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To cite this article: S A Olayanju and F M Dahunsi 2021 *J. Phys.: Conf. Ser.* **2034** 012033

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Conceptual framework for sleep modes exploitation analysis for energy-efficient 5G non-standalone new radio heterogeneous networks

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Abstract: The consideration for reduced operational expenses (OPEX) and concern for carbon dioxide (CO₂) emission effects on the environment has made energy efficiency a key ingredient in the design and operation of communication networks. The introduction of 5G wireless networks come along with millions of Base Transceiver Stations (BTSs) and corresponding billions of devices that can be connected to the networks. The future of radio communications is then posed for greater energy consumption. Energy-efficient wireless communication ("green" communication) is a compelling need. In this paper, analysis for exploiting sleep modes of 5G non-standalone New Radio (NSA-NR) heterogeneous BTS for energy consumption optimization is provided. The analysis includes the prospects of using the sleep ratio of 4G long term evolution (LTE) and 5G NR of the heterogeneous BTS to optimize energy consumption.

1. Introduction

Sustained development of the world implies the need for telecommunications will continue to grow. In order to measure up with the pace of growth and demand, future communication networks should be able to handle copious amount of user equipment while offering services at high speed and low latency for connected mobile end users. 5G network is a candidate for communication need of the future. Higher spectrum bands of 5G network means that a large number of equipment can be supported. This also implies, it requires three times more BTS to cover the same range of areas covered by 4G LTE BTS and consume power three times more than that consumed by a 4G LTE BTS offering similar services [1], [2]. Lowering energy consumption of 5G network is very crucial to Mobile Network Operators (MNOs) because lower energy consumption results in lower operational expenses and eventual increase in profit margin. Environmental concern is another very important reason why optimization of power consumption is of great importance. Of the total global energy consumed, information and communication technology (ICT) infrastructure is responsible for 3%, which corresponds to 2% global CO₂ emissions. Statistical records show that 58% of the energy consumed by ICT infrastructures comes from BTSs equipment. Energy optimization in ICT must therefore focus on reduction of BTS energy consumption in order to realise significant energy reduction [1], [3]. Improvement in the power consumption of the power amplifier (PA) has been recognized as a major way of cutting power consumption of BTSs. Different approaches exist in literature for energy consumption reduction, such as time domain energy efficiency.



This is achieved by reducing operating time of power amplifiers (PA) which is the main component in the BTS with large amount of energy consumption. This is done by limiting control signals during idle modes or when traffic is considered low. Transmission scheme is another approach in energy reduction. Multiple input multiple output (MIMO) technique is emerging as a way of reducing fading and increase throughput without necessarily increasing transmission power or bandwidth of the network. Switching off or operating unused devices in the sleep modes is a famous approach to reducing energy consumption of cellular networks [4]. This approach has seen a lot of interest and special cases of switching on/off of unused devices has emerged such as: relay techniques, cell zooming, and heterogenous networks (HetNets) [5], [6].

2. Related Works

A self-adaptive scheduling algorithm for better energy efficiency of BTS of 5G was developed in [7], neighbourhood cooperation among BTS was achieved by exploiting traffic loads of individual BTS as they switch states from active, turned off and sleep. In [2] a battery energy storage system with photovoltaic system was introduced, shedding non-critical loads in an attempt to optimize energy consumption of BTS. Power models was developed in [8], [9] for both micro and macro base stations in order to optimize power consumption of the base stations. Power consumption optimization, and minimization of switching between modes of operation while tracking the performance of the network was the focus in a work by [10]. Results from the work shows the proposed method guaranteed quality of service and achieve some measure of efficiency. Three categories of BTS in the Sahel region of Cameroon were identified by [11], energy model developed take into consideration all equipment located in the BTS, energy saving techniques were applied to minimize consumption in the BTS considered with corresponding operational cost reduction. The energy reduction capability of small low power base stations together with the conventional sites were investigated in [3]. the performance of the technique was investigated under full load conditions. The analysis of new radio standalone mode was compared with new radio in non-standalone mode in [12]. The analysis was based on system cost and complexity, coverage, and network capability. Performance analysis indicates that non stand alone is preferred when it comes to internetworking performance at least at the initial stage, while 5G non stand alone is the candidate for device performance, capability of the network, and efficiency of the network. Hence, 5G standalone new radio is preferred above its non-standalone counterpart for MNOs aiming to explore new horizons in communication industry and markets. In [13], the deficiencies of integrating the new radio (NR) BTS into the infrastructure of the existing LTE network is addressed. To ensure QoS, using 28 GHz link, a software dependent new radio serves as the air interface while the core is implemented through software dependent networking and radio access network. Simulations results from the work indicates QoS can be guaranteed by the proposed system. The focus of the research in [14] is on the challenges encountered by users connected to a network which operate a combination of 5G new radio and 4G BTS network in a non-standalone heterogeneous network. Possible solutions to the challenges were also suggested. A new handoff scheme was proposed in [15] to handle reconnection of incoming user equipment transiting from macrocell of a 4G BTS to small cell of a 5G new radio or vice versa. The scheme is aimed at reducing interruption time that is experienced during such a transition. Call blocking probability was analyzed using Markov chain technique. Results from the work shows that proposed technique was able to mitigate the interruptions and minimize call blocking probability.

3. Energy Efficiency

When radio interface technology/set of radio interface technology (RIT/SRIT) reduces radio access network energy consumption in relation to the provided traffic capacity to the minimum, network energy is said to be optimized. In relation to traffic characteristics, device energy efficiency is realised when RIT/SRIT minimized device modem power consumption. Reduced energy consumption in the absence of data communication can be achieved by the combination of both network and device energy efficiency. The sleep ratio which is a fraction of unoccupied time resources of the network and the sleeping time of

the device can be used to estimate the low energy consumption in the absence of data transmission. To evaluate enhanced mobile broadband (eMBB), sleep duration should be sufficiently long [16].

4. 5G New Radio Energy-Efficient Architecture

Significant amount of energy consumption takes place in the BTS, usually, the stations continue to consume energy when no data transmission is taking place. For a 4G BTS, mandatory continuous transmission of idle mode signals such as system information, cell reference and synchronization signals hinder shutting down of hardware components. Thus, exploitation of system idle mode to minimize energy consumption using 4G BTS is achievable, however, deep sleep duration is difficult in 4G networks. The 5G new radio (NR) was designed to support denser network and devices operating at high speed. 5G NR has the capability to offer improved energy efficiency by exploiting the sleep periods of the system. NR requires little continuous signal transmissions and thus, longer sleep periods is available wherein energy consumption can be conserved. The energy consumption saved is proportional to the number of devices that are put in sleep mode or completely turned off when no data transmission is taking place. The eventual energy saving of the 5G NR has significant effect on the total network energy consumption.

5G new radio (NR) together with Evolved Packet Core (EPC) is supported by the Evolved Universal Terrestrial Radio Access (E-UTRA) Dual Connectivity feature. Connection between a user equipment (UE) and an eNodeB takes the function of Master Node (MN) and that between UE and an en-gNB behaves just as a Secondary Node (SN). Figure 1 illustrates the E-UTRA-NR Dual Connectivity architecture.

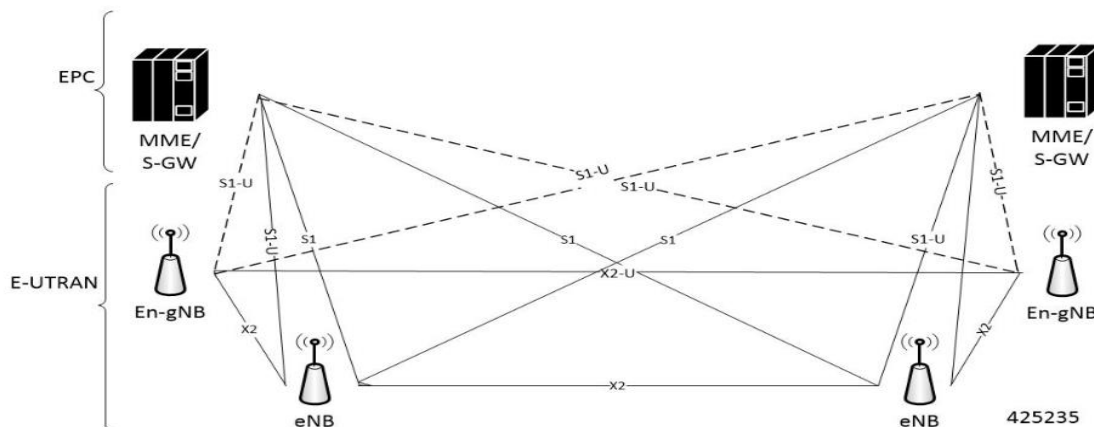


Figure 1: E-UTRA New Radio Dual Connectivity Feature. Source: [19]

5. System Model

5G network is considered a cellular network having various BTSs of equal cell size and operating at the same transmission range and power. In non-standalone architecture (NSA), 5G radio access network (RAN) with new radio (NR) is used together with the existing LTE radio and 4G core. In this way, NR is available in conjunction with 4G services and also offering capacities of the 5G network. High speed customer connectivity with 5G-enabled devices and usage of existing equipment are benefits of 5G NSA. Complete availability of 5G services without 4G infrastructures is termed Standalone Architecture (SA). BTS with standalone NR come with inbuilt mechanism for power consumption optimization and has great capacity to conserve energy usage. NR non-standalone (NSA) which depend on existing LTE BTS were first deployed, NR were included to increase capacity so as to meet data traffic demand, its power consumption can further be optimized.

6. Power consumption modelling

BTSSs is assumed to have capability of operating in three modes: the active mode, when data transmission and reception is ongoing. In the sleep mode, the BTSSs neither receive nor transmit any user traffic. Power consumed during this mode is minimal. In the turned-off mode however, the BTSSs are disconnected from the power source, power saving is highest in this mode. The network considered is a 4G LTE in conjunction with 5G NR as shown in Figure 2. The intension is to minimize total power consumed by the system; the system parameters is given in Table 1. The power model for individual cell is represented by equation 1 [8], [10], [17] :

$$P_c = \begin{cases} a \cdot P_{tx} + P_f, & \text{If BTS is ON} \\ P_{Sleep} + P_{off} & \text{If BTS is /SLEEPOFF} \end{cases} \quad (1)$$

where a is the slope of consumption, a constant; P_f and P_{tx} are fixed and variable consumption of the active mode P_{Sleep} and P_{off} are the power consumed during sleep mode and when the equipment is turned off completely.

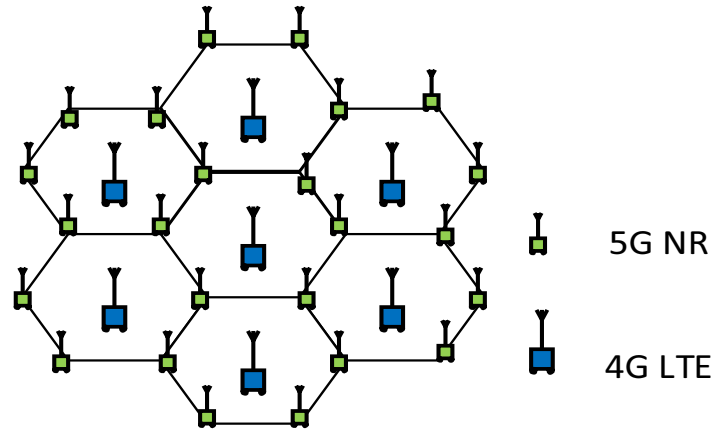


Figure 2: System Architecture [3], [10]

To reduce total power P_c , consumed, given that N is the number of BTSSs considered and M the number of user Equipment (UE) involved. Let:

$$\beta = \{BTS_1, \dots, BTS_N\} \quad (2)$$

$$U = \{UE_1, \dots, UE_M\} \quad (3)$$

The relationship between β , U and x , is given by

$$x_{ij} = \begin{cases} 1 & \text{if } UE_j \text{ is served by } BTS_i \\ 0 & \text{otherwise} \end{cases} \quad i \in \beta, j \in U \quad (4)$$

If π_{ij} is the transmission power between BTS_i and UE_j and w_{ij} is the bandwidth BTS_i assigned for UE_j . Then, UE_j obtainable data rate is given by equation 5:

$$\rho_j = \sum_{i \in \beta} x_{ij} w_{ij} \log_2(1 + \gamma_{ij}) \quad (5)$$

γ_{ij} is the SINR between BTS_i and UE_j and it's given by

$$\gamma_{ij} = \frac{\pi_{ij} \sigma_{ij} x_{ij}}{w_{ij} (\sum_{k=1}^N P_k \sigma_{kj} \zeta_k (1 - x_{kj}) + W N_0)} \quad (6)$$

where σ_{ij} is the channel gain between BTS_i and UE_j and W is the total bandwidth available, N_0 is the noise spectral density, transmission power of individual BTS_i is given by:

$$P_i = \sum_{j \in U} \pi_{ij} x_{ij} \quad (7)$$

The status of the BTS is modelled as:

$$\zeta_i = \begin{cases} 1 & \text{if } BTS \ i \text{ is Active} \\ 0 & \text{if } BTS \ i \text{ is in Sleep Mode} \end{cases} \quad i \in \beta \quad (8)$$

Total power consumed is given by:

$$P_c^t = \sum_{i=1}^N [(a \sum_{j=i}^M \pi_{ij} x_{ij} + P_0) \zeta_i + (1 - \zeta_i) P_{Sleep}] \quad (9)$$

The deactivation and power reduction of the BTSs are allowed only if the target QoS requirement is satisfied for each served UE_j . BTS transmission power to UE is given by equation 10 [18]:

$$\pi_{ij}^{(n)} = \frac{w_{ij} 2^{\frac{R_t}{w_{ij}}}}{W \sigma_{ij}} \left(\sum_{k \in \beta} P_k^{(n-1)} (1 - x_{kj}) \sigma_{kj} + W N_0 \right) \quad (10)$$

R_t is the target data rate, Equation 10 can be adjusted using equation 12 if QoS is compromised, i.e the power received at each UE_j is below the sensitivity $P_{Min j}$ of the UE_j .

For regulation purposes, all BTS must fulfil the condition given in equation 11

$$\sum_j \pi_{ij}^{(0)} = P_{Max} \quad (11)$$

$$\pi_{ij} = \max \left(\frac{P_{Min j}}{\sigma_{ij}}; \pi_{ij} \right) \quad (12)$$

Table 1: System design parameters [10]

Parameter	Value
N	Number of BTS deployed
M	Number of users
β	Set of N BTS deployed
U	Set of M users to be served
$P_{Min j}$	sensitivity of UE_j
P_{Max}	Maximum allowed BTS transmission power
R_t	Data rate target for each UE
N_p	Number of available PRBs at BTS
W	Total available bandwidth at BTS
W_p	Bandwidth of a single PRB
σ_{ij}	channel gain between BTS_i and UE_j

7. System optimization prospect

By adapting the number of active LTE cells (macro) and NR cells (micro) to variation in traffic, energy consumption optimization can be obtained. At different time of the day, system adaptation to capacity demanded can be employed to solve energy consumption optimization problems. Quality of services is also guaranteed for end users. When energy consumption is optimized, MNOs enjoys higher profit margins while the environment degradation through greenhouse gas emission is considerably contained. In the power consumption modelling, BTSs transmission power cannot be lower than that which will make power received at the UE to fall below $P_{Min j}$.

8. Conclusion

Sleep mode, the unused time resources of communication network has been identified as a component of the system that can be exploited for energy consumption optimization. In this paper, a power consumption model for LTE BTS and 5G NR is proposed for exploiting the said sleep mode of the system. The model uses QoS considerations as condition to guide sleep mode activation for energy conservation.

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