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Energy saving performance analysis for future fifth generation millimetre-wave cellular networks

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ABSTRACT

The deployment of fifth generation (5G) millimetre-wave (mmWave) base stations (BSs) will consume more energy over time due to the limited time available, despite the increasing interest in developing 5G mmWave wireless communication technology. Constructing 5G mmWave cellular network infrastructure can improve energy efficiency, which is a challenge to implement in heterogeneous networks. This paper presents analytical frameworks for monitoring the effectiveness of 5G mmWave cellular networks. Based on the state management of BS, a system model for 2-tier heterogeneous networks is developed, and particle swarm optimization (PSO) is then used to compute the total energy consumption of the heterogeneous networks. Energy consumption was compared and analysed by leveraging state switching and the aggregate delay for three methods: fundamental separation, conventional separation, and a proposed energy-saving method that introduced a sleep state. Simulation shows that the proposed energy-saving method, which is a combination of conventional separation approaches, has the lowest total energy consumption and offers a 9% reduction compared to other related works. The results validate the accuracy of the power usage used in the 5G mmWave cellular network of the proposed method.

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1. INTRODUCTION

Energy consumption reduction has earned much curiosity since it accounts for a huge amount of overall energy saving performance [1]. In conventional heterogeneous network design, several small cells are placed on a macro cell to handle the variable redistribution of traffic and rising data flow rate load and small cells are created. However, energy efficiency is no longer relevant in a normal heterogeneous network because base stations (BSs) in the small cell and macro cells must deal with data flow rate, control signal, and always stay awake [2]–[4]. On the other hand, the initial fifth generation (5G) millimetre wave (mmWave) new radio deployment will concentrate on enhanced mobile broadband, which utilises a unique combination of radio frequency bands to increase data bandwidth and energy connection efficiency [5], [6], thereby improving download and upload speeds and decreasing latency [7]–[10]. The most significant factor in creating 5G networks that must be considered is energy consumption and efficiency [11]–[13]. However, 5G networks currently face many big challenges, such as limited space in constructing 5G BSs that lead to serious energy consumption. In addition, the implementation of heterogeneous networks in 5G can improve energy efficiency, but it is difficult to manage [14]. The impact of mobile communication network energy consumption will become more significant in the future as increased traffic load is predicted in future 5G networks [15]–[17]. 5G also faces many challenges for improvement, such as requiring more mmWave BSs to get high-band coverage because wireless signals do not carry or transmit across large distances at this frequency.

The mmWave is considered for the backhaul wireless interconnection between the BS to achieve high throughput and spectral efficiency, which increases power consumption. Significant work to save energy has been done by the state management of BS to solve poor energy efficiency [17]–[20]. Directional antenna usage in mmWave transmission introduces a unique feature to mmWave systems: small, directed beams that can minimize fading, interference, and multi-path. Since adaptive arrays with precise beams reduce the influence of interference, the systems of mmWave frequently work under noise-limited instead of interference-limited situations [21]. Moreover, in device-to-device (D2D) communication, we can use this unique characteristic of mmWave for communication systems [22], which are considered standard cellular networks and may lack channel capacity that makes it beneficial to share the same power source for devices with existing user equipment (UE).

Heterogeneous networks, in contrast to homogeneous deployment, employ a variety of BSs to enhance the capacity of the networks, coverage, and energy efficiency, including traditional macro BSs as well as small power and lower-cost micro-BSs. As a result, wireless networks may become dispersed due to capacity constraints or coverage gaps. Uplink (UL) and downlink (DL) connection with the shift to heterogenous networks is different from homogeneous networks and also not compulsory to have the identical BS [17], [22]–[24]. Historically, the transmission required for DL is far higher than for UL. As a result, a lack of symmetry will happen in the resources required to support network traffic for both [25], [26]. Many attempts have researched the energy efficiency of this method since UP and DL decoupling enables better choice in shutting off some BSs, as well as energy savings at the terminal side [27], [28]. This frequency architecture is very important in mmWave, yet it is challenging in heterogeneous networks. Interference management and power control occur at several tiers, adding another challenge in cooperative green heterogeneous networks. Dynamic resource allocation is utilised in cooperative green heterogeneous networks to distribute resources cooperatively [29].

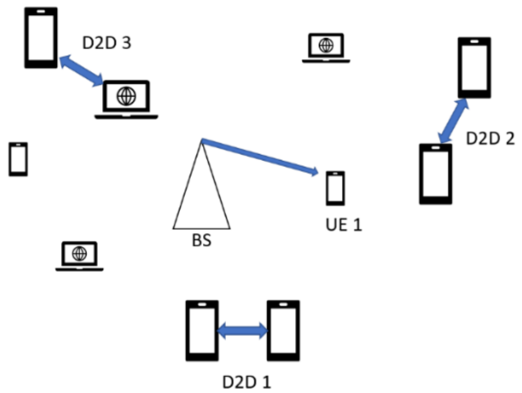
With huge quantities of spectrum available, wireless backhaul in the mmWave band, is capable of providing data speeds of several gigabits per second, and this has lately received significant interest [30]. Besides, the fast development of mmWave integrated circuits and antennas lays the door for mmWave communications to affect 5G. An energy-efficient backhaul scheduling solution is necessary to maintain current energy consumption levels [31], [32]. In this case, an evolutionary method is needed to improve speed connection efficiency and less latency for the 5G mmWave scenario. In this paper, presents an energy-saving performance analysis for the 5G mmWave cellular network BS management. Unlike in [18], we extend our previous study [23], which presents work focused on 5G mmWave cellular networks BS using the particle swarm optimization (PSO) method. This work is based on the state management for the BS approach, [17], where sleep state that is used for the BS to react faster to the modification of the UEs' traffic requirements and conserve energy. This work also assumes numerous pairs of D2D in a similar cell will be permitted to give identical resources with UE to enhance spectrum efficiency, as shown in Figure 1(a).

2. METHOD

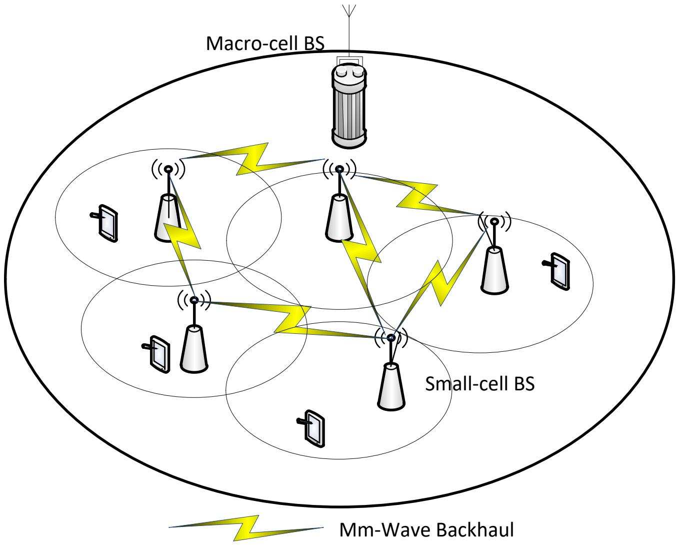
This work aims to investigate the BS state while serving the UE for two-tier heterogeneous networks, analyze the energy efficiency performance, and the reduced power usage used in the 5G mmWave cellular network. To achieve this, we assume macro base station (MBS) maintains the control signal in standard separation architecture. Small base station (SBS) manages both low and high data flow rates. At the same time, in customized separation architecture, an MBS manages the control signal with a low data flow rate, and an SBS manages high data flow rate. Furthermore, if any SBS does not cover a UE's data flow rate, it should be accommodated by an MBS. Besides, numerous pairs of D2D in a similar cell will be permitted to give identical resources with UE to enhance spectrum efficiency. If D2D communications are performed using mmWave transmission, highly directional beamforming minimizes interference to adjacent co-channel transmission lines. We depict a standard mmWave mesh backhaul network connection for densely distributed small cells where mobile users are associated with SBS, and BSs are linked via a mesh backhaul network in the mmWave band, as shown in Figure 1(b).

Let g_j and h_j, be the binary notation to represents the "on and sleep", respectively, or the off state. Gradient of conditional load power usage in SBS and MBS, denoted by, ρ_T and ρ_L, respectively. The power usage of SBS, $P(j)_{SBS}$, is given by:

$$P(j)_{SBS} = g_j(1-h_j)\left(P_T^f + \rho_T + P_T^{tx}(j)\right) + h_j(1-g_j)P_T^e \tag{1}$$



(a)



(b)

Figure 1. Schematic for; (a) D2D communication and (b) backhaul technology for SBS for mmWave

The optimization power usage of MBS, P_{MBS}, can be defined as (2):

$$\min P_{MBS} = P_L^f + \rho_L P_L^{tx} \tag{2}$$

where P_L^f is the permanent power usage (*on* state) and P_L^{tx} is the maximal power usage of MBS. Let f_j and s_j, be the binary transition state of SBS that indicates switches to Off and Sleep, respectively, or otherwise. Hence, the power usage of SBS during switching, denoted by, respectively, P_{on_s} and $P_{on_{off}}$, for (*on* to *sleep*) and (*on* to *off*). The power usage of transitions state for total m of SBS, denoted by, P_{ss}, can be calculated:

$$P_{ss} = \sum_j^{m-1}\left[f_j(1-s_j)P_{on_{off}} + s_j P_{on_s}(1-f_j)\right] \tag{3}$$

Based on (1)-(3), the total of power usage, P_{sum}, can be modelled as (4):

$$P_{sum} = P_{MBS} + \sum_{j=0}^{m-1} P(j)_{SBS} + P_{ss} \tag{4}$$

Hence, the total time taken for UEs to get serve by the BS, denoted by, T_{agg} , is given by:

$$T_{agg} = \sum_{j=0}^{m-1}(1-g_j)(1-h_j)f_j T_{on_{off}} + h_j s_j T_{on_s} + \sum_{i=0}^{n-1} o_i T_C \tag{5}$$

where T_{on_s} and $T_{on_{off}}$, respectively, is the delay for SBS during switching for (*on* to *sleep*) and (*on* to *off*), while T_C is the time taken for UE and BS to establish a new connection.

We consider heterogeneous networks in 5G, in which control and data planes are split also by considering different kind of data flow rate which is low and high data flow rate. The suggested energy saving system for 5G mmWave BS is nearly identical to the conventional separation method and identical to comparable studies in [15]. However, instead of only two states of SBSs, this work proposes the addition of a *sleep* state for energy-saving operation. With a spirit, when an SBS has many UEs that require a high data flow rate and UEs within the overlapping region frequently surrounded by the specified BS and adjacent BSs, it will be in *sleep* state rather than the *Off* state, as shown in Figure 1(b). BS state management follows the conventional separation method for BS, with only *on* and off states. Although shutting down BSs saves energy, it will cause latency in responding to user traffic requirements because BSs must first activate to fulfil UEs.

For the PSO algorithm, the energy consumption is obtained due to the energy consumption of the BSs due to state switching, traffic processing and aggregate delay in terms of the number of UEs being tested, for three separations. Basic separation is the technique that consists of an *on* state. In contrast, conventional separation consists of *on* and *off* state, and our proposed energy saving is combines of three states which is *on*, *off* and *sleep* states. For the PSO, the parameters are set by initialized the condition for the BSs between *on* or not and *sleep* or not, setup requirements of user data traffic that requests high or low data traffic, set up the connections between users and BSs to get load power usage, total permanent power, and load-dependent power usage. From this, the power usage of SBSs, P_{SBS}, and the power usage of MBSs, P_{MBS} will be calculated. Furthermore, the transition of the SBSs from *on*, *off* and *sleep* is also being initialized to get the power consumption of SBSs due to state switching, P_{ss}. Two-tier heterogeneous networks also relate to this work since heterogeneous networks can enhance the energy efficiency of BSs. Later, the simulation is carried out for data of P_{MBS}, P_{SBS}, and P_{ss} and using MATLAB at a frequency of 38 GHz to analyse the total energy consumption of the BSs, P_{sum} for all three methods.

3. RESULTS AND DISCUSSION

This section presents the simulation result for the total power usage, P_{sum} using the proposed energy saving method based on PSO. We also compare evaluation with the basic separation method, which assumes a random selection of the BS's state, and the conventional separation method, which always assumes a full plus complex state. Figure 2 shows the total energy consumption of BSs resulting from the processing of traffic using various methods. All methods exhibit an upward trend as the number of UEs increases, with the basic separation method consuming the most energy to process traffic. The increase in UEs and traffic volume necessitates the activation of additional SBS to support the data traffic.

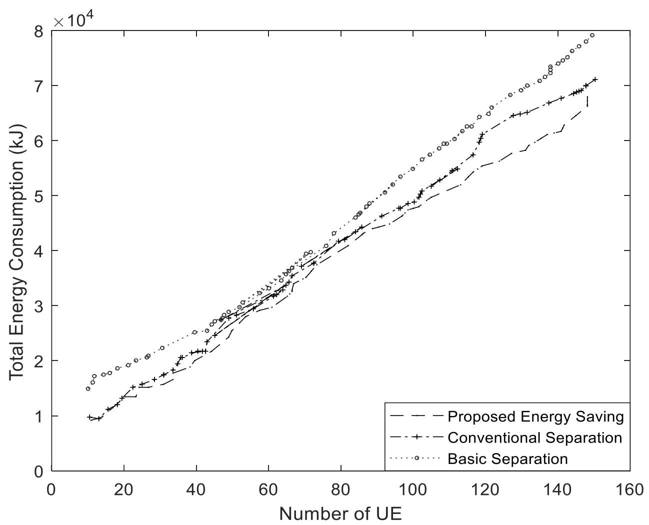
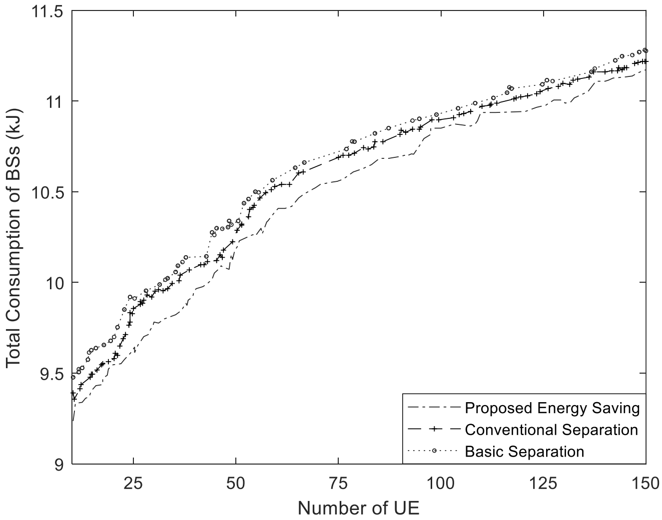
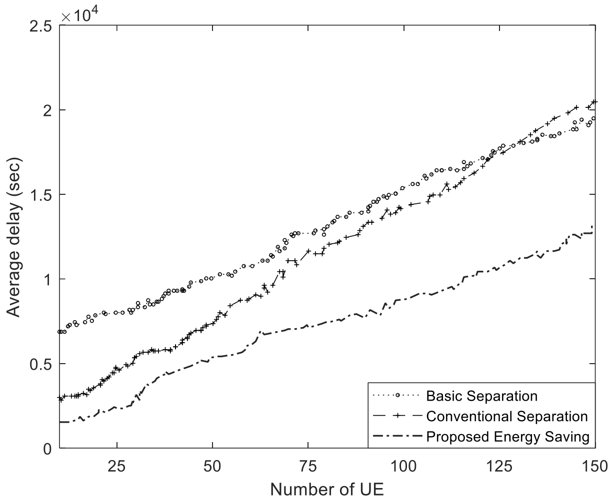


Figure 2. Energy consumption of BSs based on the traffic processing

Figure 3(a) shows the results for the total energy consumption of the BSs for various methods. Figure 3(b) presents the total delay for the BSs where the proposed energy saving has the smallest delay among the three methods. This delay indicates that both basic and conventional separation must transition from off to on in order to serve the traffic load, a process that requires more time than the transition from *sleep* to *on* state. For small UE values, the basic separation is greater aggregate delay due to small cells that manage both high and low data traffic, requiring SBSs to be active to service this data traffic. For conventional separation, SBSs serve only high data traffic, whereas MBSs serve only low data traffic. As the number of UEs increases, the aggregate delay begins to decrease for the basic separation method because some SBSs are already awake to serve requests from UEs with high and low data traffic.



(a)



(b)

Figure 3. Performance of; (a) energy consumption and (b) aggregate delay with various method

Figure 4 depicts the total energy consumption caused by state switching for the BSs. The proposed energy saving yields the lowest energy consumption since the BSs in this method only change from *on* to *sleep* states rather than *on* to *off* states. In the basic separation method, the energy consumption due to state switching increases proportionally with the number of UEs since BSs serve both high and low data rates. However, if the number of UEs is sufficient, the total energy consumption caused by state switching will begin to decrease. State switching necessitates the same amount of energy consumption for both conventional and basic separation methods. However, it increases and decreases gradually, as conventional separation only supports heavy data traffic. For the basic separation, the highest energy consumption value is 79244 kJ, while the proposed energy savings value is 71971 kJ. From this value, the proposed energy savings reduce the total energy consumption from the basic separation method by approximately 9%.

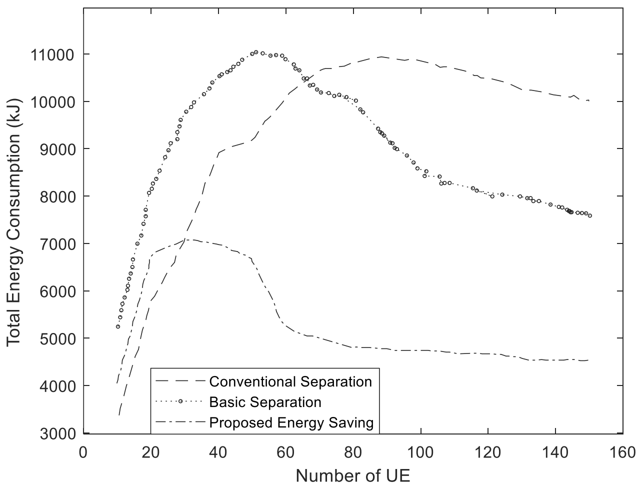


Figure 4. Total energy consumption of BSs based on state switching

4. CONCLUSION

In this paper, the factors on the 5G mmWave cellular network that contribute to the increase in energy consumption, where BS state management plays a significant role, are identified. Simulation results for energy-saving 5G mmWave cellular network BS management based on the PSO method provide an evolutionary method that increases connection speed efficiency. In addition, an analysis of the 5G mmWave cellular network's energy efficiency performance and the precision of its power consumption is presented. The proposed energy saving provides the smallest power consumption and aggregate delay for the BSs which is due to sleep states that were introduced. Furthermore, since mmWave transmission is used for D2D communications, highly directional beamforming minimises interference to adjacent co-channel transmission lines.

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