ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul1805

Optimization of Base Station Densities in Hybrid 5G DenseNets

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Publication Date: 2026/08/29

Abstract: The fifth-generation (5G) networks will provide high capacities with less transmission delays. To meet these features, it is depicted that these networks must be densified that is with many base stations (BSs) dominated by small BSs. The BS density to be deployed in a network is a vital design issue since an inappropriate BS deployment could give rise to displeasing consequences, such as excess interferences, void cells that is cells without users, excess power consumption and operating costs since over 50% of the total cellular network energy consumption is by BSs. In this paper, the simplex method of linear programming is used to determine the optimal BS density that can consume the optimal power based on maximizing the service area. Using the cell edge conditions, we generate radii of the two cells and hence respective areas are determined. Results show that although all the minimum powers and their respective BSs cover the entire service area, there is an optimal BS combination with an optimal power consumed.

Keywords: *Network Densification, Hybrid Network, Power Consumption, Simplex Method.*

How to Cite: Fredrick William Mukalazi; Edwin Mugume; Jonathan Serugunda (2026) Optimization of Base Station Densities in Hybrid 5G DenseNets. *International Journal of Innovative Science and Research Technology*,11(7), 3862-3868. https://doi.org/10.38124/ijisrt/26jul1805

I. INTRODUCTION

Network densification is depicted as one of the ways to meet the extreme features of 5G cellular networks. Network densification is termed as the deployment of base stations (BSs) with short coverage enabling local spectrum reuse. In addition, shorter transmission links are experienced by users hence enjoying spatial and spectral resources [1]. While small cells help to increase the network capacity, there can arise some problems especially inter-cell interference mitigation and power control [2]. The BS density to be deployed in the network is a vital design issue since an inappropriate BS deployment could give rise to displeasing consequences, such as excess interferences, void cells that is cells without users, high excess consumption and operating cost [2]. In addition, BSs account for the bulky energy consumption of more than 50% of the total cellular network energy consumption. Majority of BSs in cellular network close to 80%, work for most of the time in a serious unsaturated state that is at a load less than 20%, hence wastage of a lot of energy [3]-[4]. Besides wastage of energy, high energy consumption leads to escalation of green house gas emissions considered as a notable threat to the protection of the environment. Green communication strives to lower energy consumption without a trade-off of quality of service. This can be addressed through a number of approaches including green cellular BS [5]. On that note, this justifies the reason why network densification must be done in a controlled manner.

In [6], a new metric for power spectral efficiency (PSE) was proposed as way to estimate the total power and the spectral efficiency to cover a considered area based on a given criterion for network performance. The PSE metric was designed to provide a likelihood to determine the optimal parameters of transmission power for each BS and the BS density, hence determine the minimum power consumed to extend over the area considered. The new metric was based on derivation of the average area of each BS , the aggregate power consumed, and the mean ergodic capacity expressions. Results show that the PSE metric provides a new perspective on the design and optimization of wireless communication systems, mostly on the transmitting power selection. Authors in [3] proposed a cell zooming algorithm based on load balancing (LB) which in turn improves a traditional cell zooming algorithm based on load concentration (LC algorithm) to improve energy efficiency (EE) in a heterogeneous cellular network. This network model includes one macro BS (CBS) and many small BSs (SBS). The CBS is designed to provide coverage as the SBSs dynamically adjust the transmit power as a way to achieve cell zooming. LB algorithm is achieved by adjusting the transmission power of SBSs with heavy load, and dispersing the traffic to the neighboring SBSs with light load while the improved LC algorithm is achieved by closing the SBSs of which the load are less than the threshold thereby users are absorbed by the surrounding SBSs. It is seen from the results that both algorithms can aid reduction in the energy consumption and improvement in the EE of heterogeneous cellular network compared with no cell zooming. Researchers

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in [3] employ one macro and many micro BSs but do not specify the number of base stations deployed in the network.

In [4], optimization of BS density in a two-tier network was done based on achieving high EE performances utilizing a stochastic geometry model. The EE performances were made trackable and analyzable by transforming the BS density optimization in each tier into an equivalent problem to jointly optimize the sum and ratio of BS densities. The generated monotonic optimization problem was solved using a dynamic gradient based iterative algorithm through solving the quadratic functions. Results show that for the quantitative analysis of EE performances based on the data fitting method, there is an approximately linear relationship between the optimal BS density and the user density but holds only when users are particularly dense.

In this paper, we develop a metric to determine the optimal number of BSs, that cover the total service area with the minimum total consumed power for a two-tier network. We achieve this by generating an optimization problem using a linear power model based on maximizing coverage of the total service area. The optimization problem generated is linear so it solved by the simplex method.

II. SYSTEM MODEL

➢ *Network Topology*

A hybrid cellular system of 4G and 5G BSs is considered as shown in Fig.1. 4G and 5G BSs operating in UHF and mmWave bands respectively are located uniformly in the service area. The 4G tier operates at 2 GHz while the 5G tier operates at 28 GHz. This work considers the downlink of the network since it is responsible for bulky energy consumption.

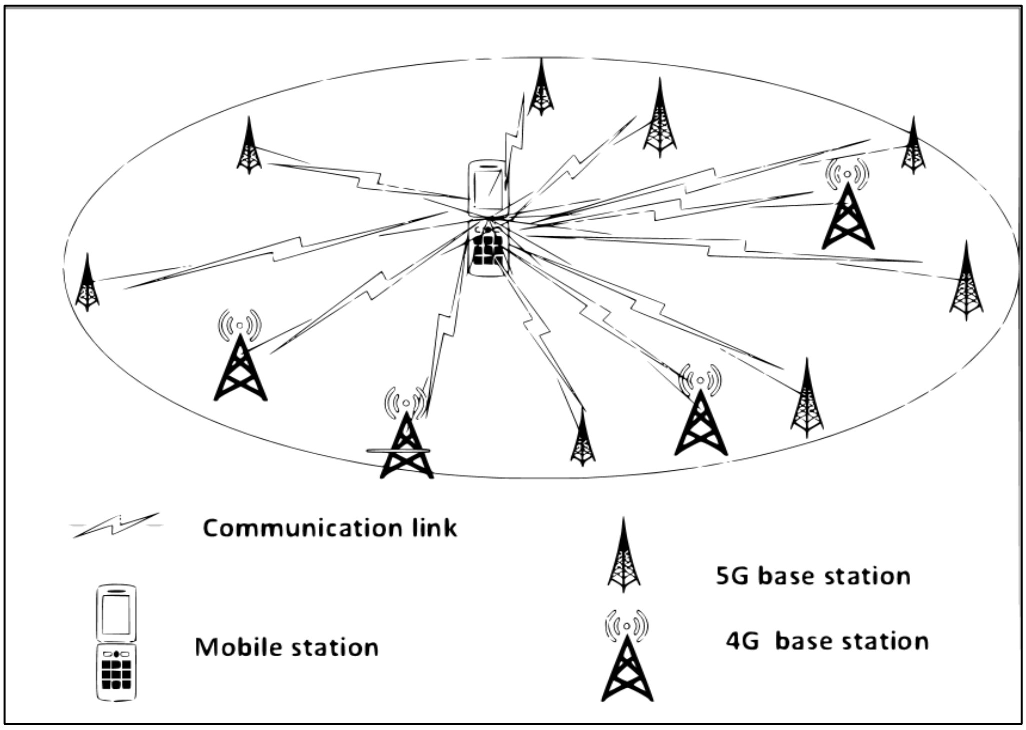

Fig 1 Hybrid Network Configuration

➢ *Path Loss Models*

The Stanford University Interim (SUI) model and the close in free space reference distance (CI) model are adopted for the 4G tier and the 5G tier respectively.The SUI model works for frequencies up to 3.5 GHz, a cell radius ranging from 0.1 km to 8 km, BS height ranging from 10 m to 80 m and receiver antenna height from 2 m to 10 m. The model caters for specified terrain types: terrain A models very dense environments (fit for urban centers); terrain B models suburban areas; and terrain C is recommended for rural areas [7]. In this work, terrain A is considered and the path loss is expressed as:

$$P_{L_4} = A + 10n\log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + \mathcal{S} \quad (1)$$

Where S models shadowing effects (where S ~ (8.2,10.6) dB), n is the path loss exponent, d is distance between the transmitter and the receiver in kilometers, d_o is the close-in reference distance, X_f is correction for frequency above 2 GHz, X_h is the correction for mobile station (MS) height in meters, and P_{L4} is the path loss in dB. Note that $d > d_o$.

$A = 20\log_{10}\frac{4\pi d_o}{\lambda})$, where λ is the wave length in meters,

$$n = a - bh_b + \frac{c}{h_b}, \quad (2)$$

Where parameters a, b and c are defined in [7] for different terrains, and h_b is the BS height. According to [7] ,

$$X_f = 6\log_{10}\left(\frac{f}{2000}\right), \quad (3)$$

Where f is frequency of operation in MHz, and

$$X = \begin{cases} -10\log_{10}\ \frac{h_r}{2000})\text{Terrain A and B } h \\ -20\log_{10}\ \frac{h_r}{2000})\text{Terrain C,} \end{cases} \quad (4)$$

Where h_r is the MS height. The CI model can be applied for frequencies ranging from 0.5 to 100 GHz [8]. In this model, the path loss P_{L5} is expressed as:

$$P_{L5} = \text{FSPL}\,(f, d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) + \mathcal{X}, \quad (5)$$

Where f is the frequency of operation in Hz, n is the path loss exponent, d is the distance between the transmitter and receiver in meters, d_o is the close-in reference distance, X models the shadowing effects in dB, and FSPL is free space path loss given by:

$$\text{FSPL} = 20\log_{10}\left(\frac{4\pi f}{C}\right), \quad (6)$$

Where C is the speed of light.

➢ *Power Consumption Model*

This paper considers a linear power model expressed as:

$$P = \begin{cases} N_{TRX}P_O + \Delta_p P_{out}, & 0 \le P_{out} \le P_{max} \\ N_{TRX}P_{sleep}, & P_O = 0, \end{cases} \quad (7)$$

Where P is the power consumed by a BS, P_O is power consumption at the non-zero output power, Δ_p is the slope of the load-dependent power consumption, N_{TRX} is the number of the transmit chains, P_{out} is transmitted power, and P_{sleep} is sleep mode power. The parameters for the different BSs are shown in [9]. The power consumed by the 4G BS and 5G BS is denoted as P_4 and P_5 respectively.

III. PROBLEM FORMULATION

➢ *Radii Derivation*

Basing on the two tier network model, the user switches from one tier to the other depending on the received powers. At the cell edge, the user receives equal powers from the two neighboring tiers. The power received from the 4G tier and the 5G tier is denoted as P_{R4} and P_{R5} respectively. P_{R4} is expressed as:

$$PR4 = PT4 + GT4 + GR - PL4\,, \quad (8)$$

Where P_{T4} is the transmitted power by the 4G BS in dB, G_{T4} is the 4G BS antenna gain in dBi, G_R is the MS antenna gain in dBi , and P_{L4} is the path loss in dB. Similarly, P_{R5} is expressed as:

$$PR5 = PT5 + GT5 + GR - PL5, \quad (9)$$

Where P_{T5} is the transmitted power by the 5G BS in dB, G_{T5} is the 5G BS antenna gain in dBi, G_R is the MS antenna gain in dBi , and P_{L5} is the path loss in dB. Let $\gamma = P_{T4} + G_{T4} + G_R$, $\beta = P_{T5} + G_{T5} + G_R$, and substitute them in (8) and (9) respectively. P_{L4} and P_{L5} are also substituted in (8) and (9). Since $P_{R4} = P_{R5}$ at the cell edge, then:

$$\gamma - 20\log_{10}\left(\frac{4\pi f_4 d_{o_4}}{\text{C}}\right) - 10n\log_{10}\left(\frac{d_4}{d_{o_4}}\right) - X_f - X_h - \mathcal{S}$$
$$\neq\beta \quad - 20\log_{10}\left(\frac{4\pi f_5 d_{o_5}}{\text{C}}\right) - 10n\log_{10}\left(\frac{d_5}{d_{o_5}}\right) - \mathcal{X}. \quad (10)$$

Values of γ, β, X_f, X_h, X and S are obtained using parameters in Table I and using (3) and (4). For example γ = 28 dB, β = 19 dB, X = 8 dB, S = 9.65 dB, X_h = 32.4 dB, and X_f = 0 dB. Substituting the values of X_f, X_h, X, S, and collecting like terms, (10) becomes:

$$\gamma - 20\log_{10}\left(\frac{4\pi f_4 d_{o_4}}{\text{C}}\right) - 10n\log_{10}\left(\frac{d_4}{d_{o_4}}\right) - 42.05$$
$$\neq\beta \quad - 20\log_{10}\left(\frac{4\pi f_5 d_{o_5}}{\text{C}}\right) - 10n\log_{10}\left(\frac{d_5}{d_{o_5}}\right) - 8;$$
$$\beta \quad - \gamma - 20\log_{10}\left(\frac{4\pi f_5 d_{o_5}}{\text{C}}\right) + 20\log_{10}\left(\frac{4\pi f_4 d_{o_4}}{\text{C}}\right)$$
$$= 10n\log_{10}\left(\frac{d_5}{d_{o_5}}\right) - 10n\log_{10}\left(\frac{d_4}{d_{o_4}}\right) - 34.05;$$
$$\beta \quad - \gamma + 20\log_{10}\left(\frac{4\pi f_4 d_{o_4}}{4\pi f_5 d_{o_5}}\right) = 10n\log_{10}\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right) - 34.05;$$
$$\beta \quad - \gamma + 20\log_{10}\left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right) = 10n\log_{10}\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right) - 34.05 \quad (11)$$

Substituting the values of γ, β and collecting like terms, (11) becomes:

$$19 - 28 + 10\log_{10}\left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right)^2 = 10\log_{10}\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right)^n - 34.05$$
$$25.05 + 10\log_{10}\left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right)^2 = 10\log_{10}\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right)^n. \quad (12)$$

Further simplification of (12) gives,

$$10\log_{10}\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right)^n = 10\log_{10}\left[\left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right)^2 \times 319.89\right]. \quad (13)$$

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jul1805

Then (13) becomes:

$$\left(\frac{d_5 d_{o_4}}{d_4 d_{o_5}}\right)^n = \left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right)^2 \times 319.89 \tag{14}$$

Hence, d_5 can be expressed as:

$$d_5 = \sqrt[n]{319.89 \left(\frac{d_4 d_{o_5}}{d_{o_4}}\right)^n \left(\frac{f_4 d_{o_4}}{f_5 d_{o_5}}\right)^2} \tag{15}$$

The above relationship is used to determine the radii of the two tiers. For generality, the area of a circle is considered. Area (A) of the circle is given by $A = \pi r^2$, where r is the radius of the circle. The area of the 4G tier and the 5G tier is denoted as A_4 and A_5 respectively. A_4 is expressed as:

$$A_4 = \pi d_4^2, \tag{16}$$

Where d_4 is the radius of the 4G cell, and A_5 is expressed as:

$$A_5 = \pi d_5^2, \tag{17}$$

Where d_5 is the radius of the 5G cell. Hence, the total area of the two tiers is denoted as A_T, expressed as:

$$A_T = A_4 + A_5. \tag{18}$$

- *Optimization Algorithm*

In this paper, optimization is achieved by the simplex method. The objective function of the optimization problem is not computed at every point but instead, it is computed starting from a corner point of the feasibility region (at the origin where all the main variables of the function are zero) to all corners until the optimal values are obtained [9]. A primary linear programming problem involves determining extreme values of the function based on certain constraints. We either try to maximize or minimize the value of this linear function, such as to maximize or to minimize profit or cost [10].

In this work, we generate the objective function as the total power consumed by all BSs in the network. The constraints of the optimization problem are generated based on covering the service area (A). The first constraint is generated based on the total service area each tier covers, where the sum of the areas covered by the two tiers should be greater or equal to A. The second constraint is generated based on the fair deployment of BSs to minimize power consumed. This is achieved based on the assumption that deployment of a macro (4G) BS should be followed by deployment of its equivalent micro (5G) BSs in terms of area covered. So the sum of the area covered by one macro BS and the area of its equivalent micro BSs must be greater or equal to twice the area covered by the macro BS. The objective function and its constraints are expressed as:

$$\text{Minimise } P_{cons} = P_4\lambda_4 + P_5\lambda_5 \tag{19}$$

Subject to:

$$\begin{aligned} A_4\lambda_4 + A_5\lambda_5 &\geqslant \mathcal{A} \\ \lambda_4 + \frac{A_4}{A_5}\lambda_5 &\geqslant 2A_4 \\ \lambda_4 \geqslant 0, \lambda_5 &\geqslant 0 \end{aligned} \tag{20}$$

Where P_{cons} is the total power consumed by all BSs, λ_4 and λ_5 is the number of 4G and 5G BSs respectively, A_4, and A_5 is the area of the 4G and the 5G tier respectively.

Table 1 Simulation Parameters

Parameters	**4G tier**	**5G tier**
A [km^2]	4	4
Carrier frequency [GHz]	2	28
Transmit power [dB]	13	8
Transmitter gain [dBi]	14	10
Transmitter gain [dBi]	1	1
C [m/s]	3×10^8	3×10^8
Average shadowing [dB]	9.65	8
n	4.795	4.795
$do4$, $do5$ [m]	30	1

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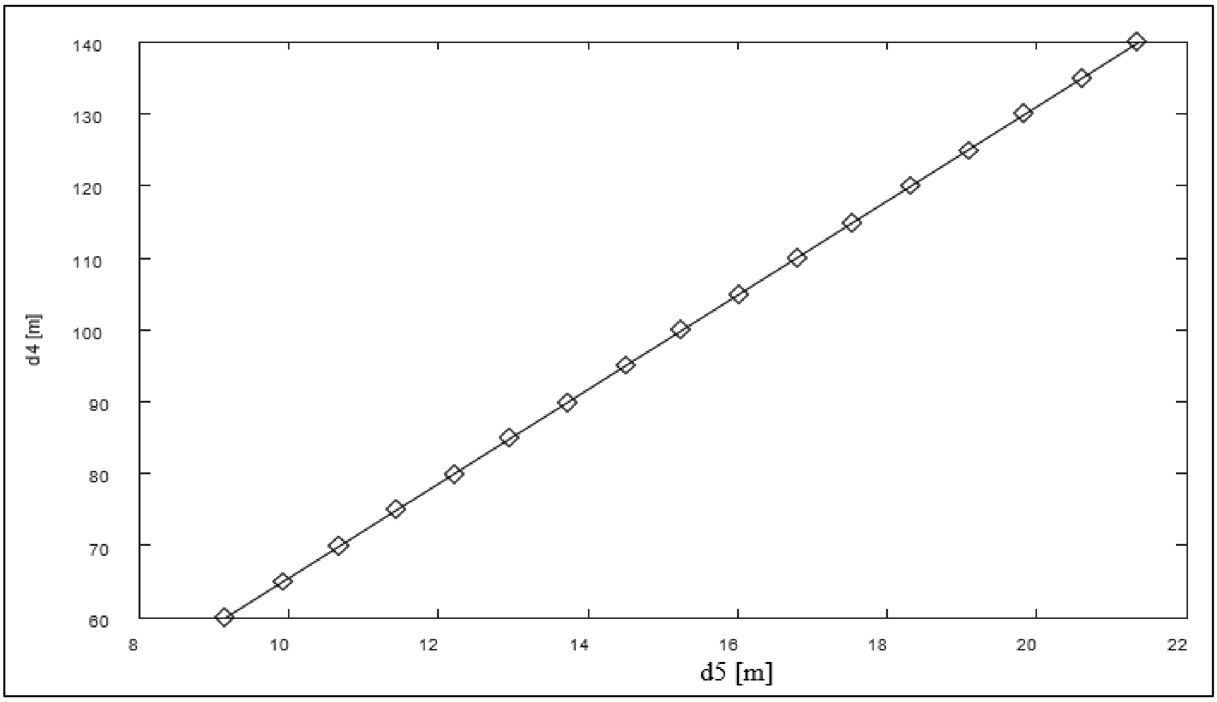

Fig 2 Radii Relationship of the Two Tiers

IV. NUMERICAL RESULTS

The simulation parameters are presented in Table I, unless otherwise stated.

Fig. 2 shows the relationship between the radii of the two tiers. It shows that there is a linear relationship between the radius of the 4G cells and 5G cells. This is because we equalized the received powers at the cell edge of the two tiers. The received power at the cell edge fades with the transmission distance. Therefore, for the received powers to be equal, if the transmission distance in one cell increases, the transmission distance in the other cell increases too.

Fig. 3 shows the 3D plot of the minimum powers (denoted as Pc) consumed against the 4G BSs and 5G BSs. It is seen that the number of 4G BSs below the optimal point are more than those above the optimal point while the number of 5G BSs below the optimal point are less than those above the optimal point. This implies that the number of 4G BSs reduce while the number of 5G BSs increase as the function tends towards its optimal point. This is because there is a linear relationship between the two radii of the two cells. An increase in the radii of the 4G cell increases its area covered hence reduction in the number of 4G BSs needed while this increases the number of 5G BSs. It is further seen that the optimal minimum power.

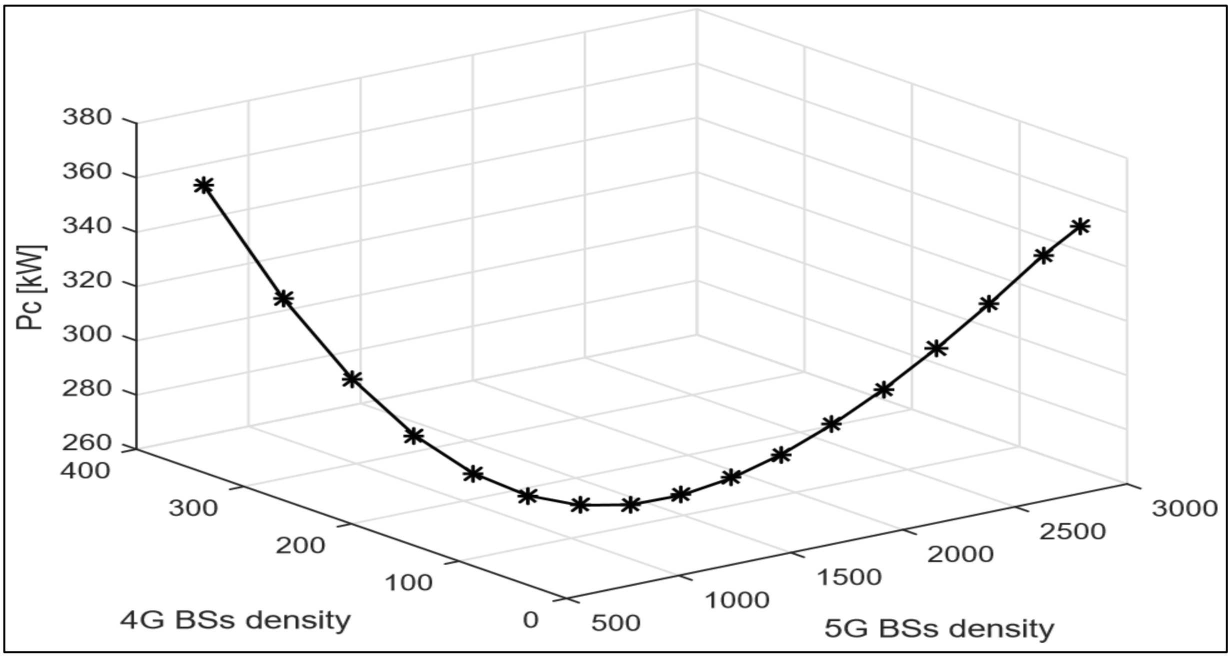

Fig 3 A 3D Plot of Minimum Power Consumed Verses Number of BSs

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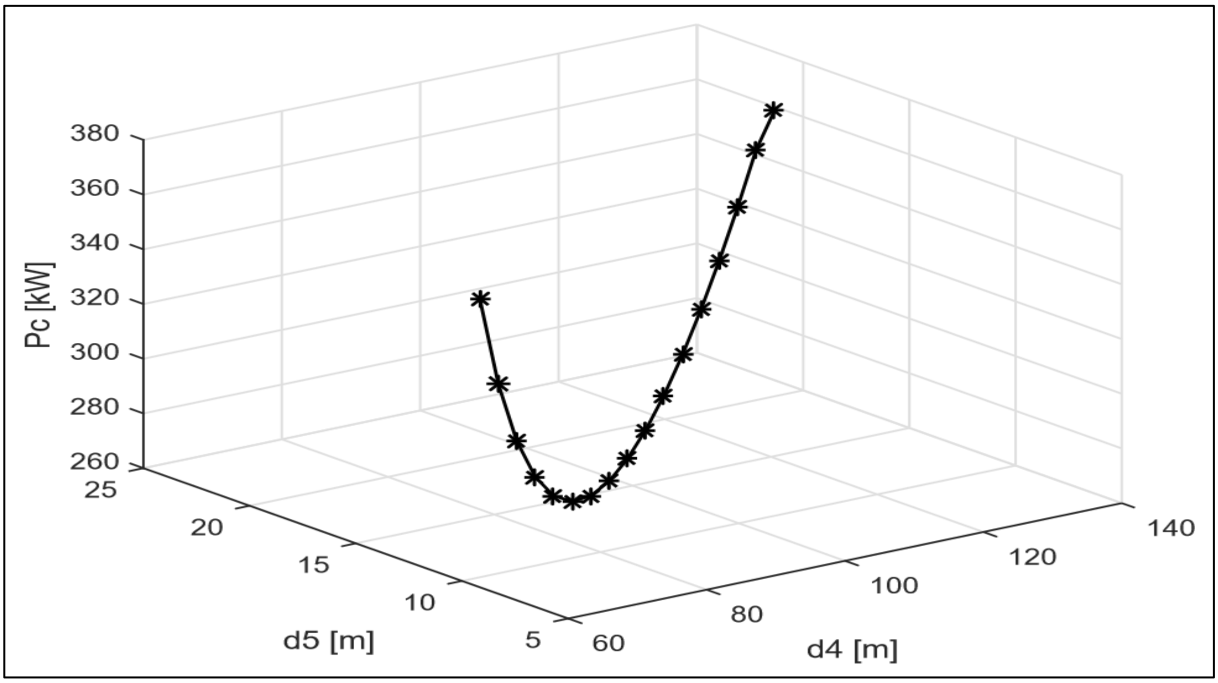

Fig 4 A 3D Plot of Minimum Power Consumed Verses Radii

Consumed is close to 265 kW obtained at 130 4G BSs and 1181 5G BSs. Therefore, 130 and 1181 BSs are the optimal 4G BSs and 5G BSs to obtain the optimal minimum power consumed by the network.

Fig. 4 shows the 3D plot of the minimum powers consumed against the radii of the two cells. It shows that the optimal minimum power consumed is obtained when d_5 and d_4 are 13.7 m and 90 m respectively. This implies that these radii values generate the maximum areas for each tier respectively.

V. CONCLUSION

In this paper, we use the simplex method of linear programming to determine the optimal BSs to be deployed in a hybrid dense networks. At different radii values of the two tiers, we get the minimum powers consumed. Results show that although all the minimum powers and their respective BSs cover the entire service area, there is an optimal BS combination with an optimal power consumed. It is also seen that at this optimal BS combination, the propagation distance between the nodes is reduced most especially in a 4G tier. Therefore in dense networks, it is key to have a rational BS deployment to minimize energy consumption in a network without a trade-off of the service area coverage.

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