



Performance Evaluation of 5G H-HetNet using Novel Energy and Spectral Efficiency Model

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ABSTRACT

The performance evaluation of Heterogeneous Networks (HetNet) in the 5G era is a major factor that can be used to rate the efficiency of the network. There are many factors that affect the accurate performance of HetNet. One major factor is interference, which leads to high energy consumption due to data retransmission. To tackle this challenge, the Separation Architecture (SARC) was developed. SARC is a HetNet where the control plane is separated from the data plane. To further leverage the advantages of SARC, Hierarchical Heterogeneous Networks (H-HetNet) were introduced, essentially dividing SARC into two tiers: cellular and Device-to-Device (D2D) tiers. Despite these interventions, there is still a need to further improve the performance of SARC due to the high data rates recorded in 5G. In this context, this paper developed an Area Spectral Efficiency (ASE) and Energy Efficiency (EE) model for a Quality-of-Service Aware SARC. In QoSA-SARC, a new model for clustered D2D communication was considered for communication in the data plane. Thus, a new ASE and EE model was developed to accurately estimate the performance of the entire control and data plane, including both Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) users. Simulation results showed that the ASE performance of QoSA-SARC improved by 2.00% and 8.00% over the conventional SARC at user arrival rates of 5×10^{-3} and 4×10^{-3} . Also, when the EE of the network was analyzed, the QoSA-SARC has an improvement of 11.00% and 15.00% over the conventional SARC at user request arrival rate of 4×10^{-3} and 5×10^{-3} respectively.

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INTRODUCTION

The need to improve the network performance of users using network resources is a quest that has demanded a lot of research. Due to this demand, there have been generations of technologies that denote several improvements in cellular communications. The journey from the First Generation (1G) to the Fifth Generation (5G) has brought many breakthroughs in the telecommunication industry (Mustafa *et al.*, 2016; Shobowale *et al.*, 2023). Heterogeneous

Networks in 5G also pose many challenges, this is due to the massive increase in the number of users and a corresponding shift from voice traffic to data traffic. The paradigm shift comes with a host of challenges that have led to poor performance of 5G networks in terms of Area Spectral Efficiency (ASE) and Energy Efficiency (EE). In order to analyze the performance of HetNet, researchers have developed many models to estimate the EE and ASE of cellular networks (Umoh *et al.*, 2019). Furthermore, to

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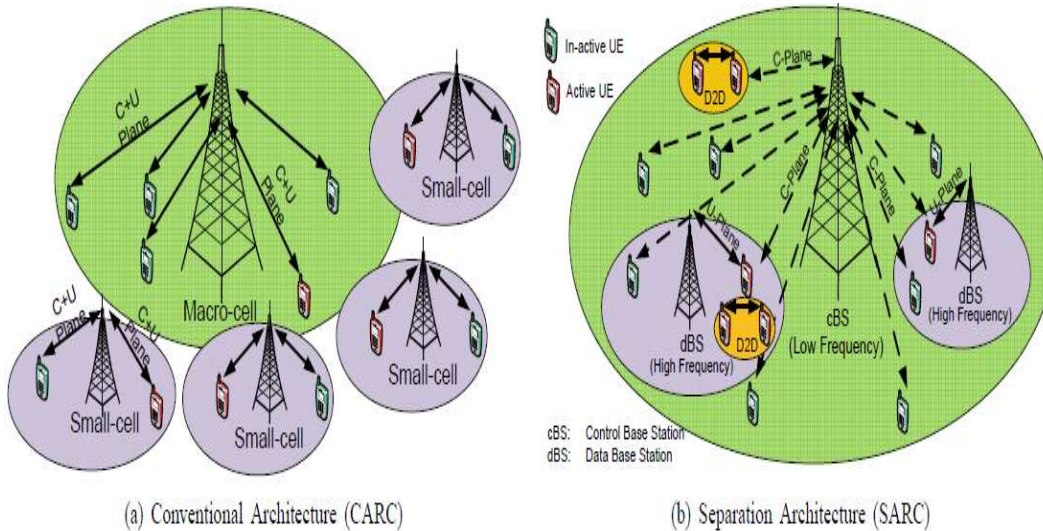
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mitigate the aforementioned problem, the traditional architecture for cellular networks was modified in such a manner that the control plane was decoupled from the data plane (see Figure 1). In the conventional architecture, the Base Stations (BS) are coupled together. This implies that a

single BS is responsible for simultaneously carrying out control and data services. However, in SARC, the data Base Station (dBS) and control Base Station (cBS) handle the data and control plane respectively (Liang *et al.*, 2019).



(a) Conventional Architecture (CARC) (b) Separation Architecture (SARC)
 Figure 1: Conventional and Control/Data Plane Architecture (Mustafa *et al.*, 2016)

The decoupling of the control and data plane was able to reduce the interference problem that has led to a significant decrease in network ASE. Many techniques have been developed to solve this problem. For example, Inter-cell Interference Coordination (ICIC), enhanced ICIC, and Coordinated Beamforming (CB) are major techniques that have been employed to address the problem of interference. In addition, the Separation Architecture (SARC), which involves the decoupling of the control and data plane, has introduced the creation of D2D communication in the data plane (Pizzi *et al.*, 2018). The use of D2D communication in the data plane demands the development of ASE and EE model equations that will estimate the performance of the network generally (Abubakre *et al.*, 2021; Aliu *et al.*, 2021). The accurate estimation of the network's ASE and EE would improve the Quality of Service (QoS) of the network. QoS of the network checks the

performance of the network based on user-defined parameters (Umar *et al.*, 2023). The use of Beamforming (BF) is a more promising approach in solving both intercell and intracell interference. The BF technique allows for the adjustment of antenna orientation in such a way that interfering channels will be muted. In coordinated beamforming, the coordinating set of Base Stations (BS) share their Channel State Information (CSI) to enable proper quantization and cancellation of interfering channels (Mustafa *et al.*, 2016). The SARC adopts the BF approach to enable efficient data transmission. However, due to the ever-increasing data traffic, the existing BF approach in SARC demands additional enhancements for effective QoS. In this vein, D2D communication is adopted. D2D communication is mainly classified based on several factors given in Figure 2.

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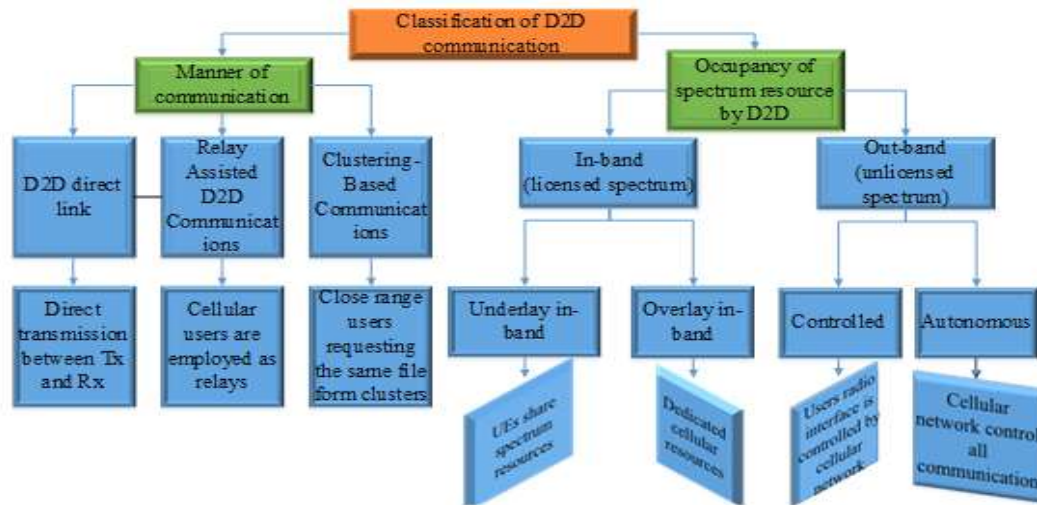


Figure 2: Classification of D2D Communication

The use of D2D in is due to its flexible applicability in many areas (see Figure 3). These applications are very sensitive in the current 5G as

most research is done with the aim of achieving flexible applicability (Della, 2018).

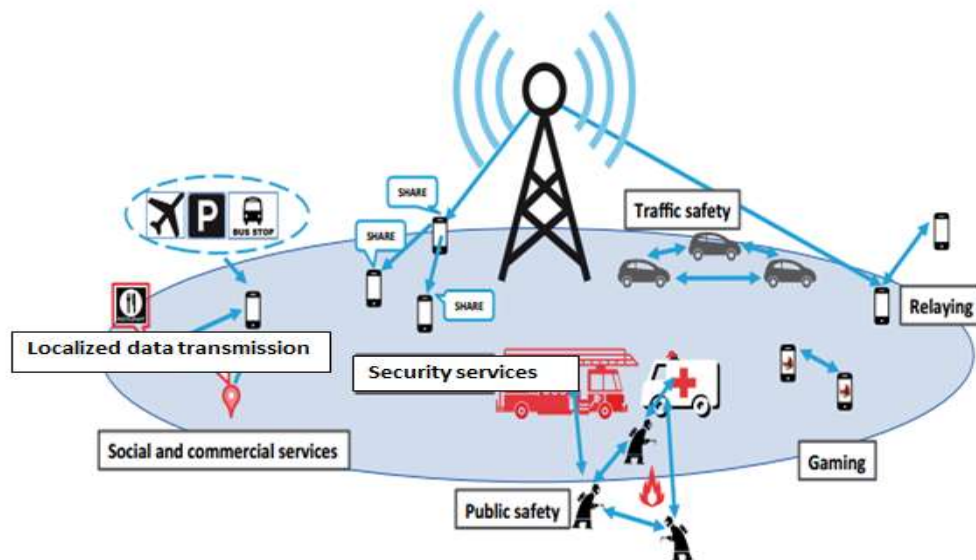


Figure 3: Application of D2D Communication

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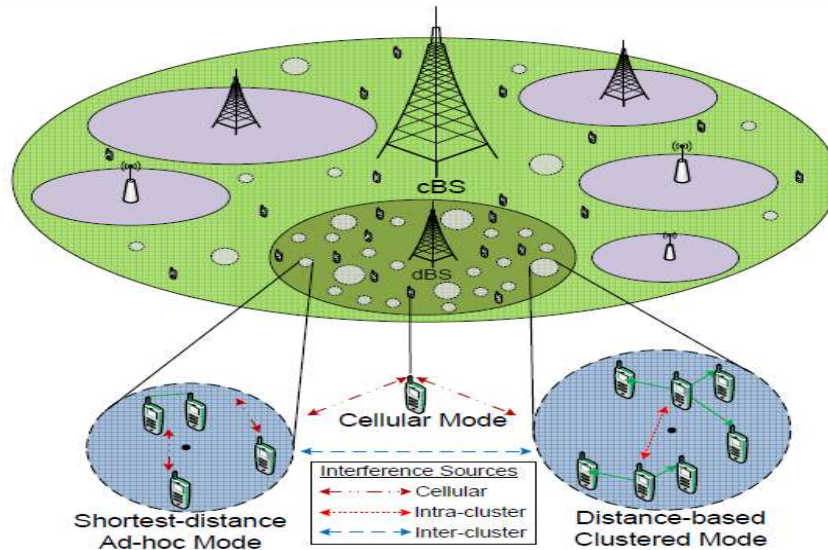


Figure 4: Interference sources in SARC and D2D Clustering (Mustafa *et al.*, 2016)

However, the intracell problem is still imminent in SARC using D2D clusters. The interference sources in SARC are given in Figure 4. This paper focuses on the development of ASE and EE algorithms for estimating the performance of SARC using D2D communication. The developed models will estimate the EE and ASE of both the control and data plane. The existing models estimate either the ASE or EE of data/control plane separately and then perform addition. This method has the probability of introducing inaccuracy in the estimation of network performance. Section two of this paper carried out a review of similar works to check the current state-of-the-art in the area of discussion. Section 3 describes the methods used to develop the ASE and EE model for efficient performance evaluation. Section 4 presents the results obtained and the corresponding discussion. Finally, section five concludes the paper.

REVIEW OF RELATED WORKS

This section reviews works related to this study. The review aims to introduce various concepts related to this work and highlight the current progress made in this research area. Bohli *et al.*, (2016) proposes a dynamic spectrum

access (DSA) approach for efficient cell association in 5G heterogeneous networks, addressing interference management challenges. The DSA scheme utilizes a cognitive monitor channel and maximum holding time distribution, prioritizing highest signal-to-interference-plus-noise ratio-based cell association. Analytical and simulation results demonstrate improved coverage probability, throughput, and energy efficiency in macro and small cell tiers, offering a promising solution for next-generation mobile networks.

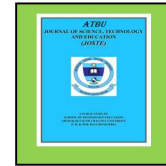
Pizzi *et al.*, (2018) developed an energy-efficient multicast service delivery model exploiting single-frequency device-to-device communication in 5G new radio systems. The work specifically designed a technique to efficiently deliver multicast traffic in a 5G new radio network by taking advantage of D2D communication and single-frequency operation, aimed at improving network EE. The researchers defined different multicast rules for cell center users and cell-edge users. Cell center user's multicast their messages using the traditional direct link method of multicasting, while cell-edge users engage in multicast transmission using relay D2D nodes. Simulation results showed that the

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developed scheme outperformed existing schemes. The drawback of the work was that intracell interference among the D2D nodes still existed. To further improve this work, (Zhao *et al.*, 2018) performed an Energy-Spectral Efficiency (ESE) analysis and optimization of HetNet cellular networks. To achieve enhanced ASE and EE, the researchers developed an analytical model to categorize different levels of acceptable ASE and EE in HetNet. This was done by analysing the relationship between ASE and EE as it affects network performance. Different traffic rates in the network were estimated as this is a major source of interference leading to reduced system ASE. Closed-form ASE and EE models were developed for the research. Simulation results showed that considering traffic rates improved the performance of SARC HetNet. However, the drawback of the work was that the traffic analysis was considered for a single cell, making the possibility of interference among neighbouring cells imminent, resulting in reduced ASE and EE. The performance models used in the work were strictly for cellular users, and the advantage of D2D communication in 5G HetNet was not considered.

Ansari *et al.*, (2019) developed a control and data plane separation architecture for dual-band mmWave networks. A control/data plane architecture operating at 26GHz unlicensed and 60GHz licensed band was considered in the work. To optimize the energy efficiency of the network and spectral efficiency, the work formulated a multi-objective optimization problem. To bring about the formulation, a joint radio resource allocation algorithm based on the Lagrangian dual decomposition method was developed. The system model considered a control plane having a single cBS serving several dBS. The work analyzed the performance of the network following two cases: one where the cBS served only the control plane users and another where the cBS served both the control and data plane users. The work recorded outstanding performance due to the SARC. However, the communication mode adopted in the work was highly directional. The use of highly directional communication in mmWave band has shortcomings in providing ideal signal coverage based on narrow beams.

Additionally, the performance estimation strategy used traditional models that separately estimated the EE and ASE of the network. To take full advantage of D2D communication, (Kim, 2020) developed a new spectrum allocation scheme for an H-HetNet, which incorporated both dual-connectivity and network-assisted Device-to-Device (D2D) communications. (Agbon *et al.*, 2022) proffered a Quality-of-Service Aware control and data plane Separation Architecture (QoSA-SARC) algorithm to improve user experience in 5G Heterogeneous Networks (HetNets). The algorithm utilizes a novel Coordinate Aided Transmission beam forming model to enhance control base station coverage probability. Simulation results in MATLAB show significant improvements in user access rate (16.13% and 6.06%) and network coverage probability (10.26% and 8.89%) compared to existing work by Liang *et al.*, (2019), demonstrating the effectiveness of the QoSA-SARC algorithm in addressing interference challenges in HetNets. (Alabi *et al.*, 2023) explores the potential of AI in spectrum management, including dynamic spectrum access, interference mitigation, and resource allocation. It highlights challenges such as algorithmic bias, security concerns, and the need for robust data sets. The study emphasizes the importance of equitable access to spectrum resources, preventing monopolistic practices, and fostering AI-based innovations in spectrum management. It serves as a reference for policymakers and stakeholders, providing insights for developing effective policies and regulatory frameworks in AI-enabled spectrum management. The work utilized a concept from cooperative games to effectively collaborate network users. A joint bargaining method was used when implementing the resource allocation scheme, specifically using the Nash bargaining method among others in the allocation of network resources to users. Users in the network, based on the estimation from the bargaining, could use D2D communication or cellular communication. The results showed that the ASE of the network improved due to successful transmission of packets. However, the expected ASE of the researchers was not met due to interference

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problems encountered in the data plane of D2D users.

METHODOLOGY

This section presents the processes followed for the development of the proposed model for ASE and EE estimation in 5G H-HetNet. The processes are as follows:

1. Setting-up the user eligibility criterion for D2D cluster head based on distance using the closeness model.
2. Implementing the cluster formation process for efficient D2D communication.
3. Calculating the probability density function of the evaluated distances
4. Evaluating the ASE and EE model for H-HetNet by considering cellular user communication.

$$C_c(U_a) = \frac{\left[\sum_{b=1}^N d(U_a, U_b) \right]^{-1}}{N-1} \quad (1)$$

where:

N is the total number of network nodes

d(.) is the shortest distance between reference node and all other nodes

U_a is the reference node

U_b can be any other node

A. Setting-Up the User Eligibility Criterion for D2D Cluster Head

The transmission process in H-HetNet allows for separate transmission by D2D and cellular users. Nodes that are not in the cluster assume cellular mode (SARC) of operation. Equation (1) was used for grouping purposes (see Figure 5). The social influence of nodes is used to categorize nodes as either cluster D2D mode or cellular mode. In the group, the cellular group of nodes is modeled as those nodes that are not eligible to be part of the cluster and, as such, will directly communicate with the dBs for content dissemination.

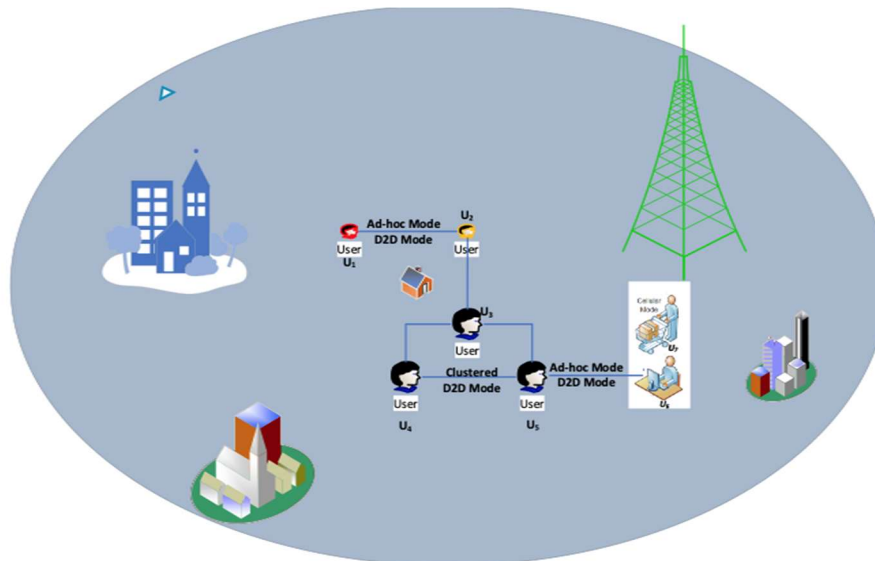


Figure 5 : Network Modes Base on Social Network Influence

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B. Implementation of Cluster Formation Process for Efficient D2D Communication

The node selection process for CH selection in 5G H-HetNet is a major challenge. In the data plane, the set of nodes that forms the cluster base on equation (1) need to select a cluster head for

effective dissemination of data amongst individual cluster and devices. Here, the energy and transmit power of participating nodes are considered for CH selection. An energy criterion based on equation (2) is used to select eligible nodes for CH selection.

$$N_{Eligible} = \begin{cases} N_{E_{max}} - N_{E_{min}} & \text{for } N_{E_{min}} < \frac{N_{E_{max}}}{2} \\ N & \text{for } N_{E_{min}} \geq \frac{N_{E_{max}}}{2} \end{cases} \quad (2)$$

Where:

$N_{E_{max}}$ is the maximum energy at i_{th} time

$N_{E_{min}}$ is the minimum energy at i_{th} time

$N_{Eligible}$ represent the nodes eligible for CH selection

From the eligible nodes, the node with maximum transmit power is selected as CH. The flowchart for CH selection is given in Figure 6.

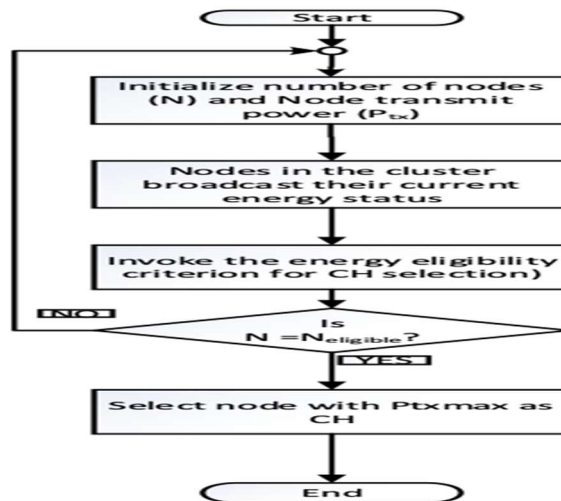


Figure 6: Flowchart of the Developed D2D CH Selection

C. Evaluation of the Probability of User Device Connection to LoS or NLoS

During transmission in HetNet, the connection probability of a user to a LoS or NLoS

dBS is given as X^L and X^N with corresponding probability H^L and H^N respectively. Let the distance between a data plane user and its

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nearest LoS dBS and NLoS dBS be d_T^L and d_T^N respectively. The probability H^L and H^N is given as (Liang *et al.*, (2019)):

$$H^L = P \left[P_t^r A^L (d_T^L)^{-\alpha^L} > P_t^r A^N (d_T^N)^{-\alpha^N} \mid d_T^L = r \right] \quad (3)$$

$$H^N = 2\pi D_d \int_0^\infty \theta^N r (1 - P_T^L(r)) dr \quad (4)$$

where:

P_t^r is the transmit power of data plane user

d_T^N and d_T^L represents the distance between a user that is nearest to NLoS dBS and LoS dBS respectively.

r is the transmission radius of LoS or NLoS dBS

D. Evaluating the ASE and EE Evaluation of D2D Data Plane Users

During transmission, the Area Spectral Efficiency (ASE) provided by LoS and NLoS dBS

$$\eta^U = \frac{1}{\ln 2} \int_0^\infty \frac{P_U^{\text{cov}}(x_o)}{x_o + 1} dx_o \quad U \in \{L, N\} \quad (5)$$

Where x_o is a predefined coverage probability threshold and P_U^{cov} is the coverage

at a given d_T^N or d_T^L on the data plane is given as

η^L and η^N respectively. This is defined as follows: (Liang *et al.*, 2018):

probability of a user served by a LoS dBS. The ASE of a given channel affects the blocking probability of the user which is given as:

$$P_b^L = \int_0^\infty P_b^L(r) f_{d_T^L}(r) dr \quad (6)$$

$$P_b^N = \int_0^\infty P_b^N(r) f_{d_T^N}(r) dr \quad (7)$$

Therefore, for a given density of dBS λ_r , the ASE in the data plane at d_T^U where device to device communication is considered is given as:

$$ASE_{\lambda_r-D} = p_u D_u (1 - P_b^L) H^L \eta^L + p_u D_u (1 - P_b^N) H^L \eta^N + p_u D_s (H^{D2D}) (\eta^{D2D}) \quad (8)$$

where:

D_u represents the density of cellular users using dBS for communication in the network

η^{D2D} denote D2D spectral efficiency

P_b^N is the average probability of a NLoS dBS user to be blocked

P_b^L is the average probability of a LoS dBS user to be blocked

η^L represents the spectral efficiency of LoS UE

η^N represents the spectral efficiency of NLoS UE

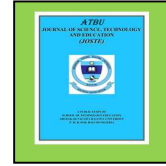
P_u is the probability of a user requiring a high down link data-rate

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Hence, the efficiency of received power to ensures reliable connection of a user in the data plane to a LoS dBS or D2D user depends on the ASE of the channel. The developed energy

efficiency for both control and data plane (including D2D) user, is the ratio of ASE and Power Consumption per unit Area (PCA) which is given as:

$$\eta_{eff} = \frac{A S E}{P C A} \quad (9)$$

$$\eta'_{eff} = \frac{p_u D_u (1 - P_b^L) H^L \eta^L + p_u D_u (1 - P_b^N) H^L \eta^N + p_u D_s (H^{D2D}) (\eta^{D2D})}{\int_0^\infty [\lambda_L(r) \varpi^L(r) f_{R_r^L}(r) + \lambda_N(r) \varpi^N(r) f_{R_r^N}(r) + \varpi^{D2D}(r) (1 - f_{R_r^U}(r))] dr} \quad (10)$$

where:

ϖ^N denotes the power consumption of NLoS dBS

ϖ^L is the power consumption of LoS dBS

λ_L represents the density of LoS dBS set

λ_N is the density of NLoS dBS set

η^L denotes the spectral efficiency of LoS dBS

η^N is the spectral efficiency of NLoS dBS

$f_{R_r^N}$ is the PDF of the distance of a NLoS user from its serving dBS

η^{D2D} is the D2D spectral efficiency

H^{D2D} denotes the connection probability of D2D users

D_s is the density of UE in a cluster

p_u represents the probability of a user requiring a high down link data-rate

$f_{R_r^L}$ represents the PDF of the distance of a NLoS user from its serving dBSs

The simulation parameters are given in Table 1.

Table 1: Simulation Parameters

Parameter	Value
Path loss exponent, α	4
LoS path loss exponent, α^L	2.5
NLoS path loss exponent, α^N	3.5
Control base station channels, C_C	50
Data base station channels, C_T	5
Probability of high downlink data rate, ρ_u	0.3
Reference link range, d_0	300m
User access rate to cBS, λ_a	$0.5 \times 10^{-3}, 0.8 \times 10^{-3}$
User access rate to dBS, λ_b	$4 \times 10^{-3}, 5 \times 10^{-3}$
Control plane channel holding time, $\frac{1}{\mu_c}$	800,320 (sec)
Data plane channel holding time, $\frac{1}{\mu_d}$	80,64 (sec)

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Control plane SINR threshold, χ_o	-10dB-30dB
Mobility	Random way point/ 350 km/h
Fading model	Rayleigh fading
Simulator	MATLAB 2017b
Duplexing	TDD
D2D node energy	15J
Beamforming	CB

RESULTS AND DISCUSSION

Figures 7 and 8 show the results of the performance of the work by Liang et al. (2019) and the developed QoS-SA-SARC in terms of network ASE against the number of data cells. From the figures, it can be observed that at the initial deployment of data cells, the network experiences limited interference due to the sparse deployment of dBSSs. However, as the number of data cells increases, the ASE shows a downward trend.

Additionally, it can be observed that the developed algorithm showed better ASE when compared to the work of Liang et al. (2019). This improvement is because the use of D2D communication further enhances channel utilization for data transmission among data plane users. From Figure 1 and 2, the ASE graph shows an improvement of 2.00% and 8.00% over the existing work at λ_b having a value of 5×10^{-3} and 4×10^{-3} respectively.

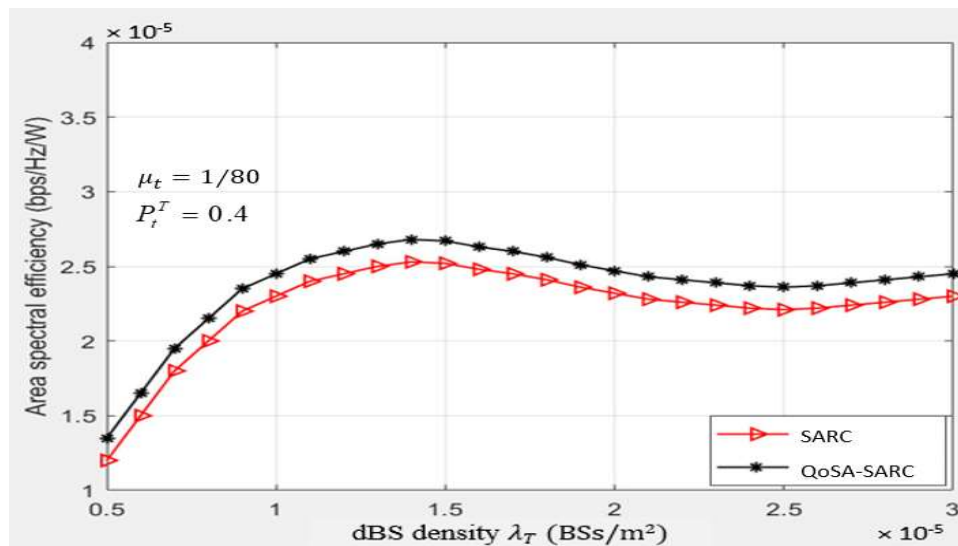


Figure 7: ASE of the Data Plane Users against dBSS Density at 5×10^{-3} User Access Rate

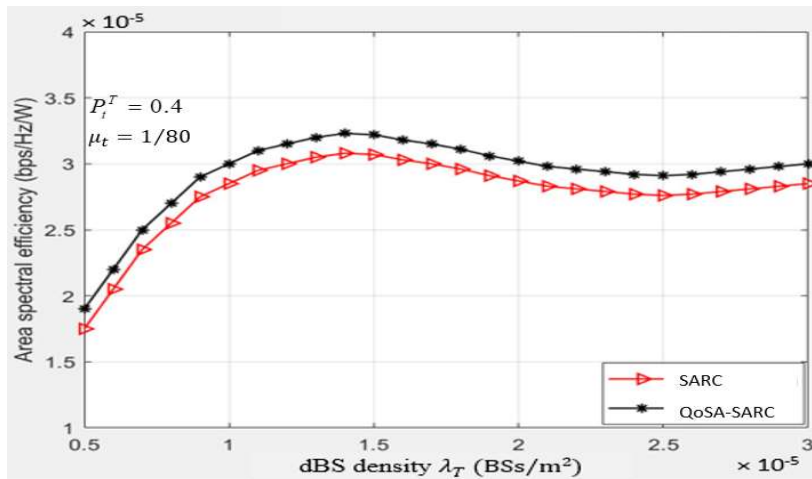


Figure 8: ASE of the Data Plane Users against dBS Density at 4×10^{-3} User Access Rate

Figures 9 and 10 are graphs of Energy Efficiency (EE) of the data plane against dBS density for various λ_b , μ_t and P_t^T values. From the figures, it can generally be observed that the energy efficiency of the network decreases with increases in the number of dBS in the data plane. This is because, an increase in the number of dBS increases the probability of having interference in the network at certain P_t^T which eventually led to retransmission of already sent data by data plane users. From Figure 9 and 10, it can be observed

that the developed algorithm outperformed that of Liang *et al.*, (2019) in terms of energy efficiency. This is due to the use of D2D communication in the data plane which improves the energy efficiency of the network, as the probability of packet drop is reduced. From Figure 9 and 10, simulation results showed that the QoSA-SARC has an improvement of 11.00% and 15% over the work of Liang *et al.*, (2019) at user arrival rate of 4×10^{-3} and 5×10^{-3} respectively.

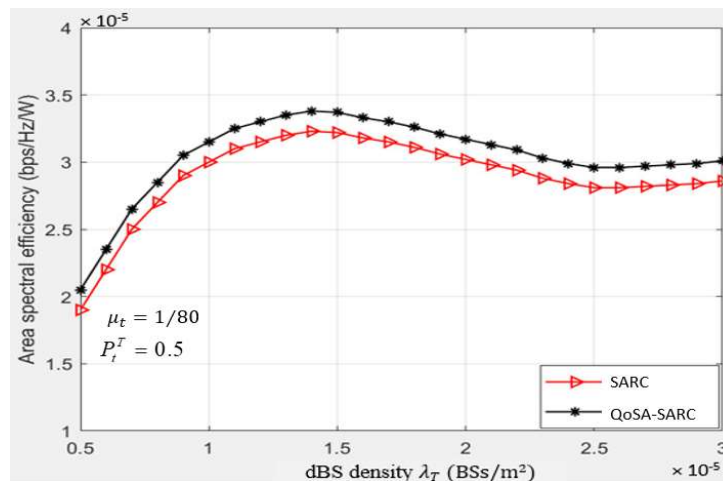


Figure 9: EE of the Data Plane Users against dBS Density at User Arrival Rate of 4×10^{-3}

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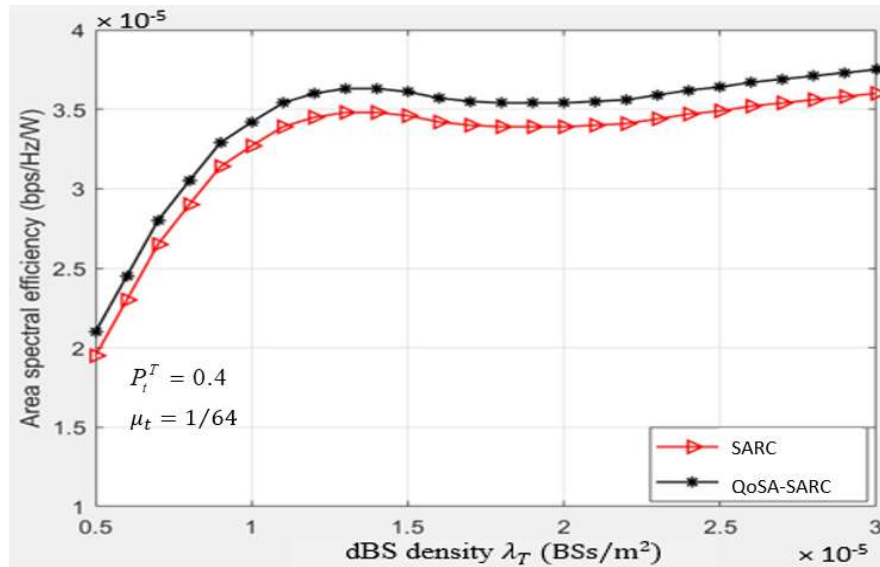


Figure 10: EE of the Data Plane Users against dBs Density at User Arrival Rate of 5×10^{-3}

CONCLUSION

This work has conducted a performance analysis of 5G Hierarchical HetNet (H-HetNet). The H-HetNet is a separation architecture where the control plane is decoupled from the data plane. In the conventional separation architecture (SARC), superimposing cellular users and D2D users in the data plane is not considered. Thus, the available ASE and EE network estimation models only consider the ASE and EE of cellular users in the control and data plane. This paper developed a Quality-of-Service Aware Separation Architecture (QoSA-SARC). The QoSA-SARC developed a new model that considers a situation where both D2D and cellular users are using the network resources in the data plane. Thus, the work developed a new model that can estimate the ASE and EE of H-HetNet.

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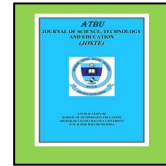
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