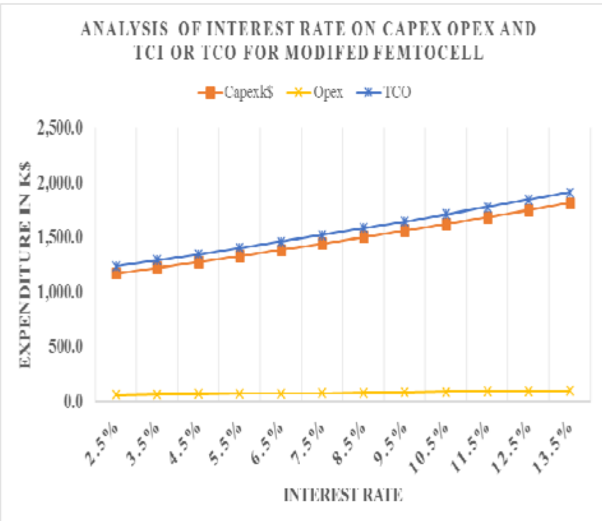

Fig. 4 Effect of Interest Rate on Capex, Opex, TCO for Femtocell

Sensitivity analysis for TCO for macrocell, modified picocell and femtocell with variable number of cells

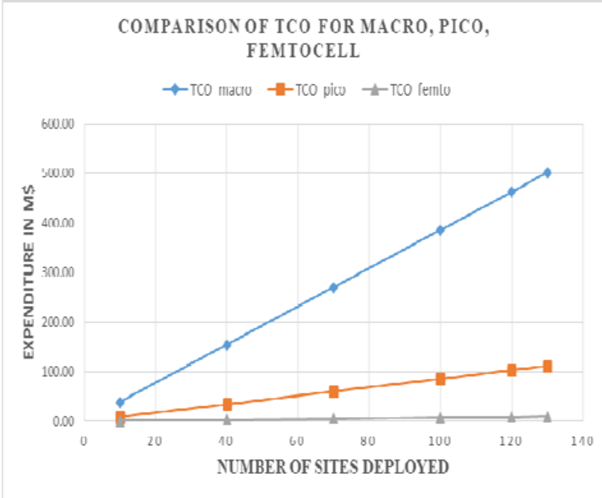

Fig. 5 Analysis for TCO for macrocell, modified picocell and femtocell with variable number of cells

4.5. Key Findings, Sensitivity Analysis and Future Work

Figure 2 shows the SA of the macrocell (gNodeB) with the interest rate as a key variable. The simulation result shows that there is an average increase in Capex of 5.883%, in Opex of 4.32% and in TCO of 5.12% when the interest rate varies from 2.5% to 13.5%. Figure 3 shows that the average increases in Capex, Opex and TCO are 4.61%, 3.34% and 3.98% respectively for an interest rate from 2.5% to 13.5%. Figure 3 depicts the SA for the femtocell, also with an average increase in Capex, Opex and TCO of 4.889%, 3.24% and 4.06% respectively. It is important to note that when the interest rate rises above 7.5%, MNO will pay more for the deployment of the new 5G technology. Fig. 5 shows the SA comparison between the cost of ownership (TCO) for macrocell, modified picocell and femtocell. The analysis shows that the TCO ratio for macrocell is one in four and a half times that of the modified picocell and 56 times compared to the femtocell. Comparing the modified picocell with the femtocell, the TCO ratio is one to 13. The SA shows that in addition to the high capital cost of the macrocell, the operational cost is also very high compared to the picocell and femtocell, which is due to the cost of maintenance and energy. Based on this analysis, MNO must be mindful of the number of macrocells to deploy in 5G technology. Very few macrocells should be deployed as the major backbone and more picocells and femtocells should be used to increase coverage. Future work could consider an NR macrocell and NR picocell with fronthauling with edge computing, A techno-economic analysis comparison of TCO, capacity and coverage could also be undertaken.

5. Conclusions

In this paper, we presented a fifth generation (5G) centralized network architecture that will provide dense coverage, high capacity and low latency. We also presented an economic model Capex, Opex and TCO for the centralized architecture. A mathematical model was also presented for capacity and throughput for a centralized wireless network. We verified the model using numerical data from the MNO and the national communication of Ghana. The result of the simulation shows that TCO for macrocell is very high compared to that for picocell and femtocell because of the maintenance and energy cost of the macrocell. The simulation results show that the centralized architecture presented is the most economical design, especially if MNO use fewer macrocells as backbone in the 5G network deployment. Finally, the result shows that MNO should be mindful of the interest rate and must not accept anything above 7.5%.

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