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Optimizing Network Performance in 5G Systems with Downlink and Uplink Decoupling

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***Abstract*—This research paper presents a comprehensive investigation into the optimization of resource allocation in 5G networks through the technique of Downlink and Uplink Decoupling (DUDe). With the growing need for accurate modeling and scenario planning in 5G systems, DUDe allows for the configuration of an additional, lower frequency signal on the uplink to complement the existing uplink signal, rebalancing the uplink/downlink difference at the cell edge and enhancing coverage and network capacity. Drawing on extensive literature and industry trends, this study explores the benefits and challenges of DUDe, considering its impact on network performance, user experience, and future developments. The paper also introduces a simulation-based methodology and experiments to evaluate the effectiveness of DUDe in improving coverage, capacity, latency, and energy efficiency. The findings contribute to the understanding of DUDe's potential in optimizing 5G networks, providing valuable insights for researchers and network operators in designing and deploying efficient resource allocation strategies for enhanced network performance in various scenarios.**

***Index Terms*—5G, Decoupling, Downlink, Uplink, Network Performance**

I. Introduction

The advent of 5G networks promises unparalleled connectivity with enhanced speed, capacity, and reliability, addressing the soaring demand for mobile services. This paper investigates the impact of Downlink and Uplink Decoupling (DUDe) on optimizing network performance in 5G systems. DUDe, a technique allowing additional lower-frequency signals on the uplink, addresses the challenge of imbalanced coverage between downlink and uplink, particularly at the cell edge. This imbalance can degrade user experience and reduce uplink capacity. DUDe aims to rebalance this discrepancy, ensuring consistent service and increasing uplink capacity, which is vital as usage patterns shift towards more balanced and uplink-heavy services like video calls, multiplayer games, and social media uploads.

Through simulation-based studies, the paper evaluates DUDe's effectiveness in improving coverage, enhancing uplink capacity, and optimizing overall network performance. Various scenarios are modeled to provide insights into DUDe's potential benefits and practical implications for network operators and researchers. The paper is organized into sections reviewing related work, presenting the system model and simulation methodology, discussing results and performance evaluation, exploring practical implementation considerations, and concluding with findings and future research directions.

By investigating the performance enhancements enabled by DUDe, this research aims to contribute to the ongoing dialogue on optimizing network performance in 5G systems, providing valuable insights for network operators, researchers, and developers working in this area.

Earlier studies conducted various experiments to showcase the workability of the 5G network to improve performance. Several researchers tried to discover the ease of working with a decoupled access network and see whether the performance would be optimized. Alrikabi et al. [1] established that, with the proliferation of technology tools, gadgets, and utility items in daily life, energy optimization must be intensified with better performance and precision. Their study revealed that in a decoupled access with a 5G network, there would be increased transfer rates of data, decreased latency, mobility as well as energy efficiency. The 4G networks used in the past are still widely used, and wireless experts are attempting to develop 5G. The 5G-based network technologies are anticipated to have the ability to transmit enormous volumes of information and signals to diverse locations, whether close by or far away.

Additionally, earlier studies record numerous problems entangled by using a coupled access network system, and using a decoupled access would be a solution to the drawbacks. Arshad et al. [2] established that decoupled access greatly enhances the network performance of HetNets by allowing access points in uplink (UL) and downlink (DL) connections to be distinct. Base stations (BSs) are progressively moving closer to consumers in HetNets by densifying small BSs, which significantly improves spectrum and energy efficiency for cellular systems. Due to the phenomenal growth in mobile data traffic, the lack of available spectrum, and excessive power consumption, Hossain et al. [3] established that traditional cellular network designs are experiencing enormous

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challenges, necessitating further research to modify them. Therefore, it is evident that there is a need to search for optimization techniques to improve the cellular networks used. In particular, this paper highlights the 5G network and how decoupled access in uplink and downlink methods would befit the users and improve network performance.

II. System Model and Methodology

Downlink Uplink Decoupling (DUDe) is employed in 5G systems to enhance network performance by segregating the downlink and uplink data streams. By enabling independent optimization of these transmissions, DUDe facilitates superior resource allocation and overall system efficiency. [4] A system model is utilized to assess the efficacy of DUDe in a 5G network, which represents the network's structure, data flows, and performance metrics. This model enables the analysis and evaluation of the DUDe technique.

To meet the growing demands of network traffic, cellular networks are transitioning from uniform single-tier networks to multi-tier heterogeneous and small cell networks (HetSNets). These HetSNets incorporate low-power nodes that offload macrocells and enhance system capacity through aggressive frequency reuse. Nevertheless, this approach to radio planning faces challenges, including load imbalance and suboptimal uplink (UL) performance, which are significant concerns.

A. Cell Range Expansion and eICIC

Cell Range Expansion (CRE) is a method employed in 5G systems to improve downlink coverage and capacity. It entails dynamically adjusting the transmit power of a base station based on the signal quality and interference levels detected by user equipment (UE). By expanding the coverage area, CRE ensures that UEs positioned at the periphery of a cell receive a strong and reliable signal for a stable connection. The procedure relies on measurements and feedback exchanged between the UE and base station, where the UE reports signal quality and interference levels, allowing the base station to analyze the information and determine the need for CRE [4]. Through CRE, the base station has the capability to boost transmit power, thereby extending coverage and enhancing connectivity for UEs located at the outer boundaries of the cell. Enhanced Inter-Cell Interference Coordination (eICIC) is a system model employed in 5G networks to separate the downlink and uplink transmissions. It tackles interference challenges in networks consisting of both macrocells and small cells. In the downlink, eICIC allows small cells to adapt their transmit power and resource allocation based on interference conditions from neighboring macrocells, thus mitigating interference caused by small cells and enhancing overall performance. For the uplink, eICIC utilizes orthogonal resources and power control mechanisms to regulate interference from small cells to macrocell receivers, ensuring that the transmissions from small-cell users do not excessively disrupt macrocell reception. In summary, eICIC efficiently manages and coordinates interference in heterogeneous networks, enabling the harmonious coexistence and operation of macrocells and small cells while boosting network performance.

B. Uplink and Downlink Splitting

UL/DL Splitting, alternatively referred to as uplink and downlink decoupling, serves as a system model implemented in 5G networks to segregate the processing of uplink and downlink data transmission. This separation is accomplished by partitioning the base station into Remote Radio Heads (RRHs) and Centralized Units (CUs). The RRHs oversee the radio frequency operations, whereas the CUs handle the digital processing responsibilities. Diverse variations of UL/DL Splitting exist, including Split Point Splitting, Partial Splitting, and Dynamic Splitting. These variations offer flexibility, reduced latency, efficient resource utilization, and centralized processing, consequently leading to improved network performance and scalability.

5G systems benefit from UL/DL Splitting in various ways. Firstly, it offers increased flexibility by allowing resources to be allocated dynamically according to traffic demands, which enables effective scaling and adaptability. Secondly, it reduces latency by minimizing processing time at the base station, resulting in improved responsiveness and user satisfaction. Furthermore, the independent scaling of UL and DL resources ensures efficient utilization of network capacity, leading to optimized resource allocation and enhanced overall system performance. Lastly, advanced signal processing and scheduling algorithms are enabled by centralized processing at the CU, facilitating efficient management of UL and DL traffic. Overall, UL/DL Splitting in 5G systems greatly enhances network efficiency, resource utilization, and user contentment.

C. Simulation Set up

In this study, we depart from the traditional method of UL/DL cell association using DL received power (RP). Instead, we propose a novel method where uplink association is determined by path loss, while downlink association still considers DL RP. This seemingly straightforward assumption has far-reaching implications for the system's design and structure. One particular challenge with this approach is the need for a mechanism to facilitate processes like Acknowledgment and channel estimation when a User Equipment (UE) establishes a link in either the uplink or downlink direction. Introducing such a mechanism would require significant design adjustments. Hence, our aim is to investigate whether the advantages of this new approach, called DUDe, justify these extensive modifications.

A two-cell network model made up of a macro cell (Mcell) and a small cell (Scell) will be used. The model is geared towards establishing the merits of DUDe most conveniently. [5] The model comprises the first and the second case. The first is a noise-limited case with a single-user experiment (UE) to illustrate the gains of uplink (UL) in a decoupled access. The second scenario is an interference-bounded case with three user experiments to showcase the gains of limiting noise interference. The model assumes that the downlink (DL) approach will be grounded on the received power whereas the uplink approach on the path loss. In a HetNet situation, DUDe causes differing cell boundaries within the UL as well as DL, where the UE will be linked to Scell and Mcell in UL and DL, respectively, as demonstrated in Fig. 1 below.

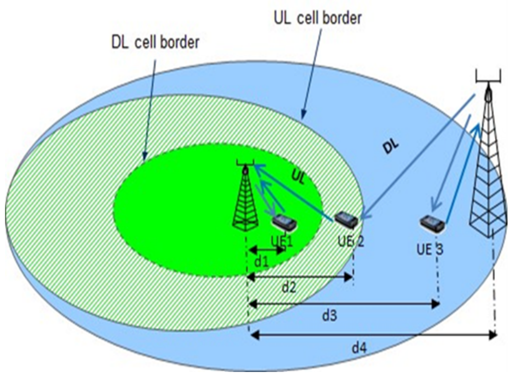

Fig. 1. The System model for Uplink /Downlink Decoupling Access

In the first case, only one UE moves towards the Mcell from the Scell when the noise is limited. UL rate will be calculated established on the received power (RP) and path loss (PL). Assuming that the UE transmit power equals 20 and the small and the macro cell have a path loss exponent of 3.6 and 4, the scale and the cell would record 46 as well as 23 dbm of transmit power, respectively. Figure 2 below shows UL rate at both Pathloss and the Received Power, indicating a higher network performance under PL, particularly the section within DL and the UL boundaries of the cell due to the low path loss in the area. Fig. 2 compares the UL rate in both PL as well as RP cases.

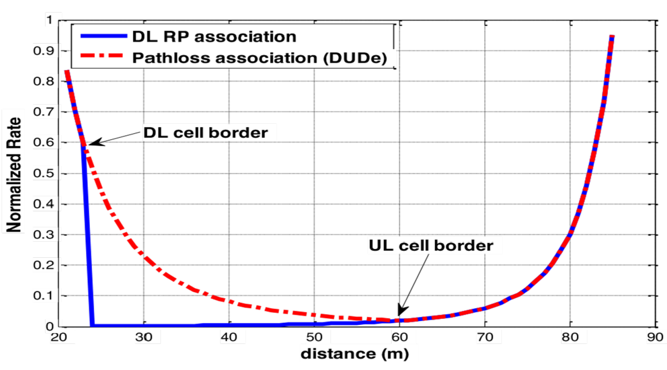

Fig. 2. Comparing UE rate in DL received power and path loss scenarios

The formula used to get the rate is given as follows:

$$R = BW \cdot \log_2(1 + \text{SNR})$$

$$\text{SNR} = \frac{P_{\text{ue}} \cdot \text{PL}(d, \alpha)}{N}$$

$$\text{PL}(d, \alpha) = \frac{d^{\alpha}}{d_0}$$

Here, N represents the noise power, which is taken to be 0 dBm of noise power, P_{ue} represents the UE transmit power, and R indicates the rate. SNR refers to the signal-to-noise ratio. BW, or bandwidth, is considered equal to one for simplicity's sake. d is the distance and the path loss exponent α affects distance-based PL. In the second case, the system model is similar, and the only difference is that it will comprise three user experiments other than one, like in the first case, represented in Fig. 1.

The simulation used in this study combines a high-frequency 3D ray tracking path loss forecasting algorithm alongside the multi-technology radio planning tool Atoll. The model considers information about the landscape, buildings, and clutter, ensuring the replication model is precise and authentic [6]. Systems-level simulations, which provide a snapshot of the Cellular network, are a capability of Atoll. The model uses a Monte Carlo technique to produce a user percentile for each trial. The distribution of users is established on traffic information taken from existing network systems. [7] Each simulation's resource distribution takes place over one second.

The paper focuses on simulation in two cases. First, the UL cell attachment is grounded on PL, simulating the DUDe method. The second situation is when the UL cell connection is established on the standard LTE protocol, the DL Reference Signal Received Power (RSRP). The simulation is based on both low and high-power Scell scenarios in the DL RSRP case to comprehend the benefits of the PL method over the DL RSRP technique with various Scell sizes.

The study relied on various parameters consistent with the metrics and techniques used to evaluate the system model, such as standard LTE protocol. [8] The simulation parameters are shown in Table I.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Operating Frequency	3.5 GHz (co-channel deployment)
Bandwidth	100 MHz (500 frequency blocks)
Simulation Time	50 simulation runs / 2 seconds each
Propagation Model	3D ray-tracing model
Maximum Transmit Power	
Macro Base Station	48 dBm
High Power Pico Base Station	32 dBm
Low Power Pico Base Station	22 dBm
User Equipment (UE)	24 dBm
Antenna System	
Macro Base Station	4Tx, 4Rx, 20 dBi gain
High Power Pico Base Station	2Tx, 2Rx, 6 dBi gain
User Equipment (UE)	1Tx, 1Rx, 0 dBi gain
UE Mobility	Vehicular (60 km/h)
Supported UL Modulation Schemes	QPSK, 16 QAM, 64 QAM

At this point, let's analyze and explain each of the given parameters from Table I:

Operating Frequency: This is the frequency (3.5 GHz) at which the system operates. It is in the mid-band spectrum, which offers a balance between coverage and capacity.

Bandwidth: The system has a bandwidth of 100 MHz, divided into 500 frequency blocks. This bandwidth determines the range of frequencies used for transmitting data.

Simulation Time: The simulation is run fifty times, with each run lasting 2 seconds. This helps in obtaining averaged results and reducing the impact of outliers.

Propagation Model (3D ray-tracing model): This model is used to simulate how radio waves propagate in the environment. It considers the three-dimensional aspects of wave propagation, including reflection, diffraction, and scattering.

Maximum Transmit Power: Different components have different maximum transmit powers: *Macro: 48 dBm, High power Pico: 32 dBm, Low power Pico: 22 dBm, UE (User Equipment): 24 dBm*. These values indicate the maximum power levels at which these components can transmit signals.

Antenna System: Different components have different antenna configurations and gains: Macro: 4Tx (transmit antennas), 4Rx (receive antennas), 20 dBi gain Pico: 2Tx, 2Rx, 6 dBi gain UE: 1Tx, 1Rx, 0 dBi gain These configurations affect the ability of the components to send and receive signals.

UEs Mobility: The User Equipments (UEs) are moving at a vehicular speed of 60 km/h. This parameter is important as mobility affects signal quality and handovers between cells.

Supported UL Modulation Schemes: These are the modulation schemes supported for Uplink (UL) communication. They determine how data is represented and transmitted over the radio waves.

Simulation Scenarios: The paper simulates two cases:

First, where UL cell attachment is based on Path Loss (PL), simulating the DUDe method. Second, where UL cell connection is established on the standard LTE protocol, focusing on the DL Reference Signal Received Power (RSRP).

The simulation considers both low and high-power Scell scenarios in the DL RSRP case to analyze the benefits of the PL method over the DL RSRP technique with various Scell sizes. These parameters are consistent with the metrics and techniques used to evaluate the system model, such as the standard LTE protocol, and help in comprehending the comparative benefits of the different methods studied in the paper.

III. Performance Evaluation Results and Analysis

In this study, we conducted a comprehensive analysis and discussion of downlink and uplink decoupling in 5G systems using MATLAB simulations and parameters. We performed a sensitivity analysis by varying parameters related to power allocation, resource allocation, antenna configuration, subcarrier allocation, and beam-forming strategies. Furthermore, we considered trade-offs associated with decoupling, such as increased complexity and resource utilization efficiency. Finally, we provided insights into future directions and potential areas of improvement for downlink and uplink decoupling in 5G systems. Overall, our findings contribute to a better understanding of the performance and optimization of decoupled systems in the 5G context.

A. *1st Experiment: UL UE Throughput vs Number of Small Cells*

Fig. 3 presents an experimental simulation that was utilized to examine the correlation between the number of small cells and the Uplink (UL) user equipment (UE) throughput in a wireless network. The simulation encompassed various scenarios and calculated the UL UE throughput for each scenario. The results were then organized and presented in Table II.

TABLE II
DL-HP, DL-LP and DUDe for macro vs Pico cell layers

				Scenario	Macro cell	Pico cell
DL-HP	5	50	90	8	45	85
DL-LP	10	55	95	12	60	92
DUDe	15	70	98	18	75	95

The results compare three different situations. The cell association, which is based on the DL RP protocol, is the initial action. Scells are made up of Pico cells (Pcells) with a low transmit power (LP) of 20 dBm, also known as DL-LP. Second, in DL RP-based cell associations, where Scells are Pcells with a high transmit power (HP) of 30 dBm, this condition is referred to as DL-HP. Thirdly, the effect of integrating Pico cells on the fifth percentile of UL performance for various scenarios, where the cell linkage is founded on path loss and represents the Downlink and Uplink Decoupling (DUDe).

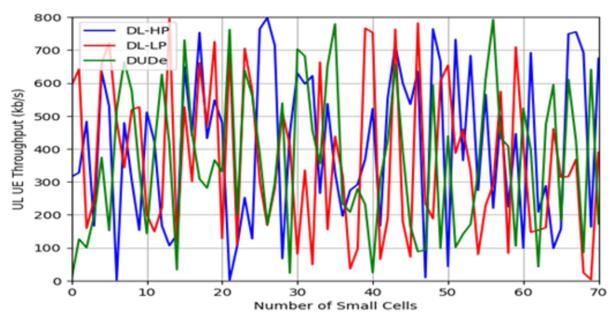

Fig. 3. Throughput vs Number of Small Cells

B. *2nd Experiment: Path loss vs Distance on UL and DL*

Path loss vs. distance analysis in 5G systems explores the attenuation of signal strength as it propagates through the wireless channel. [9] In the context of uplink (UL) and downlink (DL) decoupling, the path loss characteristics can differ between UL and DL channels. Experimental studies and simulations are conducted to investigate these differences and understand their impact on system performance. Factors such as distance, frequency, antenna height, environment, and propagation models are considered. By comparing path loss characteristics between UL and DL as shown in Fig. 4. Additionally, the experimental parameters that were used to plot the bar graph were computed as depicted in Table III.

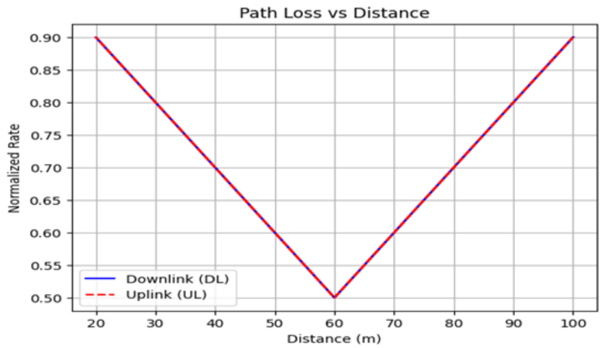

Fig. 4. Path loss vs distance on DL and LP

TABLE III
DISTANCE, DOWNLINK (DL), AND UPLINK (UL)

Distance (m)	20	40	60	80	100
Downlink (DL)	0.9	0.7	0.5	0.7	0.9
Uplink (UL)	0.9	0.7	0.5	0.7	0.9

C. 3rd Experiment: Throughput values for Macro and Pico cells layers on DL-HP, DL-LP and DUDe.

To obtaining the throughput values for the Macro and Pico cell layers on DL-HP, DL-LP, and DUDe in 5G systems through simulation requires designing and conducting simulation experiments using suitable simulation tools and models. Factors such as network deployment, channel conditions, system parameters, and simulation setup play a crucial role in determining the specific throughput values. Fig. 5, Fig. 6, and Fig. 7 show an experimental throughput on DUDe for Macro and Pico cell layers for Downlink lower power and Downlink for high power respectively.

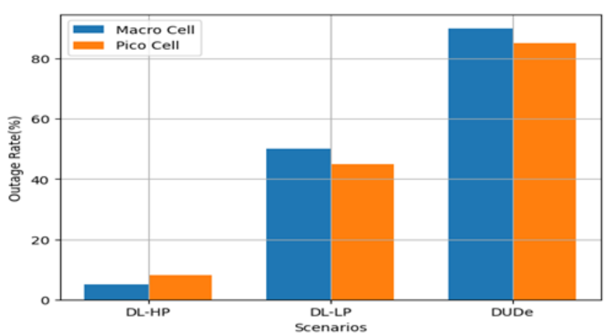

Fig. 5. DL-LP-macro vs Pico cell layers

IV. PRACTICAL IMPLEMENTATION CONSIDERATIONS

The practical consideration for 5G network providers when considering the implementation of DUDe is the availability of the necessary technologies and devices for the network. The technologies and devices may include LTE base stations, core networks, and compatible receivers. The providers must have the resources and capability to acquire the requisite devices and technologies and integrate them into existing 5G infrastructure. [10] Acquiring the resources can be a significant challenge, particularly for smaller providers needing more funds to invest in the necessary equipment. To solve the challenge, providers can rent or lease the necessary equipment and focus on purchasing the required ones to ensure the DUDe is integrated into the 5G network design. Trends have shown that successful implementation of the DUDe requires providers to obtain the appropriate support from their vendors to ensure smooth implementation without interruption.

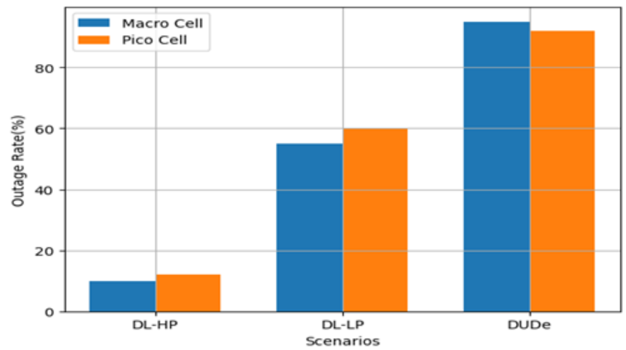

Fig. 6. DL-HP- macro vs Pico cell layers

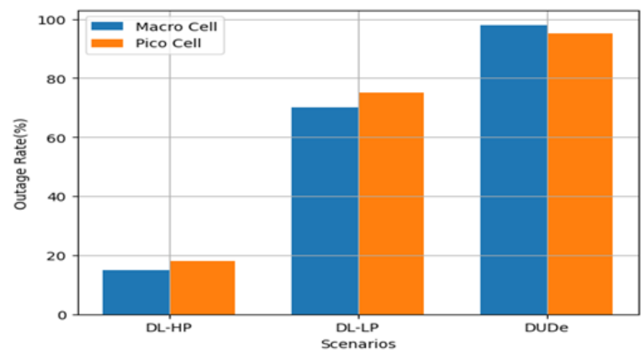

Fig. 7. DUDe- macro vs Pico cell layers

V. CONCLUSION AND FUTURE WORK

The study concludes that decoupled access would be appropriate to improve and optimize network performance. Increased implementation of the DUDe on the 5G would bring numerous gains, including increased bandwidth. The finding is supported by the evaluation made on three cases, and a decoupled downlink and uplink connectivity yielded the highest network performance, especially in an environment with high data transmission. The benefits are significant, as the DUDe approach can improve performance. Additionally, the study revealed that networks with high minimal throughput requirements have a significantly lower outage rate. [11] The study establishes decoupled access in an uplink and downlink method as the best in implementing a 5G network. However, with the ever-changing technology, the study directs further studies on optimization techniques of decoupled network access for the 5G network.

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REFERENCES

[1] H. Alrikabi, A. H. Alaidi, M. Alaidi, A. Shaker Abdalrada, and F. Abed, "Analysis of the efficient energy prediction for 5g wireless communication technologies," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 14, p. 23, 04 2019.

[2] R. Arshad, M. Farooq-i Azam, R. Muzzammel, A. Ghani, and C. H. See, "Energy efficiency and throughput optimization in 5g heterogeneous networks," *Electronics*, vol. 12, no. 9, p. 2031, 2023.

[3] M. F. Hossain, A. Mahin, T. Debnath, F. Mosharrof, and K. Islam, "Recent research in cloud radio access network (c-ran) for 5g cellular systems - a survey," *Journal of Network and Computer Applications*, vol. 139, 04 2019.

[4] M. F. Hossain, A. U. Mahin, T. Debnath, F. B. Mosharrof, and K. Z. Islam, "Recent research in cloud radio access network (c-ran) for 5g cellular systems-a survey," *Journal of Network and Computer Applications*, pp. 139, 31–48, 2019.

[5] M. Yousefvand, M. Asadi, and D. I. Kim, "Millimeter-wave communications for 5g and beyond: From fixed access to cellular networks," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 9, pp. 10379–10394, 2020.

[6] A. Łukowa and V. Venkatasubramanian, "Dynamic in-band self-backhauling for 5g systems with inter-cell resource coordination," *International Journal of Wireless Information Networks*, vol. 26, 12 2019.

[7] A. Haidine, F. Salmam, A. Aqqal, and A. Dahbi, *Artificial Intelligence and Machine Learning in 5G and beyond: A Survey and Perspectives*. 07 2021.

[8] H. Z. Khan, M. Ali, M. Naeem, I. Rashid, and M. Imran, "Resource allocation in 5g heterogeneous networks with downlink-uplink decoupled access," *Transactions on Emerging Telecommunications Technologies*, vol. 31, no. 3, p. e3831, 2020.

[9] R. Borgaonkar, I. Anne Tøndel, M. Zenebe Degefa, and M. Gilje Jaatun, "Improving smart grid security through 5g enabled iot and edge computing," *Concurrency and Computation: Practice and Experience*, vol. 33, no. 18, p. e6466, 2021.

[10] J. Zhang, G. Chuai, and W. Gao, "Energy-efficient optimization for energy-harvesting-enabled mmwave-uav heterogeneous networks," *Entropy*, vol. 24, no. 2, 2022.

[11] A. Shahid, V. Maglogiannis, I. Ahmed, K. S. Kim, E. De Poorter, and I. Moerman, "Energy-efficient resource allocation for ultra-dense licensed and unlicensed dual-access small cell networks," *IEEE Transactions on Mobile Computing*, vol. 20, no. 3, pp. 983–1000, 2021.