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A Review of 5G C-RAN Resource Allocation

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Abstract

The Fifth Generation (5G) Network will bring different use-case services like eMBB, mMTC, and uRLLC. As more devices connect to the 5G network, each user device request for data capacity will continue to grow. The increase in the number of devices and capacity request for each device will require an increase in network capacity, which will also need an increase in the number of Base Stations in the network. More Base Stations will increase the Mobile Network Operator's capital investment and operation costs. However, this increase in CAPEX and OPEX will not increase the Average Revenue Per User (ARPU) as users tend to be less willing to pay more as their capacity request increases. Mobile Vendors and Mobile Network Operators will face the challenge of providing higher capacity for the same or less ARPU for their customers to maintain their customer base and business profitability. C-RAN was identified as a new and promising paradigm to help Mobile Network Operators reduce their CAPEX and OPEX while delivering higher capacity to their customers and maintaining business profitability. How C-RAN resources are allocated and managed within the 5G network will determine how efficient and profitable this optimization process will be. This article provides a high-level review of the main enabling 5G Technologies and an exhaustive study of C-RAN resource allocation algorithms for 5G networks emphasizing resource allocation metrics/parameters. The main resource allocation metrics considered in this work include BBU computational/processing resource, capacity, Power/ energy consumption, wavelength, UE-RRH mapping, and RRH-BBU mapping. Energy Harvesting in 5G C-RAN, including its architecture, categorized taxonomy, and requirements, are also discussed. Lastly, future research directions and open research issues for efficient C-RAN resource allocation are highlighted.

Keywords: ARPU, C-RAN, CAPEX, OPEX, Energy Harvesting.

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1. Introduction

1.1 Overview

Implementing the Fourth Generation (4G) system had network capacity and coverage as principal challenges to meet user requirements for varying applications. Research over the years resolved these challenges by developing and implementing different technology solutions such as MIMO, beamforming, DAS, small cell concept, carrier aggregation, and improved coding schemes. Although there is still a need for high network capacity in 5G, the existing 4G technologies coupled with the 5G frequency bands will further remedy the network capacity and coverage challenges. However, the diverse service type requirements in 5G, namely eMBB, mMTC, and uRLLC, will bring other difficulties than network capacity and coverage issues. The capacity requirements for 5G will continue to grow as more users and devices connect to the 5G network. Also, each user request or device request for data capacity will continue to grow for each application. The small cell concept or network densification will become prevalent in 5G even though it will increase capital expenditure and operations expenditure for the network operators as more base stations will be needed to grow capacity. The overall cost of the network will increase for the mobile operator. The operator cannot increase the price per bit in the form of Average Revenue Per User (ARPU), as users are unwilling to pay more for increased data usage. This, the mobile vendors and mobile network operators are in a dilemma of building a high-capacity network that will generate less revenue. Developing more enhanced and enabling technologies for 5G will become imperative to maintain profitability. C-RAN was identified as a new and promising paradigm to help mobile network operators overcome the above dilemma by reducing their CAPEX and OPEX while delivering higher capacity to their customers and maintaining business profitability. The successful implementation of 5G systems and the delivery of its various services will significantly depend on how the different C-RAN resources are allocated and managed. As 5G deployment and implementation become a reality, research in resource allocation in 5G C-RAN will continue to gain ground over the years [1]. This article presents an exhaustive survey of resource allocation schemes in 5G C-RAN with an emphasis on resource allocation metrics/parameters with a view on the role Energy Harvesting Technologies will play in 5G.

1.2 Review of existing literature

Many reviews and surveys exist on 4G and future 5G C-RAN resource allocation schemes over the year. Below is some literature work done in this area.

Waleed E. et el. in [3] presented a survey in which they discussed C-RAN resource allocation and management elements with a framework that includes objectives, constraints, optimization type, solutions/algorithms, applications, etc. In particular, the review presented C-RAN emerging use cases, including H-CRAN, mmWave CRAN, DAS, V-CRAN, NOMA-based CRAN, Fullduplex capable CRAN, cell-free massive MIMO, and the different Radio Access Technologies, which the C-RAN architecture could support. The review ends with discussing and classifying various constraints, objectives, optimization taxonomy, and solution types involved in a C-RAN-based 5G network.

Rehenuma T R. et al. in [4] presented a survey that classified C-RAN resource management techniques into radio and computational resource management techniques. The radio resource management technique uses limited radio frequency spectrum resources, radio infrastructure, strategies, and algorithms for transmission of power control, dynamic channel allocation, spectrum management, cache management, and joint optimization. In contrast, the computational resource management technique uses resources in the BBU Pool, such as memory, processing power, data storage, time and bandwidth, to manage the base station’s functions. After examining the C-RAN architecture, the authors contrasted these techniques with those used to evaluate each scheme. Finally, they reviewed C-RAN research challenges and future study directions. As game theory continues to provide optimal solutions to various engineering problems, wireless communication was not an exception, as the author in [5] presented a survey of the 4G radio resource allocation problem and its optimization based on the existing advanced game theory. The authors describe the various types of games before demonstrating how the radio resource allocation and optimization problem in 4G and its extension to 5G might be solved using game theory.

In [6], Yongjun Xu et al. presented a survey introducing different heterogeneous network scenarios for 5G communications with their corresponding resource allocation models. In particular, they showed that HetNet could significantly improve spectrum efficiency and decrease coverage holes in a mobile network by allowing various small cell types (microcells, picocells and femtocells) to coexist with macrocells. The macrocells can overlap with the same spectrum band at the exact location. The author further showed that HetNets could improve the wireless network's spectral efficiency and reduce its energy consumption by combining cloud computing and HetNet to provide broader network coverage and higher throughput while coping with data processing and control.

The authors in [7-10] presented the security challenges associated with the 5G network. FENGYU T. et al. in [7] proposed a three-layered C-RAN architecture and reviewed its security concerns. They presented the C-RAN architecture regarding physical, control, and service planes. They outlined the corresponding security threats and attacks associated with each layer. The review showed the different security threats at each logical layer of the C-RAN. By defining a Service-Oriented C-RAN Architecture for 5G, the author opened a new research direction to investigate how this work could satisfy the anticipated security requirements in C-RAN. Praveen Kumar in [8] provided a security and privacy requirement to meet new threat models introduced by integrating new technologies, such as SDN, Virtualisation SBA, etc, for 5G networks. He discussed security as a driving factor for 5G services and network evolution. Among the proposed solutions, AI will be a critical and fundamental solution for network security. He concludes this review by presenting the 5G security road map. Shobowale et al. in [9] introduced the security concerns of 5G and its associated enabling Technologies that optimize the performance of the 5G Architecture. They reviewed the security challenges of 5G technologies based on their architecture. The primary security challenges of the 5G system presented are Authentication and Authorization. They also proposed both hardware and software solutions. In [10], Muhammad T. et al. discussed the latest advancement in 5G Mobile network security challenges, including device identification, network accessibility, data encryption, protection, and intrusion prevention. Security measures due to the different 5G enabling technologies are also considered, such as IoT, mMIMO, SDN, NFV, etc., and 5G safety management. Authors in [11-13] discussed the different RAN topologies required for 5G Networks. Mohammad Asif Habibi et al. presented in [11] & [12] an exhaustive review of several radio access network topologies for 5G networks. These topologies included C-RAN, H-CRAN, V-CRAN, and F-RAN. The authors also compared and contrasted several viewpoints, such as system architecture, spectral efficiency, energy consumption, resource allocation, network performance, and operations expenditure. They also reviewed 5G Key enabling technologies such as MEC, NFV, SDN, Network Slicing, AI, etc., and some Radio Access Technologies, namely mmWave, mMIMO, and D2D communication. Furthermore, the authors compared C-RAN, H-CRAN, V-CRAN, and F-RAN for 5G mobile networks using different characteristics such as storage, caching, latency, reliability, energy consumption, CAPEX, OPEX, Management, etc. Lastly, the authors concluded this review with an exhaustive discussion of the various research issues and directions associated with the different 5G C-RAN architectures highlighted above. Jun Wu et al. described the physical, control, and service planes in [13] as a new logical design for C-RAN. With an emphasis on service-oriented resource scheduling and management, this architecture presents the idea of a service cloud, supporting the development of new computing and communication systems. The author demonstrates how C-RAN can leverage current schemes to construct new algorithms that fit the C-RAN architecture instead of just converting existing algorithms from traditional architecture to C-RAN.

Authors in [14-18] discussed Fronthaul capacity limitations and delays as the main bottleneck/challenges to C-RAN implementation. The authors in [14] examined the different Fronthaul Architectures with their respective Challenges: Optical Fronthaul with Constant bitrate one-one mapping and connection, Wireless Fronthaul with Limited Spectrum, and Ethernet Fronthaul with latency and Jitter issues. The author concludes with the different Fronthaul compression techniques as a solution to resolve the Fronthaul capacity limitation challenge, namely Uplink Compression, Downlink Compression, and Point-to-Point Compression. Besides the theoretical studies, the author examines the different practical testbeds for C-RAN implementation. In [15], Chathurikain et al. discussed the various Fronthaul technologies, including CPRI, PLS, and ARoF, while highlighting the dependency of Fronthaul bandwidth capacity on the number of antennas. By analyzing the Fronthaul Capacity challenge, Chih-Lin et al. in [16] described the novel Ethernet-based Next Generation Fronthaul Interface (NGFI) design for 5G networks. By considering high-performance collaborative gain technologies, this novel design detached cells from user equipment's processing dependency and Fronthaul bandwidth's dependence on the number of antennae. This Ethernet-based fronthaul benefits from the flexibility and reliability of capacity management. The authors also discussed the Ethernet-based NGFI challenges such as latency, jitter, frequency, and time synchronization as future research directions for the fronthaul network. Aleksandra C. et al. in [18] evaluated, by mathematical and simulation methods, the different fronthaul splits for network level energy and cost efficiency considering the expected service quality.

In [19-22], the authors presented Artificial Intelligence's role in wireless communication. [19] covered how machine learning and deep learning, two subcategories of artificial intelligence, could help 5G wireless networks become proactive and predictive. The authors also discussed the different machine-learning solution approaches for 5G systems. In [20], Youness et al. provided an overview of Artificial Intelligence for 5G wireless communication design specifications, covering topics such as radio resource allocation, energy efficiency, network slicing, cyber security, and network administration. The survey also discusses different case studies and associated challenges for the specifications above. In [21], Paulo et al. highlighted the role of Machine Learning techniques and self-organizing networks in future cellular wireless networks in making them more autonomous and flexible. The authors of [22] thoroughly analysed and surveyed Deep Learning methods applied to C-RAN. They specifically offered DL as a workable method for forecasting dynamic traffic in C-RAN Networks and facilitating data processing for cloud resource management. The survey was categorized based on several optimization goals, including QoS maximization, power consumption optimization, and network performance optimization. The authors concluded the study by examining the challenges arising from the convergence of Deep Learning and C-RAN technologies: DL Training Models, Deep Learning Data dependency, Deep learning Spatio-Temporal Traffic patterns, DL in IoT, Discrepancies in Deep Learning simulation and implementation, multi-objective optimization schemes. Lastly, they discussed the open research issues relating to the different challenges and future perspectives. In [23], Fatima H. et al. evaluated the conventional IoT network resource management strategies and explored resource management difficulties for cellular and low-power IoT networks. This work also explored how machine learning and deep learning approaches will affect and manage these networks' resources. The authors used machine and deep learning to discuss D2D communication, MIMO, NOMA, and HetNets network resource allocation methods. The authors concluded by discussing the costs and interoperability issues associated with managing IoT resources using machine learning and deep learning approaches., development, training, and retraining of Machine Learning models.

With growing and advanced research in AI, the authors in [24-27] have taken the contributions of Artificial Intelligence in communications systems further using graph theory. The authors used graph-structured data to represent communication features/components such as network topology, routing, and signal interference. These graph-structured data use Graph Neural Networks (GNN) concept to control, model, and manage communication networks, especially for 5G systems. In [24], Shiwen H.et al. presented a survey of Graph-based Deep Learning techniques, e.g., Graph Convolutional Networks (GCN) and Graph Attention Networks (GAT), to model different types of communications networks such as wireless networks, wired networks, and Software-defined networks. In [25], Weiwei Jiang introduced Graph-Neural Networks as one of the deep learning techniques used to exploit the graph-structured data and contextual information nature of wireless networks. The author discussed the construction of Wireless Communication Graphs for meshed/ad-hoc networks, Cellular networks, WLAN, etc., with the different types of GNN. Several applications of GNN in wireless communications, such as resource allocation and other emerging fields, were also presented. In [26], Jose Suarez et al. used communication network fundamental components such as topologies, routing, signal interference, etc., represented by graph structure to demonstrate the use of GNN in communication systems. They showed that GNN could be a fundamental tool for controlling, modelling, and managing wired and wireless communication systems. The GNN has unprecedented generalization capabilities when applied to other networks and configurations unseen during learning and training. Mengyuan Lee et al. in [27] provided an overview of the interplay between GNN and Wireless communication, including GNNs for wireless communications (GNN4Com) and wireless communications for GNNs (Com4GNN). The authors also showed how they could construct graphical models for wireless communication systems using GNN4Com and how they could develop wireless communication mechanisms for the practical implementation of GNNs.

In [28] and [29], the authors presented an overview of 5G key enabling Technologies and network requirements. These technologies will include, among others: C-RAN, D2D communications, NFV/SDN, MEC, AI mmWave, mMIMO, etc. Both articles presented C-RAN as an emerging 5G network concept emphasizing Ultra Dense Network deployment and Multi-Radio Access Technologies capable of optimizing CAPEX and OPEX for the mobile network operator.

In [31-34], the authors presented an overview of the role of energy harvesting technologies in 5G networks. Energy harvesting is presented as an alternative energy source to extend the life span of devices and networks. In [31], Muhammad et al. outlined the energy harvesting process and discussed the requirements and benefits of energy harvesting technologies in 5G networks. The harvested energy is categorized and classified based on the following attributes:

- The energy harvesting source
- The energy harvesting devices
- Harvesting phases
- Harvesting models
- Energy conversion methods
- The energy propagation medium

The authors also highlighted how energy harvesting would improve the 5G C-RAN resource allocation process. Lastly, the authors outlined challenges and future research perspectives for energy harvesting deployment. In [32]. Sanae et al. described the requirements for RF energy harvesting deployment. In [34], Xumin et al. takes energy harvesting a step further by introducing the concept of a mobile charger and Software capability for energy harvesting. The concept of a portable charger as a device that allows nodes deficient in energy to replenish their energy from the charger while nodes with excess energy will upload their surplus energy to the mobile charger was also discussed. This process led to the bidirectional energy flow, which overcame variations in energy harvesting. The introduction of software capabilities led to the creation of Software Defined Energy Harvesting Network (SD-EHN) Architecture, which allows for the decoupling of the data plane, energy plane, and control plane to support flexible energy scheduling and boost energy efficiency. All these authors ended up with core research challenges and trends needed to make energy harvesting an enabling 5G technology for the 5G systems.

Since 5G will be an ultra-dense network, Energy consumption, and carbon dioxide emission will become global issues. Authors in [35-37] discuss Energy efficiency algorithms and methods as a major solution to maintain a reasonable energy consumption level and to reduce carbon emission in 5G networks. In [35], the authors proposed the integration of C-RAN with Renewable solar energy to provide an energy-efficient 5G network with low CAPEX and reduced carbon dioxide emission. Because of the regional and unpredictable nature of solar energy that may affect the service quality of the network, the author's proposed solution is a hybrid of solar energy with traditional grid power supply to reduce the effective grid power consumption for the network. Voore S. et al. in [36] presented a 95% energy-efficient C-RAN network that dynamically allocated BBU resources to RRHs based on facing traffic of the RRHs. At the same time, the proposed C-RAN network minimized the energy consumption of the centralized BBU by being in active or in-active mode using the Particle Swarm Optimization algorithm. In [37], Jing Gao et al. proposed a new energy-efficient model for C-RAN networks (mixture of on-grid and green energy) that take into account the total energy consumption of various networks components (remote radio head (RRH), fronthaul link, BBU pool, and wireless charging equipment of user equipment) in 5G. In addition to considering the user's quality of service (QoS), data rate requirements, the transmission power of RRHs, and maximum battery capacity constraints, the solution also considered the fronthaul link capacity constraints. A joint strategy of power allocation, resource block (RB) allocation, and power allocation ratio adjustment using the Lagrange dual decomposition method is used to solve the resulting optimization problem.

Table 1 summarises various reviews and surveys on resource allocation over the years from different perspectives. In this article, we have provided a review of 5G C-RAN resource allocation from a metric/parametric viewpoint and highlight the role that energy harvesting will play in 5G systems.

Table 1: Summary of existing Surveys/Review

Title of Article	**Ref**	**Central idea/New concept**
A Comprehensive survey on Resource Allocation for CRAN in 5G and Beyond Networks	[3]	Resource management techniques schemes in C-RAN from an optimization viewpoint with a detailed optimization taxonomy on various aspects of resource allocation
Resource Management in Cloud Radio Access Network: Conventional and New Approaches	[4]	Resource management techniques classified as : -RRM Technique -CRM Technique
Review on Radio Resource Allocation Optimization in LTELTE-Advanced using Game Theory	[5]	4G-LTE radio resource allocation problem and its optimization based on the existing advanced game theory.
A Survey on Resource Allocation for 5G Heterogeneous Networks. Current research future trends and challenges	[6]	Definition and different network scenarios of HetNet before presenting the different RA models. Specifically, HetNet allows many types of small cells to coexist while overlapping macrocell networks
A Survey on C-RAN Security	[7]	C-RAN logical layers (Physical Plane, Control Plane and Service Plane) and the corresponding security threats and attacks
A Comprehensive Survey of RAN Architectures Toward 5G Mobile Communication System	[11]	Comparison of various perspectives of C-RAN Architectures, such as energy consumption, operational expenditure, resource allocation, spectrum efficiency, system architecture, and network performance are presented.
Cloud Radio Access Network (C-RAN):	[14]	Presentation of a novel logical structure of C-RAN that consisting of a physical plane, a control plane, and a service plane.
Fronthaul Design in Cloud Radio Access Networks: A Survey	[13]	Examines different C-RAN architectures and fronthaul architectures
Rethink Fronthaul for Soft RAN	[16]	The Next Generation Fronthaul Interface (NGFI) based on ethernet is proposed as to reduces the high fronthaul capacity and latency requirement for C-RAN implementation
Artificial Intelligence in 5G Technology: A Survey	[19]	The role of AI in 5G networks is highlighted as a means to improving Network efficiency, latency and reliability of applications
Artificial Intelligence for 5G Wireless Systems: Opportunities, Challenges and future research directions	[20]	Role of AI in 5G wireless Communication systems using case studies, associated challenge and providing future research direction
Machine Learning for Resource Management in Cellular and IoT Networks: Potentials, Current Solutions, and Open Challenges	[23]	Role of Artificial Intelligence in Cellular networks and in C-RAN in particular
5G Wireless Communication Network Architecture and Its Key Enabling Technologies	[28]	Key enabling technologies and requirements for 5G deployment are exhausted in these reviews
A Survey of Self-Organizing Networks	[30]	Self-Organised networks are presented as an important tool in the automatization that will be required in 5G C-RAN applications.
Overview on 5G Radio Frequency Energy Harvesting	[32]	RF-Energy Harvesting in 5G context is reviewed with its techniques, constraints and research trends.
Software Defined Energy Harvesting Networking for 5G Green Communications	[34]	Energy Harvesting Technology is discussed further to include a mobile charge and the role that software capabilities can play in delivery a more sustainable energy efficient 5G networks
Recent research in cloud radio access network (C-RAN) for 5G Cellular System - A survey	[39]	The most recent advances in C-RAN research focusing on the analysis and enhancement of its major aspects: C-RAN architectures, throughput enhancement, interference management, energy efficiency, latency, security and system cost reduction
Cloud-RAN-Innovative radio access network architecture	[40]	The different C-RAN architectures ae reviews in this work
Energy-efficiency and high-Spectrum-efficiency Wireless Transmission	[76]	Latency and energy consumption are discussed as energy-efficient and spectrum efficient drivers of 5G networks

1.3 Contributions

This paper makes the following contributions:

- Highlights resource allocation metrics/elements as characterizing features in C-RAN Resource allocation algorithms/schemes.
- The idea of a new concept accompanying C-RAN Technology in developing new resource allocation schemes is identified in this work.
- Energy Harvesting is a future enhancement of C-RAN and a possible enabler for 5G deployment.

This paper is organized as follows: Key enabling technologies for 5G systems are presented in Section II, and the fundamentals of C-RAN architecture, including its advantages and disadvantages, are covered in Section III. Section IV presents a thorough analysis of C-RAN Resource Allocation Algorithms in tabular form, and Section V discusses the energy harvesting function in 5G C-RAN. Section VI discusses unresolved challenges and potential research directions for C-RAN resource allocation plans. While Section VII provides the paper's conclusion.

2. 5G Key Enabling Technologies

The Next Generation Mobile Network (NGMN) Alliance describes 5G as an end-to-end ecosystem that supports value creation for partners and customers while allowing a fully mobile and connected society. The 5G system will provide a consistent user experience and enable viable business models by utilizing existing and upcoming use cases. Fig.1 shows the anticipated 5G network fundamental needs for 2024. The amount of mobile data traffic in each area is expected to increase by a factor of 1000. Still, user data rates and connected devices are predicted to increase by at least 100 times. Battery life for low-power devices is anticipated to increase by ten times, and E2E latency is also expected to decrease by 5. [2] & [29]

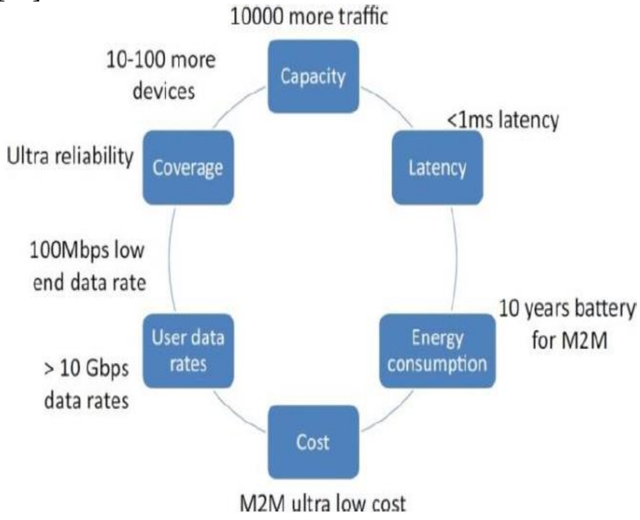

Fig.1:5G requirements (Source [29])

The 5G Mobile system development is thus motivated by the rising demand for data volume and user diversity requirements. Fig.2 shows Cisco networks' monthly mobile data traffic forecast in exabytes between 2017 and 2022. While Smartphones and Tablets dominated data generation in early 2020, Machine-to-Machine and IoT connections and devices are expected to take the lead in data generation by 2024.

Fig.2: Mobile data traffic forecast by cisco (Source [2])

5G will highlight three main types of use cases, namely:

- Enhanced Mobile Broadband (eMBB) is characterized by high bandwidth connectivity.

- Massive Machine-Type Communications (mMTC) is characterised by many connected nodes.
- Ultra-Reliable Low Latency Communications (uRLLC) is characterized by extreme low-latency applications

Fig.3 shows the different service categories above with specifications: eMBB will include applications like High-Definition video streaming, photo sharing, broadband access everywhere, and virtual and augmented reality, all characterized by high throughput requirements. The mMTC will include services like intelligent farming, smart cities, smart homes, and e-health care, all of which are IoT applications distinguished by the connectivity of many nodes and low sensitivity to latency. Meanwhile, uRLLC will include use cases with the most down latency requirements among the three use cases with improved reliability, such as self-driving cars and mission-critical apps [31]. The 5G network will inculcate HetNets, D2D communication, and the densification of small cell base stations to enable these use cases. Decreased mobile transmission power, high spectra efficiency, and increased network energy consumption are consequences of network densification. However, implementing these technologies will have as a real consequence the improvement of the following RAN feature

- Spectral Utilization,
- Spectral efficiency,
- Network densification.
- Energy Efficiency

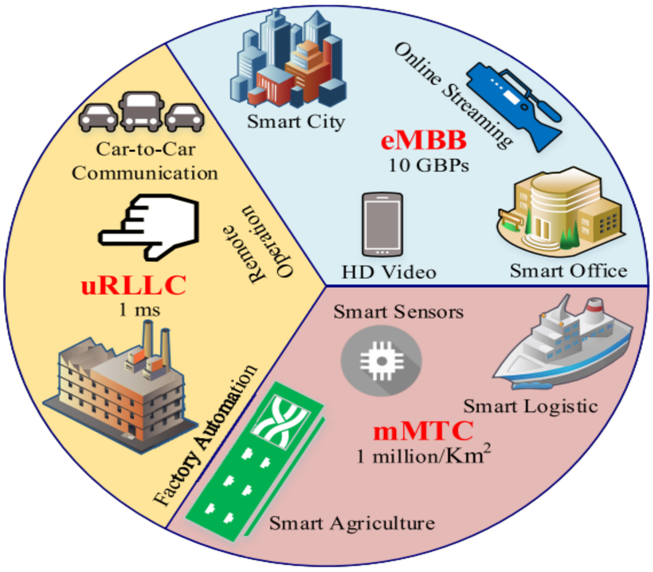

Fig.3 5G Service categories (Source [8])

The expected massive network capacity requirement and increased user experience for 5G systems will necessitate a drastic revolution in the architecture of cellular and wireless technologies [29]. The 5G key enabling technologies can be classified as either Wireless or Network. The 5G radio access network will have the most significant challenges as it has to manage different enabling techniques from spectral utilisation and spectral efficiency through network densification to Energy efficiency. This will drive wireless research in various dimensions, as in Fig.4.

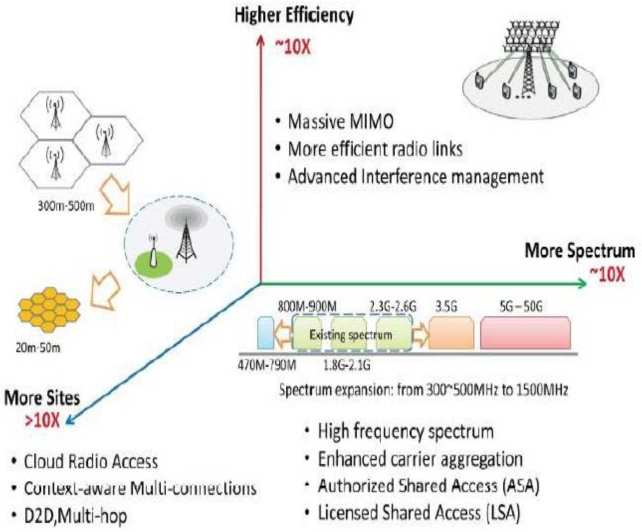

Fig.4: Three-dimensional representation of 5G (Source [29])

2.2. 5G Wireless Enabling Technologies

The 5G key enabling wireless technologies are discussed below:

mmWave: 5G systems will use mmWave frequencies (between 6GHz and 300GHz) to spread out the currently crowded 700MHz to 2.6GHz radio spectrum bands used for 3G and 4G wireless communication, in addition to existing techniques like spectrum allocation, carrier aggregation, etc., required to improve spectrum utilization. The mmWave Frequency will allow for more significant carrier frequency bandwidth allocation, resulting in higher data transfer rates, and this will enable system operators to expand their channel bandwidth ahead of the 20MHz bandwidth used by current 4G Networks. Additionally, increased bandwidth will reduce digital traffic latency, supporting Internet-based access and applications like factory and process automation, smart grid, intelligent transport systems, drone controls, etc., that all fall under the umbrella of 5G services. When mmWave combines with massive MIMO and adaptive beam forming, it can accommodate heterogeneous network backhauling at the BS. mmWave can be used for macro-cells and small cells in 5G to enhance greater network capacity than in 4G systems, as shown in Fig.5. mmWave has some challenges, such as propagation loss when the signal penetrates buildings and requires directional connectivity compared to current LTE frequencies.

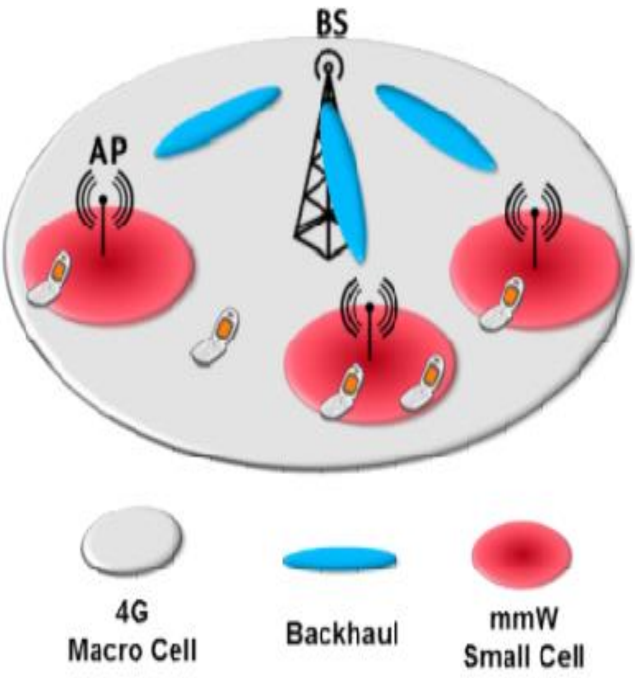

Fig.5: mmWave for small cell Backhauling (Source [28])

Massive MIMO. MIMO is when several antennas (tens or hundreds) are used at the base station (BS) or receiver as antenna arrays. This procedure makes it feasible to serve multiple users concurrently and effectively while strengthening the energy beams directed at the gadget. Massive MIMO can offer enormous spectrum efficiency, leading to significant capacity gains necessary to meet the anticipated growth of data traffic demands in 5G, as shown in Fig 6. When combined with small cell concept or densification, channel modeling, channel coding, and signal waveform already used in 4G, mMIMO can provide enormous benefits.

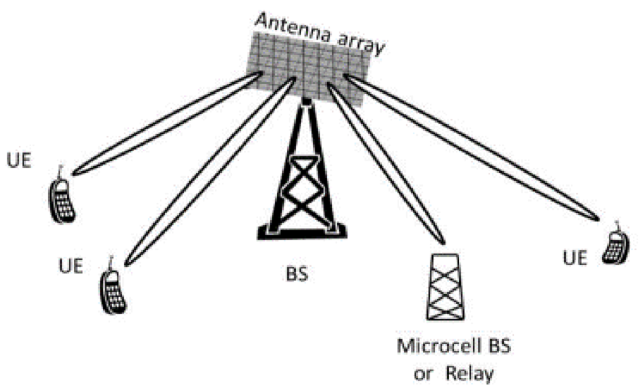

Fig.6: BS using Massive MIMO to serve UEs (Source [29])

C-RAN: Though network densification significantly improved 4G systems capacity, its continuous use in 5G is over-emphasized in what will be termed the Ultra-Dense Network. An Ultra-Dense Network will mean a large amount of radio processing function to be managed by the Base Stations. Thus, C-RAN technology is introduced as a promising 5G enabler to reduce base station processing function by separating the Baseband Processing Unit (BBU) from the Remote Radio Heads (RRHs). In the process, it allows centralized processing and assignment of radio resources. Thus, moving the BBU to a distant location in a pool/cloud, usually in a Data Centre, can optimize resource utilization. The RRH carries out the transmission of radio signals computed from the cloud. The RRH connects to the cloud BBU pool by a fronthaul, while the virtualized BBU pool connects to the core network via a backhaul. The RRHs are usually simpler and cheaper, allowing for more scalability and densification. C-RAN can also adapt to a Heterogeneous Network (HetNet) context, leading to Heterogeneous CRAN (H-CRAN) commonly used in a 5G system, as shown in Fig 7. In these circumstances, various node types, such as High-Power Nodes as in 4G Base Stations and Low Power Nodes as in Pico BS, femto BS, etc., are permitted to cooperate utilizing the same computing pools and solutions to resolve inter-tier interference, which enhances joint processing gains.

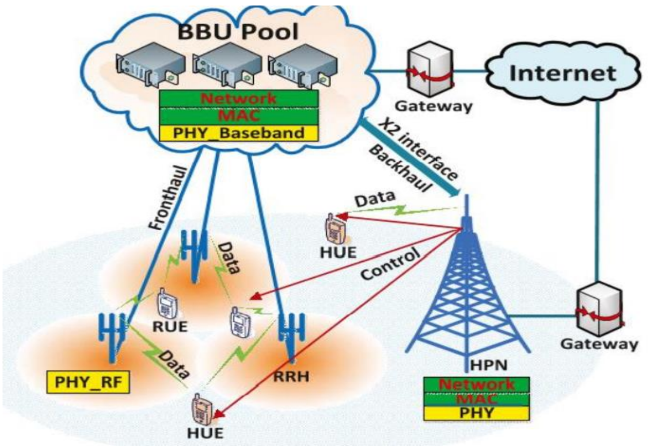

Fig.7: H-CRAN: (Source [32])

Energy Harvesting and Energy Efficiency: Network densification to improve 5G Network Capacity and Coverage will directly lead to high energy consumption and emission of carbon dioxide for the network. The need to optimize energy consumption and reduce carbon emissions will become imperative. Meanwhile, improving the network's overall energy efficiency and extending the battery life of user equipment will be necessary. Given the high cost of energy consumption, it will be vital to incorporate affordable and alternative energy sources to keep the overall cost of implementing 5G low. Therefore, energy harvesting technologies were introduced as an alternative source to produce energy from the surrounding environment such as RF signals, vibrations from human bodies, Solar, wind, and Thermal sources could be used to power wireless devices (5G BS, RRH, phones, IoT devices, etc.) and this can provide excellent and cost-effective solutions to 5G deployment. The Energy consumption of Base Stations can be optimized when Base Stations go to sleep mode (zoom out) to save energy or the base stations zooms in to maintain the coverage area of current users using RF-EHN or SD-EHN etc.

2.3. 5G Network enabling Technologies

The following are key enabling 5G technologies from a network perspective.

NFV/SDN: Network Function Virtualization enables sharing of common resources among operators. Several virtual resources can accelerate scalability following increased network demands by using automation mechanisms to abstract physical resources. NFV can install network function software in virtual machines deployed in a virtualized commercial server but not on individual dedicated network equipment. Therefore, the RAN operates as an edge cloud while Core is a core cloud. Software-Defined Networks can connect virtual machines at the edge and the core clouds. NFV/SDN allows network linking to the cloud to enable ultra-flexibility. SDN enables the orchestration of the NFV virtual and physical infrastructure resources through configuration, network connectivity, and bandwidth provision, as shown in Fig.8 below. NFV/SDN not only allows for flexibility, adaptability, programmability, and capabilities, but it can also provide, among others, efficient service life-cycle management, OPEX and CAPEX reduction, speedy service creation and deployment, improved quality of experience and energy consumption reduction required for 5G systems.

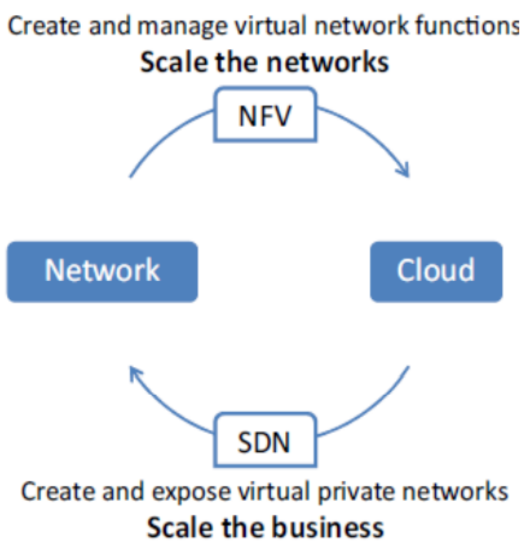

Fig 8: NFV Vs SDN (Source [29])

Network Slicing: Since the 5G system will deliver various services with different characteristics and requirements, it will not be possible and cost-effective for the 5G ecosystem to build dedicated networks for each service or application type since each service type will utilize a network with unique billing, policy control, security, mobility, latency, and dependability features (like mobile broadband, massive IoT, and mission-critical IoT). The envisaged solutions will be to design the 5G ecosystem with the capability to use the same physical infrastructure to build several logical networks called Network Slices, with each slice dedicated to specific services or applications. Consequently, based on the service requirements, the physical web will be divided into virtual E2E entities. Each entity or slice consists of several network functions, each with its radio access technology and settings for the specific use case and business model. Error propagation among network entities can be prevented by conceptually dividing the slices and giving them dedicated resources.

Self-organizing Networks (SON): The dense heterogeneous 5G network with different access technologies will require a change in network management. There will be a need for more automation, dynamic prediction, and allocation of resources. Self-Organising Networks (SON) are already deployed for 4G systems and will be significantly extended to 5G networks to reduce and optimize CAPEX and OPEX for the Mobile Operator, as shown in Fig.9. The critical features of SON will include:

· **Self-configuration**: Automating Network Elements set-up processes can save considerable time and effort for the network operator. Some configuration tasks significantly simplified by SON technology will include Software updates, handover path definition, cell identifier assignment, automatic neighbor relations, etc.

· **Self-optimization**: Some of the optimization functions of SON include mobile load balancing, mobility robustness optimization, frequent handover and interference mitigation, coverage capacity optimization, access robustness optimization, signal strength, and quality optimization, minimization of drive testing, crowd measurement reports optimization, energy conservation, and handover forwarding processes.

· **Self-healing:** Automatic fault repair is a vital feature of SON. Some of the self-healing tasks of SON include compensating for cell outages, detecting them, identifying cell deterioration, recovering from them, and so forth

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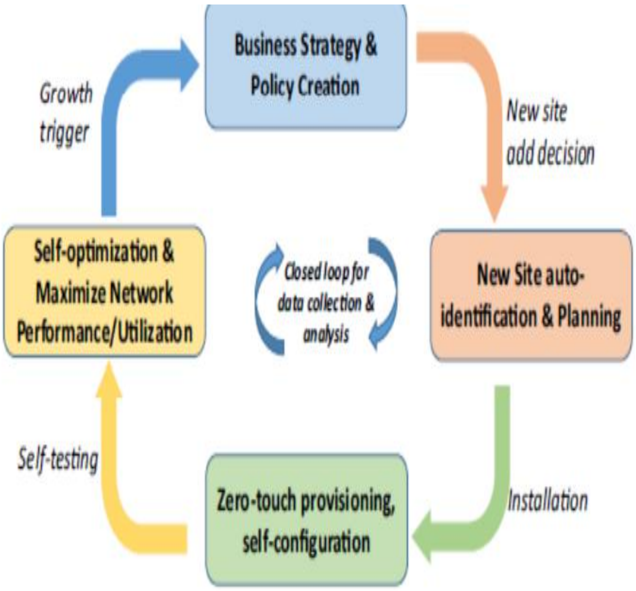

Fig.9: SON deployment with close loop automation (Source [29])

Device to Device Communications (D2D): 5G systems will have voice-centric communication with prior spatial proximity and the possibility for collocated devices to communicate and share content or interact wirelessly. When devices set up multi-hop communication networks and serve as transmission relays, device-to-device communication will increase capacity and coverage. Fig.10 shows how D2D communication will be helpful in 5G applications, especially concerning massive IoT applications.

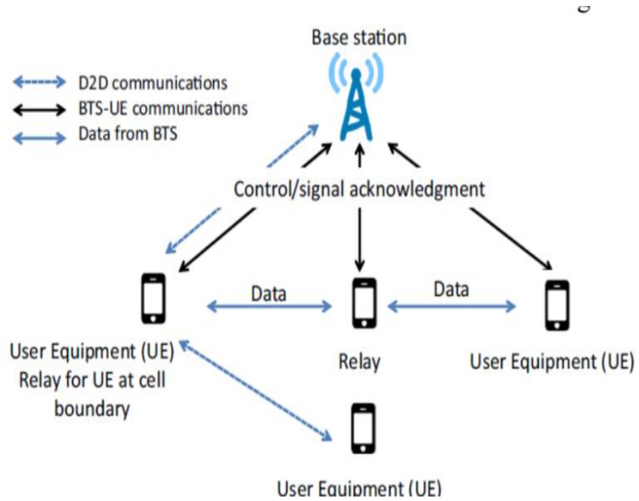

Fig.10: D2D communication (Source [32])

Mobile Edge Computing / Fog Computing: The vast amount of data generated in a 5G Ultra Dense Network with diverse applications must be transmitted across network nodes, which may require centralized cloud computing capabilities. Extending Cloud computing capability to the network's edge can reduce traffic congestion. Services and applications demand that enable ultra-low latency, radio network information, and high bandwidth can be provided by Information Technology and cloud computing capabilities to mobile subscribers as Mobile Edge Computing Technology. The MEC technology will be helpful for context-related applications such as RAN-aware content optimization, Augmented Reality content delivery, dynamic content optimization, etc. Fig.11 illustrates the quality of the end users' experience with MEC nearby. Fog computing can extend cloud computing to the network's edge for uniform distribution of resources and services. Cloud and fog computing can combine all IoT verticals while enforcing service and security. Fog nodes can be placed at the edge in various geographically distinct places distant from the cloud to offer applications with device location and context awareness. Table 2 compares Fog and Cloud computing features.

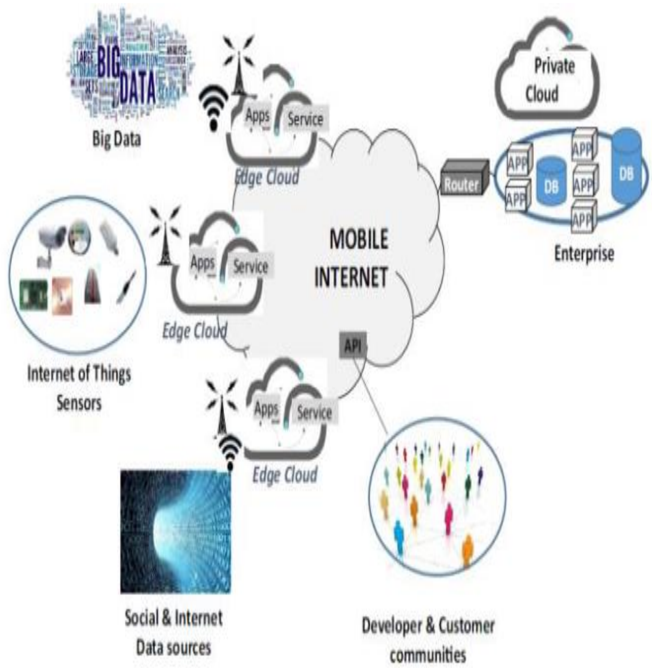

Fig.11: QoE with MEC in proximity to end users (Source [29])

Table 2: Fog and Cloud Computing compared (Source [29])

Features/Xtics	Fog Computing	Cloud Computing
Target users	Mobile users	Internet users
Service type	Limited localized information Services related to specific deployment locations	Global information Collected from worldwide
Hardware	Limited storage, compute power and wireless interface	Ample and scalable Storage space and Compute power
Distance to Users	In the physical proximity and communicate through single-hop wireless connection	Faraway from users and communicate Through IP networks
Working Environment	Outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls, etc)	Warehouse-size building with air conditioning systems
Deployment	Centralized or distributed in regional areas by local business (local telecoms vendor, shopping mall retailer.	Centralized and Maintained by Amazon, Google, etc.

Artificial Intelligence: The dynamic and flexibility requirements for 5G systems will require the network to be intelligent enough to interact with its environment to provide a complete wireless communication system to support its diverse applications and use cases (eMBB, mMTC, uRLLC). These applications will require different performance criteria for capacity density, latency, connection reliability, system spectral efficiency, energy efficiency, spectral utilization, peak throughput, air interface, etc. Summarily, 5G networks will determine the provisioning mechanisms for applications and services using other enabling technologies. However, this will also introduce system design, configurations, optimization procedures, resource allocation, operation, and maintenance complications. AI is an engineering and global intelligent problem-solving technique and will broadly apply its learning, proactive and predictive capabilities in designing, configuring, and optimizing 5G networks. The different Artificial intelligent methods will be relevant to 3 main technical problems: Combinatorial optimization, Detection, and Estimation.

3 C-RAN Architecture

The RAN is the component of a wireless telecommunications system that connects individual user devices (UE) to other parts of the network through a radio or air interface [38]. The basement of the base station can house the Radio and Baseband units (BBU) in traditional RAN architecture. Fig. 12 shows the radio and baseband units merged within the BSs in 2G.

Table 3: Mobile backhaul network primary locations (Source [38]).

Generation	Base Station	Controller	Backhaul Interface	Backhaul aggregation
2G	BTS	BSC	Abis	TDM
3G	NodeB	RNC	Iub	ATM/IP
4G	eNodeB	eNodeB, MME & SGW	S1	IP

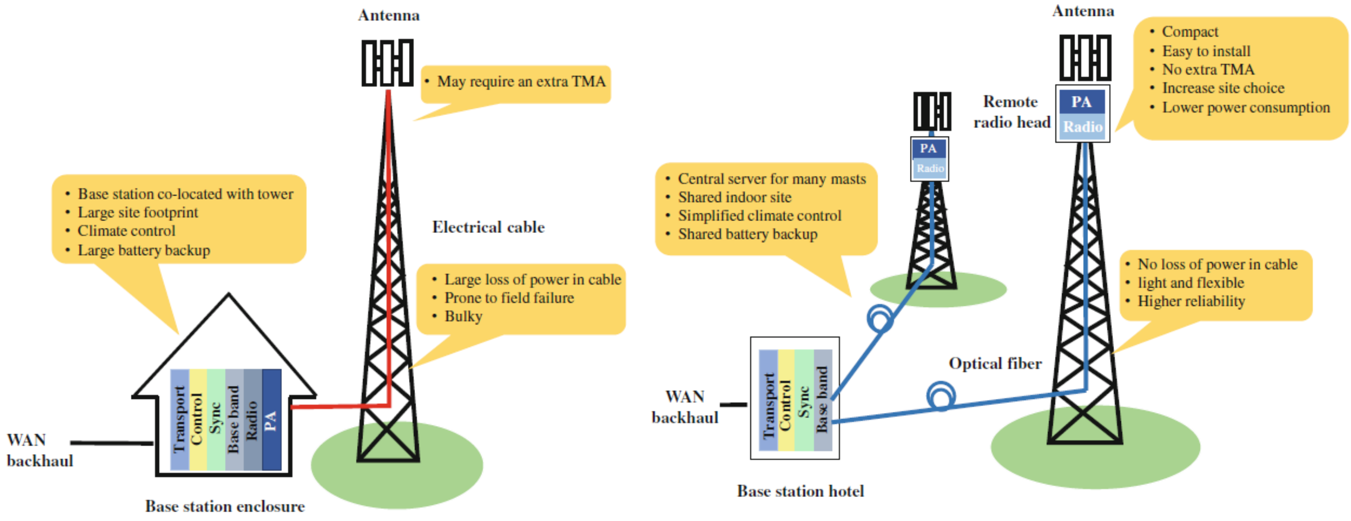

Fig.12: Traditional RAN Architecture (Source [38])

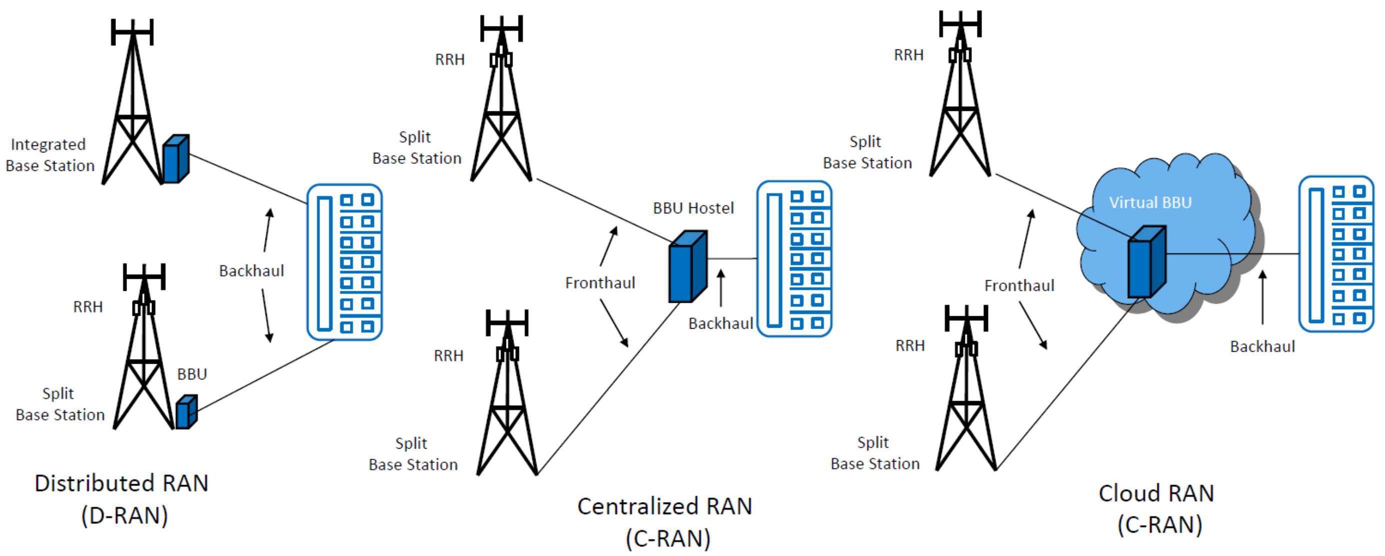

Fig.13: C-RAN Architectures (Source [41])

In 3G and 4G, the BBUs and RRHs are separated, with the BBUs located conveniently away from the RRHs. Fig 13 shows this type of RAN, called Distributed RAN (D-RAN). The ever-increasing traffic growth in 4G and 5G networks will require MNO to increase network capacity. Increasing the number of cells (Base Stations) or deploying techniques like Massive MIMO, DAS, Beam Forming, etc., or using a combination of the two can boost network capacity for the network. Either scenario will result in an overall increase in the Total cost of ownership of the network, whether due to CAPEX (the construction of additional base stations) or OPEX (increase in power consumption and maintenance cost). Unfortunately, this increase in TCO is not followed by a corresponding increase in Average Revenue Per User (ARPU), as the typical user is unwilling to pay more for data usage. Mobile Network Operators will incur a network cost that may exceed the revenue generated. Therefore, new paradigms, architectures, technologies, and protocols must remedy this situation. This increase in network cost will become particularly prevalent in 5G networks where service differentiation is common. The Cloud Radio Access Network (C-RAN) became a novel cellular topology to resolve the above challenge by removing the BBUs from the Base stations and relocating them to a central point called the BBU Hotel or BBU Pool for centralized data processing. At the same time, the RRHs remained at the cell site to perform simple radio functions. This concept was developed concurrently in 2010 by IBM and China Mobile. Thus, the idea is to split the base stations into the Baseband Unit in a high-performance data center with DSP processors and leave the Remote Radio Heads at the cell site. A high bandwidth optical Fronthaul network linked the RRHs to the BBU Pool, as illustrated in Fig. 14. Compared to the traditional RAN architecture, C-RAN thus possesses this unique feature of separating the BBUs from the RRHs.

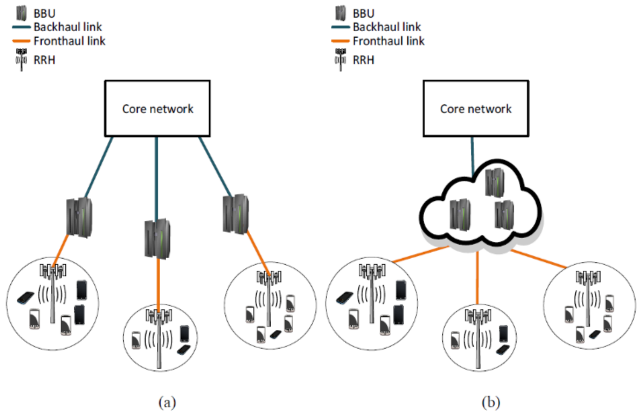

Fig 14: Distributed RAN and C-RAN 3G-4G (Source [4])

3.1 C-RAN Components:

The major parts of the C-RAN architecture are described below: [4].

1-Baseband Unit /BBU Hotel: The BBU is usually situated in a data center far from the cell site, with shared and virtualized functionality, and is responsible for packet and baseband processing. Many BBUs can be installed at the same location to form a BBU Hotel or BBU Pool. The BBUs can be installed as virtual machines and consist of high-performance programmable processors that use virtualization technologies. To handle the traffic load of various cell types, the cloud controller in the BBU Hotel acts as a resource manager and balances load amongst cloud base stations.

2- Remote Radio Heads RRH/RRU: The RRHs usually consist of two parts used for connecting wireless devices to access points. While the transmitting component first gets the digital signal via a CPRI and converts it to the analog signal, the receiving element collects RF signals from users and sends them to the cloud over the optical fiber transmission link. The RRHs provide digital processing, such as digital-to-analog and analog-to-digital conversion, power amplification, filtering, etc., and also act as the fiber interface.

3-Fronthaul: The link between the RRH and BBU can be an optical fiber, wireless technology, or Ethernet. It connects the baseband unit and one or more RRU/RRH. In LTE, the FH network uses CPRI over fiber Links to transmit IQ data streams, which requires high bandwidth. For instance, to deliver its IQ samples across the CPRI interface, an LTE base station supporting 150 Mbps of downlink bandwidth in the access network will need more than 2 Gbps of optical bandwidth. Thus, high capacity and low latency/delay will remain the two critical requirements for the Fronthaul network [13]. The 5G fronthaul network will have huge capacity requirements to support targeted data rates and low latency requirements to meet end-user applications. Table 4 shows typical capacity requirements for the CPRI Fronthaul network.

Table 4 CPRI fronthaul bandwidth requirement (Source [12]).

Parameters	Current LTE	5G requirement
N_s	3	3
N_a	1	8
S_f	30	30
S_{bw}	30.72 (for 20 MZ)	30.72*5 (for 100MZ)
B_e	16/15	16/15
L_c	10/8	10/8

Depending on the radio access technique being used, the necessary bandwidth for a CPRI link can be determined by

$$B_{CPRI} = N_s * N_a * S_f * S_{bw} * B_e * L_c \quad \text{Eq 1 (Source [15])}$$

where, N_s is the number of sectors per RRH, N_a is the number of antennas corresponding to the antenna configuration, S_f represents the sampling frequency, S_{bw} is the sampling bit-width for I/Q samples, B_e is the ratio considered for the controlling overhead (a basic frame consists of 16 words and one used for controlling purposes), and Lc is the factor that accounts for the capacity increase due to 8B/10B encoding used.

MIMO antennas from 3sectors antenna, a 147.5 Gbps of optical fiber CPRI-based fronthaul network will be required to transport wireless data. For a specific CPRI network design, the bandwidth will be fixed and unaffected by the actual traffic load [15]. A constant bandwidth of 48.3 Gbps will be needed for each RRH, even if the capacity demand of CPRI links may decrease using compression techniques (2:1) and even if the RRHs do not have any user traffic to transmit. At the same time, the 5G network will require a latency margin of less than 1ms for end-to-end communication. The Fronthaul network delay must be increased beyond a few hundred microseconds to achieve the targeted FH performance. When building 5G C-RAN, the fronthaul technology, and the fronthaul architecture must be considered to achieve such low latency.

The Next Generation Fronthaul Interface (NGFI) technology based on Ethernet can resolve the fronthaul capacity and latency constraint in 5G C-RAN. NGFI will remove the dependency of fronthaul bandwidth on the number of antennas and decouple cell and user equipment processing, thus focusing on high-performance gain collaborative technologies [16]. Utilizing the tidal wave effect on mobile traffic will offer the advantages of lower bandwidth and enhanced transmission efficiency, improving the flexibility and dependability of the Fronthaul transport network. Fig. 15 shows the Ethernet-based NGFI architecture.

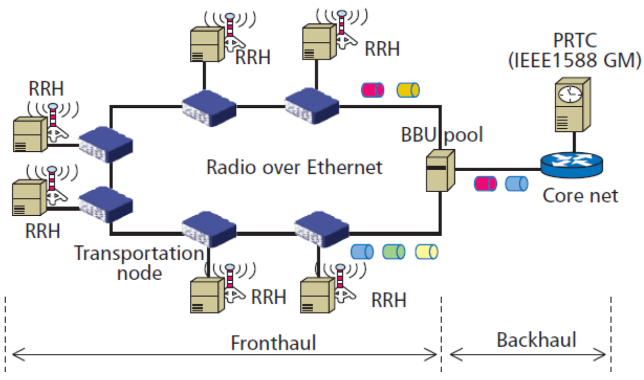

Fig.15: Ethernet- based NGFI Fronthaul (Source [16])

3.2 C-RAN Specific Features

The C-RAN network architecture shares several features with the conventional RAN but differs significantly in many essential ways, as discussed below [7].

Firstly, BBUs are centralized. The traditional Base Station is an all-in-one architecture, each having a separate computer room. C-RAN uses a distributed architecture in which BBUs and RRHs together play the role of the base station. A large computer room may accommodate hundreds or thousands of BBUs, while the RRHs are outside.

Secondly, distinct BBUs within the same virtualized BBU pool closely collaborate. Various BBUs may communicate ideal spectrum resources, channel information, and user data information to reduce inter-cell interference and increase the system's capacity by implementing a real-time, high-speed internal infrastructure.

Thirdly, there is a one-to-many mapping between BBUs and baseband computing resources. In the C-RAN design, baseband computing resources will not belong exclusively to a single BBU but to a pool of virtualized BBUs. The distributed resources will share the group of virtualized resources.

Fourthly, with the C-RAN design, the base station is software-defined. The BBUs can support several standards for air interface protocols and perform baseband processing based on a unified and open software radio platform. They can easily upgrade wireless signal processing algorithms. Table 5 below compares the traditional Base station and the C-RAN functionalities.

CPRI-based fronthaul network to transport wireless data

Table 5: COMPARING TRADITIONAL BASE STATION, BASE STATION WITH RRH AND C-RAN (Source [1])

Architecture	**Radio and BBU Functionality**	**Problem it addresses**	**Problem caused**
Traditional Base Station	Co-Location in one unit	-	-High Power consumption -Inefficient use of resources
Base Station with RRH	-Split between RRH and BBU -RRH and Ant are placed together at Remote site -BBU located within 20-40km away. 4G today	-Low Power consumption -Convenient Placement of BBU	-Inefficient use of resources
C-RAN	-Split between RRH and BBU -RRH and Antenna are placed together at Remote site -BBU from many sites are co-located in a pool within 20-40km away. 5G tomorrow	-Mush lower Power consumption -Fewer BBUs needed -Lower Cost	Considerable transport resources between RRH and BBU required

3.3 Types of C-RAN Network.

According to the functional division between the BBU and the RRH in the base station, as shown in Fig. 16, there are three basic types of C-RAN Networks. A partially centralized, fully centralized, or hybridized C-RAN architecture is possible. [4].

Layer 1, Layer 2, and Layer 3 functionalities are all located in the BBU, which is in charge of tasks like extending network coverage area, supporting the multi-standard operation, maximizing resource sharing, signal processing, offering multi-cell collaborative, etc. in the Fully Centralized Architecture. This architecture's key feature is that it places a heavy burden on the fronthaul link and demands a lot of bandwidth. Sampling, modulation, resource block mapping,

antenna mapping, and quantization are among the Layer 1 tasks. At the same time, the transport-media access control is a Layer 2 functionality, and radio resource control is a Layer 3 functionality.
In the Partially Centralized C-RAN, the BBU performs Layer 2 and Layer 3 duties, while the RRH handles radio functions and Layer 1-related tasks. The RRH now handles several baseband processing tasks previously held by the BBU, which reduces the bandwidth needs between the BBU and RRH in this design. This architecture is less adaptable for multi-cell collaborative signal processing updates.

In the hybrid centralized C-RAN architecture, the RRH handles some Layer 1 functions like user or cell-specific signal processing tasks while the BBU handles others. This architecture demonstrates increased resource-sharing flexibility and can lower BBU's energy usage and communication overhead.

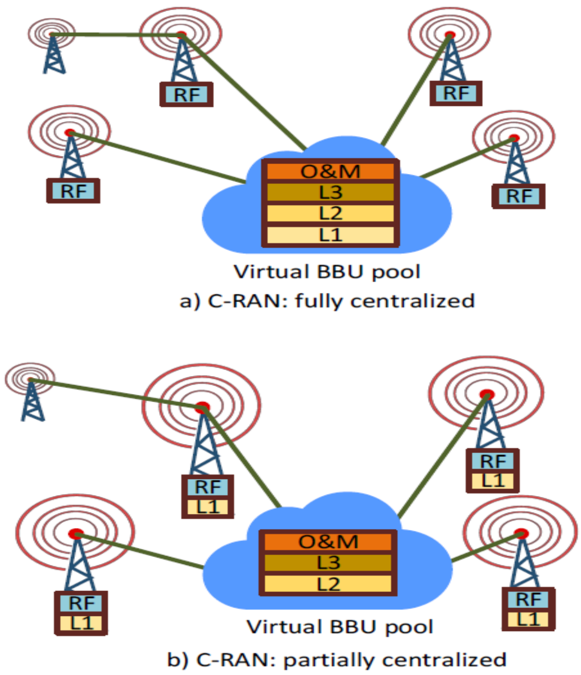

Fig.16: C-RAN Types Source [4])

3.4 C-RAN Benefits and Challenges

Benefits: C-RAN presents considerable benefits compared to the traditional RAN, as highlighted below [1], [4], [38], [39], [40].
Adaptability to Non-Uniform Traffic and Scalability: The non-uniform nature of mobile traffic at different places (city centers Vs. residential areas) and times of the day (Day Vs. Night) results in the inefficient use of communication resources. This spatial-temporal variation in traffic may cause some BS to be overloaded sometimes. In contrast, others can be underutilized and processing power can be wasted for sites without heavy traffic. C-RAN can improve the utilization of radio and BBU computing resources by balancing non-uniform traffic in the network. The centralized nature of BBUs may cause RRHs with no traffic to be turned off to reduce energy usage, while RRHs with low traffic loads can be combined and managed by a single BBU.
On the other hand, RRHs with significant traffic loads can be given numerous BBUs at various times. This dynamic allocation of network resources during different times resolves the ’tidal effect’ problem of mobile traffic. The C-RAN design is very scalable at all times. Using various network technologies, such as wireless sensors, cognitive radio, MIMO technology, etc., the C-RAN design can allow high scalability, making it simpler to add or remove BBUs and RRHs from the network without network downtimes.
Network cost savings resulting from BBU Pool statistical multiplexing gain: The Mobile Network Operator can efficiently reduce its CAPEX and OPEX by building BBUs in one pool. Turning off a few RRH or BBUs in the pool will make it feasible to lower the network's energy usage without compromising overall network coverage. Furthermore, joint transmission, reception, joint processing, and coordinated beamforming technology can reduce inter-cell interference.
Increase of Throughput, Decrease of Delays- 5G C-RAN will incorporate advanced features and Technologies such as HetNets, Small cells, self-organizing networks, MIMO, mmWave, etc., improving network throughput and spectral efficiency.
Easy Network Maintenance and Upgrades: Network maintenance and upgrades are more straightforward using the C-RAN design, which has many RRH and co-located BBUs. Virtualization in the BBU Pool can introduce new standards and hardware in C-RAN. The C-RAN architecture can use Software Defined Radio (SDR) to implement software for radio tasks like coding, signal creation, modulation/demodulation, link layer protocols, etc. Upgrades to new standards and frequencies can use software processes instead of upgrading via hardware, as is typically done. Therefore, a multi-mode C-RAN base station will lower the cost of network construction and O&M (Operations, Administration, and Maintenance) (OAM).).
Challenges: As promising as the C-RAN paradigm may be, it also presents a couple of challenges in the design and implementation of 5G [1], [3], [4, [38], [39]: These may include: the use of virtualization techniques, security, BBU cooperation and clustering and in particular the need for high Fronthaul capacity. Some critical challenges include:

High fronthaul capacities requirement: The Fronthaul is the link connection between the RRHs and the BBUs in C-RAN and should have high bandwidth capacity, low latency, and low-cost requirements. The fully centralized solution is the most widely used C-RAN design and will likely have a high communication cost on the fronthaul link. The Fronthaul link usually uses wireless technology, Ethernet, or Optical Fiber Communication to resolve this high Fronthaul bandwidth challenge. Optical Fiber communication using

CPRI has been the most commonly used fronthaul technology to provide the bandwidth required, although it comes with a very high implementation cost. Hence there is a need to choose a solution that offers the best compromise between delay, bandwidth, and cost, thus enabling multiple modeling parameters for the resource allocation process considered. Ethernet fronthaul is a promising new technology that makes use of virtualization, SDN, and IP concepts, which are already used in the industry [15], [16], and [18]. However, Ethernet fronthaul presents two significant challenges: the delay, which should be within 100µs, and the jitter, which should be within 65ns. Research on how to resolve these challenges is ongoing for practical C-RAN deployment.

BBU Cooperation: BBUs in the same pool must work together to facilitate scheduling, gathering channel feedback, and user data sharing. Since This kind of cooperation, dealing with high bandwidth, user privacy, and low latency communication across BBUs may become problematic and challenging.

Cell Clustering: Assigning BBU pools and optimally clustering the cells for maximum gain with minor overhead is still challenging. A BBU pool will support RRHs in severally scattered geographical locations, such as offices in various states, and optimize the amount of transmitted and received channels to reduce fronthaul overheads and delays. Therefore, solving the problem of cell clustering and BBU assignment in C-RAN systems is still challenging.

Virtualization Technique: Although virtualization allows operators in a cloud architecture to handle and share resources, its implementation in C-RAN is more challenging in wireless communications. Due to the BBU's requirement for dynamic, real-time processing, this presents a significant difficulty. Because this differs from the conventional IT cloud requirement, it is necessary to adapt the cloud infrastructure on which the BBU runs. More studies and testing will continue before the actual deployment of C-RAN.

Security: C-RAN deployment will continue to face substantial difficulties concerning trusted parties and user privacy security. As resources are shared amongst BBUs in the distributed and centralized C-RAN architecture, accessing presumed securely protected data and violating user privacy will be a potential security breach. Furthermore, although RRHs and BBUs in C-RAN are presumed trustworthy, given the substantial user base subscribed to such a system, such presumptions may need to be more accurate. Such a sizable virtualized system will present opportunities for misbehavior and security threats from some users. Therefore, C-RAN implementation will engender new security problems not previously thought of in addition to the general weaknesses presented by regular cellular networks, such as Eavesdropping, jamming, impersonation, PUEA, wireless channel, and other security threats.

3.5 C-RAN Resource Allocation Elements / Metrics

Because the BBU Pool contains all the data about the associated RRHs and the RRH only broadcasts and receives radio signals, the C-RAN resource allocation duties occur there. Managing the resource allocation tasks can be very challenging because of the many conflicting objectives and constraints required to maintain the required QoS and QoE of the different entities. Thus, the resource allocation algorithm, optimization solution, or scheme used to manage or perform the tasks will depend on the resource allocation element or metrics considered [3]. Below are some of the main C-RAN resource allocation elements or metrics used.

User Assignment: Choosing a particular group of users for a specific period to increase network throughput is known as user assignment or user scheduling. Given the limited resources and interference restrictions present in C-RAN, intelligent and efficient user scheduling will consequently play a crucial role in improving the network throughput, even if this procedure frequently proves to be a computationally demanding effort.

RRH Selection: Although the RRH's primary duties are radio signal transmission and reception, the network's spectral and energy efficiency will impact the RRH's selection. The RRHs work together to complete the centralized beamforming duty, which directly affects how well the wireless channel's throughput performs.

BBU Computational/Processing Resources. BBU resources (CPU, Memory, Disc size, Connecting Ports, etc.) will play a significant role in performing the resource allocation task since all these processes occur in the BBU Pool.

Throughput: Although many techniques such as mmWave, network coding, mMIMO, beamforming, power management, etc., have been adopted to enhance the throughput in 5G networks, the C-RAN framework also provides an additional enhancement in the throughput to meet the ever-growing 5G capacity demand.,.

Network utility: Network utility consists of the different QoS parameters such as delay, outage, throughput, blocking probabilities, and network design objectives usually used to ensure minimal QoS requirements.

Spectrum Efficient spectrum management is one of the most prolific benefits of C-RAN technology. Therefore, creating an architecture suited for combining licensed and unlicensed bands at the RRH will increase the effectiveness of the 5G spectrum. Spectrum management will be necessary to avoid any compromise of legacy WiFi users, and it will provide an appropriate solution for using mmWave in the backhaul links.

Power Allocation: RRHs will be installed close to one another in 5G, which may cause interference problems affecting network power efficiency. These RRHs will also impact the spectrum and energy efficiency of the C-RAN system.

The resource allocation parameters such as Virtualization, Uplink or Downlink, Single or Multiple objectives, constraints, Homogenous networks or Heterogenous networks, Fronthaul or Backhaul, etc., enable the efficient utilization of the resource allocation elements/metrics in performing the resource allocation task and in the subsequent development of the optimization solution/Algorithm/scheme. The eventual optimized solution or resource allocation algorithm developed uses one or more parameters simultaneously in conjunction with a particular resource allocation element or metric.

3.6 C-RAN Functional split affecting Fronthaul Efficiency.

Due to the C-RAN Fronthaul high-capacity requirement, the concept of fronthaul Functional split will determine the nature of the processing tasks at the RRHs and BBU pool [13], [15], [16]. [18]. The different processing tasks may include modulation and demodulation, source encoding, multiplexing and demultiplexing, ADC, DAC, etc. The data transmitted from the RRHs to the BBU will be less if most of the processing takes place in RRH, and this will reduce the bandwidth requirement for the Fronthaul, even though it will make the RRH design more complicated and costly. On the other hand, more data will be transmitted to the BBU if most of the processing is at the BBU pool, thus making the fronthaul bandwidth requirement much higher, even though the RRH will be lighter and cheaper.
Also, the exponential traffic growth in 5G will only be possible due to improvements in Antenna design technologies such as DAS, LSAS, mMIMO, etc. These improvements will cause the FH bandwidth requirement to be proportional to the number of antennae used. Therefore, any technology or process that will eliminate or remove the dependence of Fronthaul bandwidth from the number of antennae will render the 5G C-RAN architecture more efficient. Accordingly, the RRH/BBU can be designed to remove antenna-related tasks (such as fast Fourier transform [FFT], downlink antenna mapping, equalization channel estimation, etc.) from the BBU to the RRH and the non-antenna-related tasks remain on the BBU. In such a situation, FH transport BW in a 5G network will decrease regardless of the number of antennae used [16]. Therefore, the savings on the BBU will generally be lower when more processing tasks occur at the cell sites. The fronthaul capacity demand will be lower, but the RRH design will still be expensive and complex. However, when more processing tasks occur at the BBU, more BBU cost reductions are achieved at the trade-off of increasing fronthaul capacity requirements. There will always be a trade-off between RRH complexity and fronthaul capacity to react to the most efficient architecture in C-RAN design**.** Below are the different types of possible Fronthaul functional splits.

Traditional BB-RF Split: In this functional split, RRHs are responsible only for receiving and transmitting RF signals to the BBU. To meet the traffic load of various cells, the BBU acts as a resource manager providing load balancing amongst cloud base stations [18]. The virtualized BBUs will share the baseband processing resources in a C-RAN, while baseband processing resources will statically assign the RRH in a traditional RAN. As a result, baseband processing is believed to require fewer processors in the C-RAN than in the standard RAN. The CPRI protocol operates at a constant bit rate regardless of user activity, and fronthaul links do not experience multiplexing gain.

UE-CELL Split- (Decouple Cell /UE Processing): The constant-bit-rate FH transport is typically incompatible with the tidal-wave nature of mobile traffic, which varies with time and place. This tidal-wave nature frequently results in the wastage of resources on the network. Baseband processing can be cell processing or user equipment (UE) processing, and regardless of the number of active UEs, cell processing is unaffected by traffic load. Physical broadcast channel (PBCH) processing, a cyclic prefix (CP) insertion and removal, inverse FFT (IFFT/FFT), cell-specific reference signal, primary synchronization signal, and secondary synchronization signal production are a few examples of BB processing duties in LTE. Therefore, separating the processing of the cell and the UE by moving all cell processing tasks from the BBU to the RRH will be more effective. If cell processing moves from the BBU to the RRH, the fronthaul bandwidth will be load-dependent and reduced. The load-dependent feature can utilize the statistical multiplexing benefit of the FH transport network design for the C-RAAN [16], [18]. With this statistical multiplexing improvement, fewer FH links in C-RAN will require as much fronthaul capacity. Cell-UE processing and decoupling can also be employed to cut power usage and improve network dependability because basic cell coverage signal processing is a type of cell processing. On the one hand, when there is no active UE, BBU software can be set to a dormant mode to conserve power. Conversely, even when a BBU malfunctions, RRH can continue to protect the air interface. In doing so, it gives the BBU fault processing enough time. As a result, the C-RAN network's overall energy consumption demand will decrease.

PDCH-RLC split: In this functional split, most of the data processing occurs at the cell sites, with the BBU pool processing the remaining bulk of it. With fluctuating bit rate traffic delivered over the fronthaul connection, this approach will produce a small BBU pool multiplexing gain. Notwithstanding, this split results in a limited fronthaul bandwidth capacity

Physical Layer Split: Fig.17 shows the Physical layer split fronthaul architecture. Here, the centralized BBU executes the RLC operations, MAC Layer protocols, and physical layer operations. Other physical layer operations used below wireless channel codings, such as resource mapping, modulation, demodulation, and fast Fourier transformation, are relocated to the RRH [15]. Since the Layer 1 functionalities, such as resource mapping, modulation, and demodulation, are now contained in the RRH, the PLS architecture has a lower deployment cost and lower fronthaul bandwidth demand than the CPRI. The MAC layer functions and wireless coding operations occur in the BBU, which can support advanced cooperative technologies. However, if there is a need to perform software and network upgrade functions in the RRHs, then the CPRI architecture must do such upgrades on the required equipment. Though this may appear challenging, the network function virtualization (NVF) paradigm can reverse this situation. CPRI consumes over ten times as much bandwidth as PLS, although PLS bandwidth increases with the number of users, whereas CPRI bandwidth maintains a constant bit-rate value. Even though it only lasts a few milliseconds, the symbols level processing carried out at the RRHs results in an additional processing delay of RRH for PLS compared to CPRI

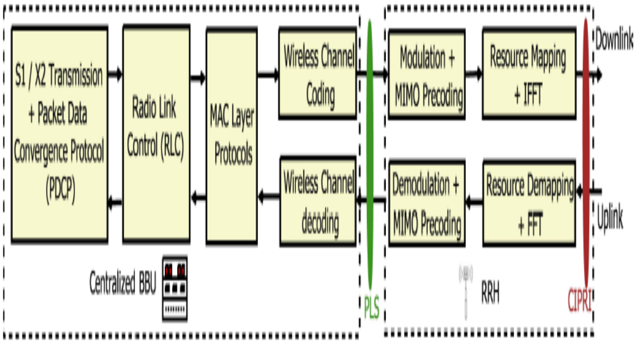

Fig 17: PLS Functional Split in CRAN Architecture. (Source [15])

Analogue Radio-over-Fiber architecture: As in DAS applications, Radio over Fiber (RoF) is a technique that combines the advantages of wireless networks and fiber to distribute wireless signals across the fiber. In analog RoF (ARoF), the centralized BBU handles most signal processing tasks, such as coding, modulation, and multiplexing, as shown in Fig. 18. RRH converts the electrical to an optical signal. Even while the nonlinear effects of noise and distortion on analog sequential transmission may put a permanent cap on ARoF, several of the upcoming 5G wireless technologies can help to alleviate this restriction. A conventional 10 Gbps fiber transceiver can be used for network traffic in ARoF because the bandwidth needed for the fiber network depends on the wireless bandwidth used.

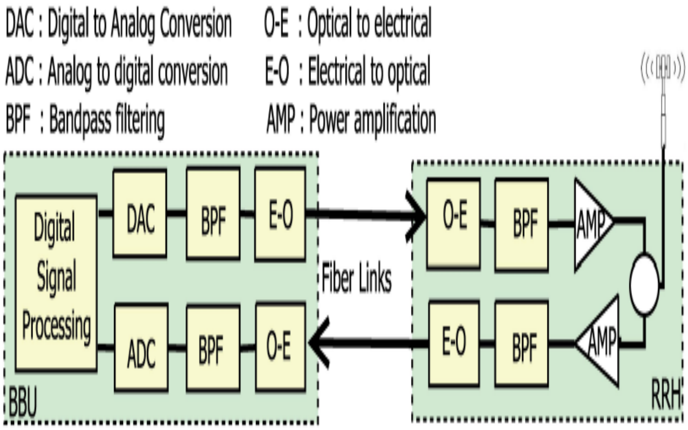

Fig 18: Analog RoF for 5G fronthaul Architecture (Source [15])

4 Review of 5G C-RAN Resource Allocation Schemes or Algorithms

This section presents a brief review of C-RAN resource Allocation schemes/algorithms in tabular format. Table 6 illustrates using different resource allocation metrics with the appropriate technology concept in developing the resource allocation scheme/algorithms.

Table 6 Summary of C-RAN Resource Allocation Schemes/Algorithms

Article No.	Year	Title	RA Elements	New Concept	C-RAN RAA
[54]	2018	Dynamic Allocation of Processing Resources in C-RAN for a Virtualized 5G Mobile Network	BBU Computational / Processing Resources (CPU, Memory, Disc size, Connecting Ports etc)	C-RAN + NFV	BBU Dynamic Resource allocation Scheme
[55]	2022	Artificial Bee Colonies Solution for Load Sharing in a Cloud RAN		C-RAN + Load Balancing	ABC and LBMM
[56]	2017	Multi-Resource Allocation in Cloud Radio Access Networks		C-RAN + Visualization	C-RAN, Virtualization / IRAA
[47]	2020	Deep Reinforcement Learning Based Dynamic Resource Allocation in Cloud Radio Access Networks		C-RAN + DRL	DRL-based resource allocation scheme
[57]	2020	Machine Learning Adaptive Computational Capacity Prediction for Dynamic Resource Management in C-RAN		C-RAN + ML	DRM-AC-PF and DRM-AC-ES -

[22]	2021	A Survey on Applications of Deep Learning in Cloud Radio Access Network		C-RAN + Deep Learning	Supervised DL/LSTM
[45]	2018	Multi-Objective Resource Allocation in Density-Aware Design of C-RAN in 5G		CRAN + Average Density of Users	MORA Algorithms in High Density Mode and in Low density Mode
[14]	2015	Cloud Radio Access Network (C-RAN): A Primer		C-RAN + Service cloud layer	Condition number-based user pairing algorithm. for optimum linear precoding in C-RAN
[58]	2017	A Resource Allocation Mechanism for C-RAN Based on Cell Differentiation and Integration Concept	Throughput / Bandwidth / Capacity	C-RAN + Cell Differentiation and Integration	C-RAN, CDI / DPSO, EA
[46]	2019	Dynamic Resource Prediction and Allocation in C-RAN with Edge Artificial Intelligence		C-RAN + Edge AI	LSTM and GARAA
[59]	2016	An Enhanced OFDM Resource Allocation Algorithm in C-RAN Based 5G Public Safety Network		C-RAN + PSN + OFDM	Generalized bender's decomposition-based resource allocation algorithm and the Feasible Pump Algorithm
[20]	2020	Cloud radio access network fronthaul solution using optimized dynamic bandwidth allocation algorithm		Bandwidth C-RAN + PON	Optimised RR-DBA algorithm -
[67]	2020	An Access Selection Algorithm for Heterogeneous Wireless Networks Based on Optimal Resource Allocation		Optimal bandwidth selection	ORAAS-Optimal resource allocation access selection algorithm.
[53]	2015	Reducing Energy Consumption by Dynamic Resource Allocation In C-RAN	Power Consumption & Energy Efficiency	C-RAN + Host Manager	Dynamic BBU Assignment and RRH selection Algorithm
[37]	2022	Resource Allocation Optimization Based on Energy Efficiency in Green Cloud Radio Access Network		C-RAN + Green Energy	The ERM algorithm
[35]	2022	Energy-Efficient Hybrid Powered Cloud Radio Access Network (C-RAN) for 5G		C-RAN + Green Energy	Energy sharing algorithm.
[36]	2022	Dynamically Energy-Efficient Resource Allocation in 5G CRAN Using Intelligence Algorithm		C-RAN + PSO	Resource Allocation Algorithm using PSO for balancing BBU overload
[51]	2022	Multiobjective Reinforcement Learning Based Energy Consumption in C-RAN Enabled Massive MIMO		C-RAN + RL + MIMO	Multiobjective Reinforcement Learning (MORL)
[52]	2022	Multi-Agent Deep Reinforcement Learning for Slicing and Admission Control in 5G C-RAN		C-RAN + DRL + Network slicing	DRL-AC, DRL-VNE & S-AC-VNE
[60]	2016	Demonstration of Dynamic Resource Sharing Benefits in an Optical C-RAN	Wavelength resource Radio and Transport Network (DRS)	Wavelength, C-RAN + DWDM	DRSS+

[61]	2019	Resource allocation scheme for 5G C-RAN: a Swarm Intelligence based approach	Spectrum Utilizations and Spectrum Efficiency	C-RAN, + Bee-Ant-concept	-Joint UE-RRH mapping algorithm -The RRH-BBU mapping algorithm
[48]	2020	Intelligent multi-agent-based C-RAN architecture for 5G radio resource management		Spectrum, CRAN + MAS + AI	Multi-agent learning cloud assisted double auction (MLCADA) Algorithm
[50]	2018	Joint PRB and Power Allocation for Slicing eMBB and uRLLC Services in 5G C-RAN	PRB, CSI and Power Consumption, Position estimate	C-RAN + Network Slicing	Penalized Successive Convex Approximation algorithm
[62]	2016	Learning-Based Resource Allocation Scheme for TDD-Based CRAN System		Position Estimate C-RAN + TDD + ML	RFA. -
[49]	2016	Dynamic Resource Allocation for C-RAN in LTE with Real-Time BBU/RRH mapping	UE-RRH / BBU-RRH Mapping or Assignment	BBU-RRH Mapping + C-RAN + OFDMA	DRAC – Downlink PRB RAA
[44]	2015	Quality of Service Aware Dynamic BBU-RRH Mapping in Cloud Radio Access Network		BBU-RRH mapping C-RAN + SON using Host Manager	GA
[61]	2019	Resource allocation scheme for 5G C-RAN: a Swarm Intelligence based approach		UE-RRH and BBU-RRH Mapping C-RAN + Network Load	Bee-Ant-CRAN Schemes
[74]	2022	Interference and QoS-Aware Resource Allocation Considering DAS Behavior for C-RAN Power Minimization		C-RAN +DAS	-Admission Control -Interference and QoS-Aware Mapping
[64]	2019	An Optimal Multi-tier Resource Allocation of Cloud RAN in 5G using Machine Learning		UE-RRH Association C-RAN + H-CRAN + HetNet + AI	
[69]	2022	Functional Split-Aware Optimal BBU Placement for 5G Cloud-RAN Over WDM Access/Aggregation Network		C-RAN + WDM	Functional Split-Aware BBU Placement Algorithms
[63]	2023	Effective Resource Allocation Technique to Improve QoS in 5G Wireless Network		C-RAN + DL	Modified Random Forest Algorithms
[66]	2016	Optimal Context-Aware Resource Allocation in Cellular Networks		eNodeB Selection	Context-aware resource allocation algorithm for UE-RRH mapping
[68]	2021	Deep Learning (DL) Based Joint Resource Allocation and RRH Association in 5G-Multi-Tier Networks		C-RAN + DL	JOINT SAPARA ALGORITHM for RHH - association
[65]	2017	Modelling Time-Aware Shaping in an Ethernet Fronthaul	Scheduler Entity	C-RAN + Ethernet Fronthaul	TS and Resource allocation in multi-tier H-CRAN
[66]	2016	Optimal Context-Aware Resource Allocation in Cellular Networks	Sum rate	C-RAN + 3 cells / 3 sectors Cellular Architecture	Context-Aware Resource Allocation Algorithm.

5 C-RAN and Energy Harvesting in 5G.

5.1 Energy Harvesting Technology

Energy and Spectrum resources will significantly contribute to 5G networks, which aim to continuously provide mobile users with higher data rates, improved quality of experience, and lower energy consumption. One consequence of 5G network densification is increased energy consumption and green gas production resulting from installing many RRHs and Base stations. Because of this increase in energy consumption required for 5G, saving and using energy efficiently during 5G network deployment will be necessary. A novel approach to extending the lifespan of devices and networks will be energy harvesting technology in 5G [31]. As illustrated in Fig. 19, EH approaches will generate energy from the surrounding environment, including RF signals, solar, thermal, wind, vibrations, and the human body. These energy sources can power wireless devices, such as 5G BS, RRH, phones, IoT devices, and others. EH will not reduce the system's energy consumption but will enable devices to be self-powered when they encounter energy shortages. In addition to providing an alternative energy source for 5G, EH will help reduce green gas (CO_2) emissions expected from the densified 5G Network.

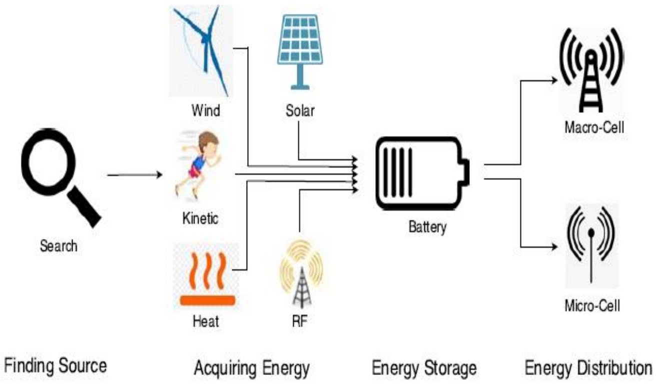

Fig.19: Energy Harvesting Process in 5G networks (Source [31])

Fig. 20 shows the six categories of the energy harvesting taxonomy for 5G: energy harvesting technology or source, energy harvesting device, energy conversion methods, energy harvesting phase, energy harvesting model, and energy propagation medium.

- Energy Sources: This may include various sources such as RF signals, Solar, Wind, Thermal, Body temperature, etc.
- EH Devices: These could be from SBS, eNB, Sensor nodes, Wearable devices, Mobile devices, etc.
- Energy Conversion Methods will include piezoelectric-based conversion, Photovoltaic conversion, Turbine based conversion, electromagnetic conversion, and Micro electro-mechanical system based.
- Energy Harvesting Phase: From an ambient source, Acquire source, store energy, and energy distribution.
- Energy Harvesting Mode: This could be Centralised, Decentralised, or Distributed.
- Energy Propagation Medium: Wired or wireless

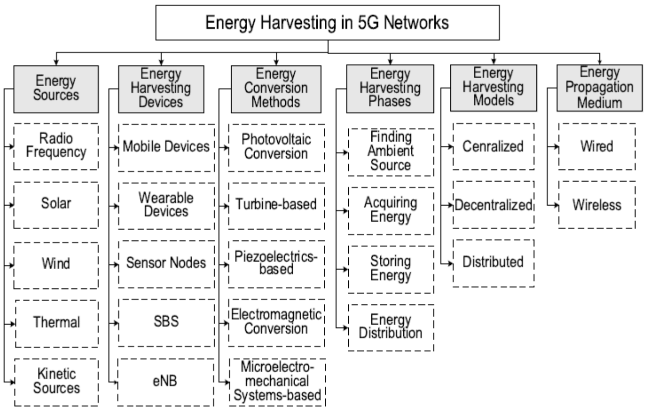

Fig.20: 5G Energy Harvesting Taxonomy (Source [31])

RF EH presents a unique and exciting feature of the many energy harvesting technologies. The RF-EH source can serve as both an energy transfer source and a data transfer source. T The RF-based EH converts electromagnetic radiations from many sources, including Bluetooth, telecom base stations, and infrared devices, into energy by using RF signals in the air. The same electromagnetic field can also communicate information to devices or end users. Simultaneous Wireless Information and Power Transfer is the name of this procedure. (SWIPT). A harvesting device, such as a wireless mobile charger, will use a wireless energy propagation medium to spread the RF energy around the surroundings through radio waves. The rectifier antenna, known as the rectenna, captures the energy and subsequently shares it between the energy and information circuits either statically or dynamically [32], as depicted in Fig. 21. However, there will always be a trade-off between the channel's energy transfer rate and its rate of information transmission.

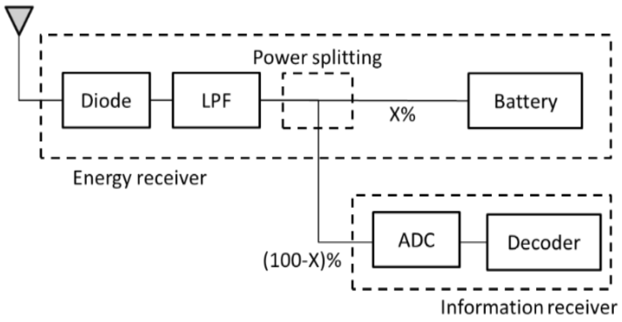

Fig.21: Integrated information and energy receiver (Source [32])

Fig.22 shows the main requirements for enabling energy harvesting in 5G.

- Continuous Uniform Energy availability
- Efficient sharing of Energy
- Hybrid Energy harvesting
- RF EH infrastructure
- Adaptive Energy management mechanisms
- Biased User Association

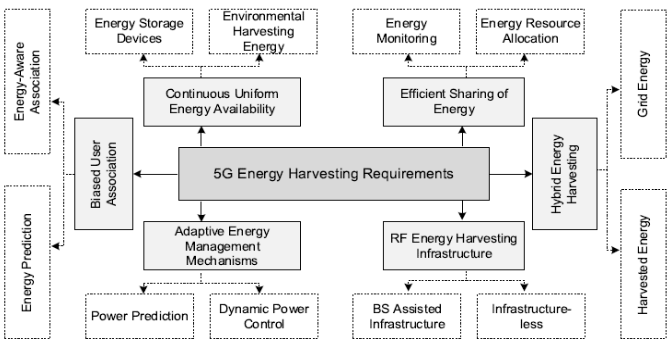

Fig.22: Energy Harvesting requirements for 5G (Source [31])

5.2 C-RAN and Energy Harvesting

The network's energy consumption will increase whenever a network becomes dense, as in the case of C-RAN and H-CRAN, with many RRHs deployed. Enhancing the access network's energy efficiency will become crucial as the RRH, the BBUs, and the MBS will deploy different techniques to adapt and optimize the power consumed. Grid/DG and EH methods could power these nodes [32], [33]. Fig.23 illustrates a conventional C-RAN network with a Grid energy supply. In contrast, Fig.24 illustrates the C-RAN with hybrid grid and solar, and Fig.25 shows another configuration of C-RAN with hybrid DG and Solar. To ensure reliability and zero outages, the RRH in Figs. An EH source powers 24 and 25 during regular operation and only switches to a grid power supply or DG when storing energy is unavailable. By enabling BS in a region to zoom in for coverage or zoom out for sleep mode, energy-efficient BS technologies like Cellular Partition Zooming (CPZ) can reduce energy consumption. The number of users primarily associated with RRHs can increase by optimizing and modelling power allocation, user association, and EH limitations, reducing the overall energy consumption of the network.

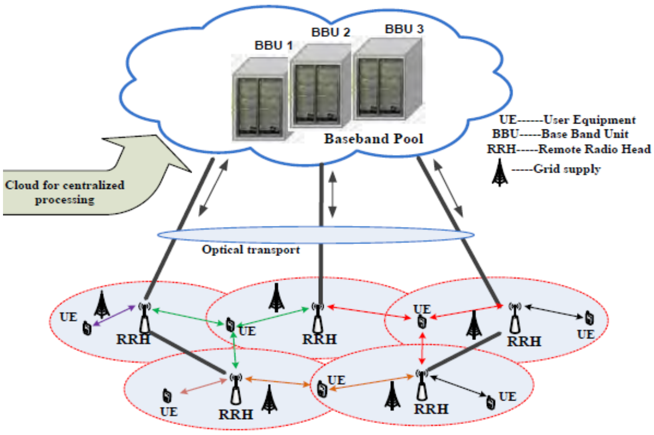

Fig.23: Conventional C-RAN with Grid Energy (Source [33])

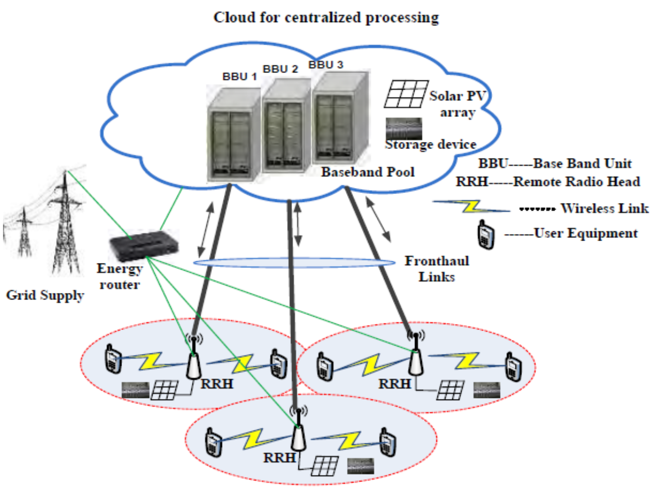

Fig.24: C-RAN with Hybrid Grid and Solar (Source [33])

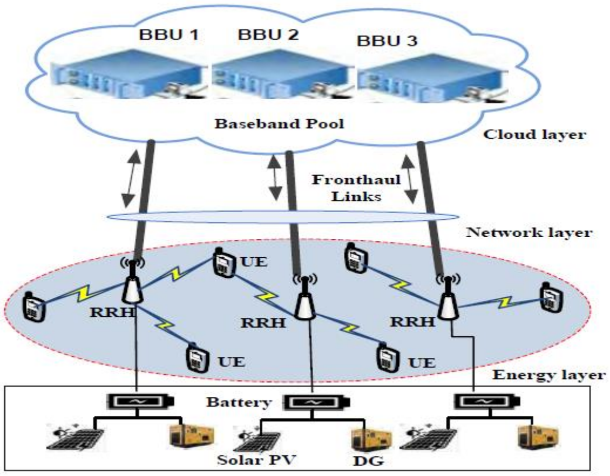

Fig.25: C-RAN with Hybrid DG and Solar (Source [33])

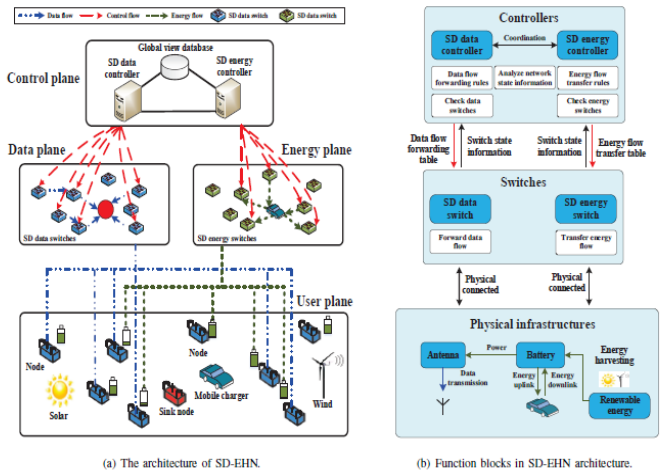

Fig 26: SD-EHN Architecture and Functional block (Source [34])

5.3 Software Defined Energy Harvesting Networks in 5G

As seen above, three unique properties of RF-EH are (1)-its ability to transfer harvested energy within the environment in the form of radio waves using a wireless propagation medium, (2)-its ability to simultaneously transfer both information and energy as SWIPT and (3) its bi-directional ability to transfer the energy depending on the energy gradient by making use of a wireless device called a Mobile Charger. Depending on their energy needs, energy-deficient nodes can download the energy they need from the mobile charger. In contrast, energy-rich nodes can upload excess energy onto the Mobile Charger. This mobile charger-based EH's bi-directional feature allows for large-scale and on-demand energy scheduling procedures by considering the spatial-temporal profiles of renewable energy changes. This coexistence of an energy flow and a data flow in the energy harvesting network can result in network control challenges. The Software Defined Networking idea, which offers centralized control for the best flow scheduling, can be used to manage this control difficulty. Thus, 5G green communication networks will adopt a Software Defined Energy Harvesting Network (SD-EHN) [26] architecture in which the data plane, the energy plane, and a control plane will coexist to facilitate variable energy scheduling and increased energy efficiency.

The nodes in an EH network have two queues: one for the data queue stored in the data buffer and the energy queue stored in the battery. These nodes use energy when they send and receive sensory data utilizing multi-hop routing in their monitoring region. Still, the process of harvesting renewable energy adds to the energy queue. In SD-EHN, four planes logically separate one another; though interrelated, each plane has specific functions. The control plane obtains and updates the network states, the energy plane performs energy scheduling tasks, the data plane performs data transmission tasks, and the control plane then schedules the energy flows. The data flows dynamically using software-defined data controllers and software-defined energy controllers, respectively. The components that make up the user plane, or physical infrastructure, include a mobile charger, nodes with batteries, antennas, and various energy-harvesting gadgets. The data and energy flow are implemented in the control plane through the different switches using appropriate Application Programming Interfaces. The two SDN controllers in the control plane can cooperate and communicate with one another to ensure logically centralized control because they separate the data and energy planes to provide independent development and update of the physical infrastructure. Furthermore, the Mobile Charger can serve as a data collector and an energy transporter that routinely moves between the nodes and gathers sensory data in various monitoring zones. The service station can receive and process the sensory data for further network monitoring and analysis. The mobile charger can be utilized as both an energy transporter and a portable data collector, as shown in Fig. 27. In this approach, the mobile charger may belong to a charging service provider. The mobile charger can also replenish energy-deficient nodes or gather surplus energy from nodes.

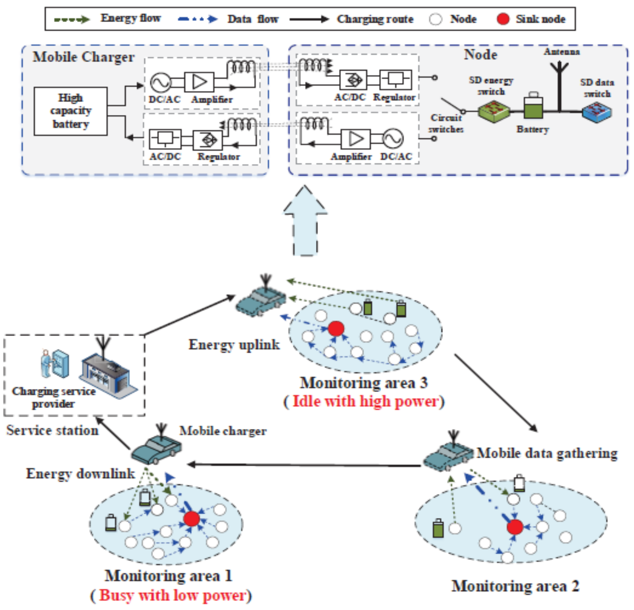

Fig.27 Scenario of mobile data gathering and bi-directional energy transfer in SD-EHN. (Source [34])

6 Open Research and Future Perspective of C-RAN Resource Allocation Algorithms

As Mobile Network Operators and Cellular Vendors continue to implement 5G networks, C-RAN deployment cannot be over-emphasized as a key 5G enabler. Fronthaul capacity and latency will continue to be the principal challenges to 5G C-RAN implementation, and the C-RAN design architectures will continue to attract research [65]. Though the Next Generation Fronthaul Interface based on Ethernet will mitigate the fronthaul capacity issue, Jitter, Delay, time, and frequency Synchronisation issues will require continuous research to make this usable. As 5G C-RAN implementation gains ground, open research areas and future perspectives of C-RAN will include, among others:

- **AI for C-RAN Resource Allocation**. Artificial Intelligence and its different sub-categories will continue to play significant roles in 5G. As a result, research in 5G C-RAN resource allocation will also extend in this regard. BBU or RRH mobility-aware clustering methods will require machine learning techniques for user mobility prediction to improve load-balancing. Mobile traffic-load prediction will require deep learning techniques to enhance the extraction of spatial-temporal mobile information in 5G Networks. The network environment will learn using reinforcement learning (RL) techniques by utilizing RL agents, which will then estimate future demand and allocate resources based on that learning. All these areas will require additional research to ensure the proper functioning of 5G.
- **H-CRAN and F-RAN:** Further research in evolved C-RAN systems will resolve the high Fronthaul capacity challenge, and this could be crucial in allocating C-RAN resources by fusing IoT with the anticipated billions of 5G connections.
- While developing various algorithms for simulating LTE UL resource allocation, centralized handover management, and BBUs collaborative radio processing, building an SDR-based C-RAN with the necessary timing requirements can also be researched.
- **SDN Deployment**: Although SDN in C-RAN offers several benefits for the 5G mobile network, significant research obstacles exist [11]. The first difficulty is placing the centralized controller in the BBU. These centralized controllers will require optimization since the controller's location will influence latency, QoS, and other network performance factors. Scalability will be a second challenge for network operators since the SDN Controller will limit the C-RAN service capability.
- Studying a generalized uplink-downlink algorithm for resource allocation with multiple BBU pools and other services in the network could be another topic of research for the 5G C-RAN.
- Ethernet jitter, delay, time, and frequency synchronization issues in the fronthaul network are exciting future research areas. Exploring the impact of different fronthaul types or technologies with new frequency bands on C-RAN deployment, analyzing multi-path Fronthaul with multi-hops, and implementing Cloud-RAN in real drones/UAVs could be further researched.
- Studying the balance between the centralized and distributed architectures in 5G for resource allocation can also be researched.
- Further research in wireless network Virtualization can improve the end-to-end C-RAN system performance. Also, virtualized C-RAN can investigate network slicing techniques to support diverse and heterogeneous 5G services. The whole RAN can be programmable by virtualizing the fronthaul switches with the CU and DU, resulting in an automated RAN. Research in this area can produce fascinating results for 5G. Lastly, a virtualized QoE metric can provide better results for network operators instead of traditional QoS-based provisioning to measure user satisfaction. The QoE assurance model for C-RAN and QoE guaranteed C-RAN design is a worthwhile subject to investigate. Since there is no current, complete QoE model for C-RAN, any research in this area will draw interest from academia and business.
- The two-timescale challenge (multi-dimensional resource allocation for handling multiple resources at different time scales) will need further investigation.
- The QoE assurance model for C-RAN and QoE guaranteed C-RAN design is a worthwhile subject to investigate. Since no complete QoE model for C-RAN

exists, any research in this area will draw interest from academia and business. Since 5G networks will consist of heterogeneous technologies and services, further improvement can be studied using real-life conditions on real networks.

7 Conclusion

Many enabling technologies will contribute enormously to making 5G cellular networks a reality, and the contribution of C-RAN as one of them cannot be over-emphasized. This article presents a review of 5G C-RAN resource allocation. We presented C-RAN fundamental concepts and elements in the report. Its resource allocation metrics or features, such as RRH selection, user assignment, BBU resource Processing, Spectrum, throughput, power allocation, network utility, etc., were discussed. We tabulated various resource allocation schemes or algorithms. We also demonstrated a new way of developing resource allocation algorithms by identifying a resource allocation metric associated with appropriate communication technology. We also discussed the role of energy harvesting as an essential requirement for 5G deployment to meet the corresponding increase in energy consumption. Finally, we identified open issues and future research trends for C-RAN

Table 7: Summary of Acronyms

Acronyms	Description
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
ABC	Artificial Bee Colony
AI	Artificial Intelligence
ARPU	Average revenue per user
BBU	Base-Band Unit
BS	Base Station
BW	Bandwidth
CA	Carrier Aggregation
CAPEX	Capital expenditure
CDI	Cell Differentiation and Integration Algorithm
CoMP	Coordinated multipoint transmission
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CPZ	Cellular Partition Zooming
C-RAN	Cloud Radio Access Network
CRM	Computational Resource Management
CSI	Channel State Information
D2D	Device-2-Device Communication
D-RAN	Distributed Radio Access Network
DAS	Distributed Antenna Systems
DBA	Dynamic Bandwidth Allocation
DL	Deep Learning
DRL	Deep Reinforcement Learning
DL/LSTM	DL Long Short-Term Memory
DPSO	Discrete Particle Swarm Optimisation
DRAC	Dynamic Resource allocation in C-RAN
DRM	Dynamic Resource Management
DRM-AC-ES	DRM with Adaptive Capacity and Error Shifting
DRM-AC-PF	DRM With Adaptive Capacity and Prefiltering
DRSS	Dynamic Resource Sharing Scheme
EA	Evolutionary Algorithm
EE	Energy Efficiency
EH	Energy Harvesting
EHN	Energy Harvesting Networks
eMBB	Enhance Mobile Broadband
eNB	Evolved Node B
FH	Fronthaul
FPA	Feasible Pump Algorithm
F-RAN	Fog-Radio Access Network
GA	Genetic Algorithm
GARAA	GA-based Resource Allocation Algorithm
H-CRAN	Heterogeneous C-RAN
HetNet	Heterogenous Networks
I/Q	In-phase and Quadrature
IoT	Internet of Things
IRAA	Iterative Resource Allocation Algorithm
JSAPARA	Joint Subchannel Assignment, Power Allocation, and RRH-Association
LBMM	Load balanced Min-Min Algorithm
LSTM	Long Short-Term Memory
LTE-A	Long-term evolution Advanced
MAC	Medium access Control
mmWave	Millimeterwave
MNO	Mobile network operators
NGFI	Next Generation Fronthaul Interface
NGMN	Next Generation Mobile Networks
MBS	Macro BS
mMIMO	Massive Multiple Input Multiple Output
mMTC	Massive Machine-Type communication
ML	Machine Learning
(MLCADA)	Multi-agent learning cloud assisted double auction Algorithm

MEC	Mobile Edge Computing	RRHs	Remote Radio Heads
MORA	Multi-Objective Resource Allocation	RRM	Radio resource management
MU-MIMO	Multi-User MIMO	SBS	Small-cell BS
NFV	Network Function Virtualization	SE	Spectrum Efficiency
OPEX	Operational Expenses	SD-EHN	Software-Defined Energy Harvesting Network
ORAAS	Optimal Resource Allocation access selection Scheme	SDN	Software Defined Networking
PHY	Physical Layer	SINR	Signal-to-interference-plus-Noise Ratio
PON	Passive Optical Networks	SON	Self-Organizing Network
PRB RAA	Primary Resource Block Resource Allocation algorithm	SWIPT	Simultaneous Wireless Information and Power Transfer
PUEA	Primary user Emulation attack	TSS	Technology Selection Scheme
QoE	Quality of Experience	TCO	Total cost of ownership
QoS	Quality of Service	UE	User equipment
RAN	Radio Access Network	uRLLC	Ultra-Reliable Low Latency Communication
RA	Resource Allocation	VB	Virtual BBU
RB	Resource Blocks	VM	Virtual Machines
RFA	Random Forest algorithm		
RF	Radio Frequency		
RL	Reinforcement Learning		
RR-DBA	Round-Robbin DBA algorithms		

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