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A Literature Survey on Cloud-RAN Architecture toward 5G Green Wireless Communication Systems

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Abstract. Cell network architectures confront enormous challenges due to the unusual rise in mobile data traffic usage, thus reducing spectrum accessibility and heavy power consumption. Research communities are looking for breakthroughs in the development of advanced infrastructure networks to meet increased consumer demand and, at the same time, to reduce network operators' capital and operational costs. Cloud Radio Access Network (Cloud-RAN) architecture is a recently proposed solution for wireless networks and is considered a strong candidate for potential 5G cellular coverage worldwide. This paper presents a literature survey on Cloud-RAN architectures toward Green 5G wireless communication systems and highlights Cloud-RAN benefits and limitations. Furthermore, this paper discusses Cloud-RAN's potential enhancement techniques, including robust beamforming, multiple-input-multiple-output (MIMO) with non-orthogonal multiple access (NOMA) cooperative scheme, massive MIMO, mmWave communication, clustering techniques, coalition formation, energy harvesting and reinforcement learning output.

1. Introduction

The more extended access points (APs) will also be introduced to leverage spatial reuse across narrow cellular networking to accommodate the increasing use of mobile data traffic in 5G wireless communication systems. Meanwhile, as described, placing traffic-aided APs is an effective way to compensate for the path-loss of traffic, which results in cellular energy-efficient networks [1]. However, the problem for the dense cellular networks is ineffective interference control. Also, further APs would lead to high operator costs and challenges. Receiving a promising network infrastructure, the Cloud-RAN has recognized that small-cell networks are embedded to collectively deal with network congestion, increase network availability, and decrease both network operator's (Network Operations) capital expenditure (CAPEX) and operational expenditure (OPEX) [2]. Cloud-RAN is connected with a baseband unit (BBU) device by a backhaul with high bandwidth links [3] to the dispersed transmitting/receiver points called remote radio heads (RRH). Cloud-RAN facilitates effective transmission/reception co-operation between various RRHs with the centralized BBU pool, assisted by real-time cloud computing.

Inter-cell interference (ICI) can be avoided by implementing first-generation code-division multiplier access (CDMA) techniques in the cellular environment. Traditional first-generation (1G), second-generation (2G), and third-generation (3G) cellular radio access networks (RANs) are not required cooperative processing techniques [4]. However, the ICI is extreme for spectrum reuse in neighboring cells in the fourth-generation (4G) of cellular networks, obtain based on the orthogonal frequency division multiplexing (OFDM) methodology, and involves cooperative operations. Joint processing for cooperative transmission in coordinated multipoint (CoMP) networks has proven its possible efficiency advantages in ICI mitigation. As a result, the intervention can be manipulated, and a substantial improvement in efficiency can be obtained by complete collaboration in CoMP systems. In the fifth-generation (5G) mobile networks, telephone operators and service providers are changing their emphasis from quality of service (QoS) to customer interface because different new services imply the need to enhance the overall value from the subjective view of the user [5].

The rest of the paper is structure as follows. Analyzes of Cloud-RAN architecture state in Section 2. The Cloud-RAN principles with benefits and limitations detail explained in Section 3. Section 4 contains potential Cloud-RAN enhancement techniques then the research direction is highlighted in Section 5. Finally, in section 6 the work is summarized. Note that the list of essential acronyms used in this paper given in Table 1.

Table 1. List of important acronyms

Acronym	Definition
5G	Fifth Generation
BBU	Baseband Unit
BS	Base Station
CAPEX	Capital Expenditure
CoMP	Coordinated Multipoint
CO	Central Office
ET	Energy Receiving Terminal
ICI	Inter-cell Interference
IT	Information Receiving Terminal
MAC	Medium Access Control
MIMO	Multi-Input Multi-Output
mmWave	Milimeter Wave
NOMA	Non-orthogonal Multiple Access
OPEX	Operational Expenditure
OLT	Optical Line Terminal
PON	Passive Optical Network
QoS	Quality of Service
QoE	Quality of Experience
RRH	Remote Radio Head
RF	Radio Frequency
SINR	Signal-to-interference-plus-noise ratio
SE	Spectral Efficiency
TCO	Total Cost of Ownership

2. Survey on Architecture of Cloud-RAN

As illustrated in Figure 1, Cloud-RAN architecture consists of the following four main parts:

- *The BBU pool:* It is developed on a centralized site in a Cloud-RAN system called a BBU. As virtual BSs, the BBU can process simple band signals and optimize radio service

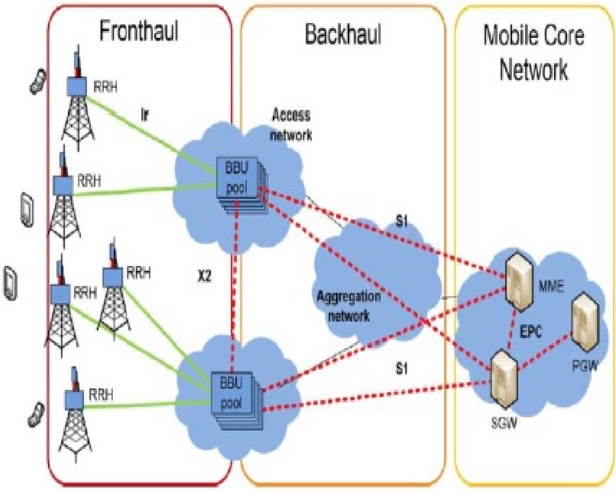

Figure 1. The architecture of a Cloud-RAN [5]

allocation. The processing power is efficiently tuned based on the traffic-aware timing of receiving terminal systems and the time-changing radio channels and most signal processing functions in the BBU pool so that the RRH can deliver on a wide scale at a cost-effective level [4].

- *The RRH:* Main components of a Cloud-RAN offer the receptor terminals a high data rate with a simple wireless signal. On a downlink transmission to the receiving terminals, a radio frequency (RF) signal is transmitting then the BBU central uplink transmission is sent out of the receiving terminals. RRHs are liable to change the interface, filter, amplify RF, convert it up and down, convert it in analog or analog format, and convert it back to digital analog [4].
- *The fronthaul:* The BBU pool and the RRH are connected to the link known as fronthaul. The form of link can be a wired or wireless connection and include the typical protocol the common public radio interface (CPRI) and the open base station architecture initiative (OBSAI) [6]. Ideal fronthaul without any constraints and non-ideal fronthaul with constraints are two types of fronthaul links in the Cloud-RAN architecture [4]. It has been written in [7] that the traditional coaxial-based systems on cell towers or legacy cell towers are being replaced by fiber for more capacity, longer-reach distance, and cost-efficiency. The wireless fronthaul's faces are considerably less costly and flexible to install at the cost of reduced storage and other limitations. Today, wireless or capacities-linked optical fiber costs are lower than the perfect optical fiber, these systems are entirely suited for practical Cloud-RANs and can be scalable to incorporate.
- *Powering Radio RRH:* Radio RRH sites can minimize energy consumption with renewable sources costs than energy efficiency significantly increased. No greenhouse gases like carbon footprint produce energy capital or carbon dioxide because green energy comes from renewable resources [8]. Renewable energy resources are friendly to the environment.

2.1. Literature Survey on General Cloud-RAN

The recent research of general Cloud- RAN are summarized below [3], [9], [10], [11] and [12].

- *Fully centralized and partially centralized :* Based on the multiple practical division between the BBU cloud and RRH [3].

- *Fully centralized, partially centralized and hybrid:* The study has been organizing into three part [9], according to the fronthaul limits boundary and the functional distinction between RRHs and BBUs. The task in Layer 1, Layer 2, and Layer 3 in traditional BS clouds had passed in the entire uniform situation. Act for typical BSs and administrative facilities in the BBU cloud. While this design is straightforward, simple and has substantial advantages in terms of service and upkeep, there is a tremendous burden on the front haul. On the other hand, RRH performs radio frequency (RF) functions with some pure RF related band processing functions in a partly centralized Cloud-RAN architecture. The majority of the Layer 1 functions and the upper layer functions manage to keep in the cloud. As a result of a significant decrease in total RRH-BBUs, the fronthaul weaknesses are minimized. The relationship between Layer 1 and Layer 2 can be an organized and cooperative process for improved technology such as CoMP and Massive MIMO that is dynamic, less efficient. The other choice is to move some of the Layer 1 functions of a hybrid unified architecture from the BBU cloud to a separate new processing unit that can be used in the cloud. This alternative enables efficient sharing of information and decreases energy usage in the cloud.
- *Hybrid Cloud-RAN:*In [10], reference making to the quantitative techno-economic study of the decision on an optimum practical split in Cloud-RAN with a minimal total cost of ownership (TCO). A hybrid Cloud-RAN architecture design based on the logical breakdown of the baseband processing chain of BS that displaying three sub-models, series of processing functions (PFs), and a realistic split-band-width model. Subsequently, numerical studies will include the TCO model for hybrid Cloud-RAN that required the fronthaul bandwidth and the computing resources imposed on a remote location. The conventional, fully consolidated Cloud-RAN and the typical distributed RAN models will achieve a lower TCO with the proposed hybrid Cloud-RAN with an optimum functional split.
- *A new logical structure with a service-oriented Cloud-RAN:* The aim of [11] is to use a physical plane, control plane, and service plane to represent either users and operators with a preferred network performed in logical structures. The physical plane focuses mainly on services virtualization, the topology, and signal processing in baseband pool interconnections such as channel decoding, demultiplexing, and accelerated Fast Transformation of Fourier (FFT). According to the physical plane and support plane service, the controlling plane consisting of the Remote Management Module (RMM) and the Service Maintenance Module (SMM) controlled. It also makes Cloud-RAN reconfiguration and Cloud-RAN selection situational knowledge and application-conscious. The service plane, on the other side, is a network where fixed and mobile networks are ready. The device distribution, mobility management, multimedia devices allowed, network control and security are some of the key facilities that this plane also provides.
- *Passive optical networks (PONs):* The network model [12] design of three components. The central office (CO) consists of the cloud and the optical line terminal (OLT). The optical splitter task accommodates many RRHs using a single fiber optic cable, which the OLT employs to assemble several RRHs to provide power via the optic fiber cables. The CO has handled the comprehensive network service, together with wireless and optical link management, the control of RRHs, the energy management, the transmitting of power from OLT to RRHs, and other activities including MIMO, CoMP, and the conversion of power. The architecture and operational methodologies of the proposed Cloud-RAN to ensure the anticipated quality of experience (QoE) are review in this study. The aims of QoE levels are described by suggesting three divided QoE levels. The model also indicates the quantity of RRH and OLTs needed to satisfy the required QoE in a given area. This paper also reviews the RRH sleep and power transmission reciprocal control scheme of OLTs for transmission power reductions without lost the independent QoE.

The comparison of recent research on general Cloud-RAN summarizes in Table 2.

Table 2. Comparison of Recent Research on General Cloud-RAN

Main features	Approach	Performance Metric
Fully centralized and partially centralized [3]	Theoretical framework and analysis	None
Fully centralized, partially centralized and hybrid [9]	Theoretical framework and analysis	Sum-rate (bits/channel), data rate (Mbps) and delay per UE (sec)
Hybrid Cloud-RAN [10]	Theoretical framework and analysis	Throughput (Mbps)
A new logical structure with a service-oriented Cloud-RAN [11]	Optimization and numerical analysis	Sum-rate (bit/channel)
Passive optical networks (PONs) [12]	Theoretical framework and analysis	Transmission power (Watt) and Value of QoE

2.2. Literature Survey on Heterogeneous Cloud-RAN
The recent research of Heterogeneous Cloud- RAN are summarized below [13], [14] and [15].

- *Heterogeneous Cloud-RAN:* The proposed Heterogeneous Cloud-RAN architecture presented in Figure 2. Some heterogeneous nodes that result in a user-center architecture allow users to benefit from the variety of coverage. Determining the optimum user-to-RRH association that gives the best results is a high-complexity mix optimization problem. Exhaustive quest is not feasible for any reasonably-sized network, except with efficient [13] cloud processors.

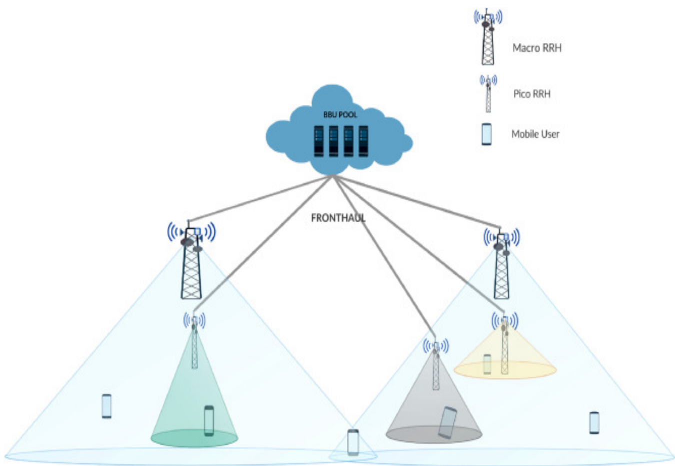

Figure 2. The Heterogeneous Cloud-RAN [13]

- *Small-cell dynamic operation for Heterogeneous:* This paper proposes to adjust SBS operating modes to support uniformly and non-uniformly distributed users dynamically analyzed the HetNet power minimization problem in both cases with uniformly and non-uniformly distributed users [14].

- *Small cell clustering in dense heterogeneous:* This paper proposes to test the benefits of small cell clustering in a dense heterogeneous network for downlink MIMO [15]. It has demonstrated that there are appropriate cluster sizes and that each cluster forms a virtual MIMO network in which users are segregated by spatial multiplexing using jointly constructed downlink beamforming vectors [13].

The comparison of recent research on Heterogeneous Cloud-RAN summarizes in Table 3.

Table 3. Comparison of Recent Research on Heterogeneous Cloud-RAN

Main features	Approach	Performance Metric
Heterogeneous Cloud-RAN [13]	Theoretical framework and analysis	Sum-rate (bits/channel) and data rate (Mbps)
Small-cell dynamic operation for Heterogeneous [14]	Theoretical framework and analysis	Throughput (Mbps) and Power consumption
Small cell clustering in dense heterogeneous [13], [15]	Theoretical framework and analysis	Sum-rate (bps/Hz)

3. Benefit and Limitation of Cloud-RAN

3.1. Benefit of Cloud-RAN Architecture

The advantages of green Cloud-RAN implementation in wireless communication systems are summarized as follows.

- *Capex and Opex reduced:* BS Microcells (MBS) production and start-up are time-consuming, expensive, and costly. But Cloud-RAN demands a lower cost, space and time, RRHs [15] installation and operation. Cloud-RAN computing services are applied to a few wide clouds and a simple RRH feature has been developed to save a great deal of OPEX and management costs.
- *Spectral efficiency (SE) enhancement:* Cloud-RAN would also extend the network SE by the integration of coordinated, cooperative connectivity/collection approaches, such as improved inter-cell interference (ICI) and coordinated multipoint transmission (CoMP) delivery in the same cloud, to boost the speed and reliability of higher SE [16].
- *Latency reduction:* In various processes, Cloud-RAN can reduce latency. For example, the transferring time may be decreased and reached within a cloud, rather than between BSs. The loss rate in the transition can also be decreased. Furthermore, the total signal volume sent to the core network will decrease in Cloud-RAN and the delay will also be decreased. [15].
- *Enabling BBU switching:* The continuation of each BS remains restricted for Cloud-RAN. Any approach is running in the remote cloud. With transformation and processing functions transferred to BBU pools, it is possible to minimize energy use and load congestion. It helps many BBUs to turn to low-power sleep or even shut down to save resources [11].
- *Enhanced management of interference*: Cloud-RAN allows rapid channel state information sharing (CSI), data traffic, and monitoring of data between cooperating BSs on mobile services. The multiplexing on the same canal with significantly reduced reciprocal [11] interference will make for a more practical multi-point synchronization. The efficiency of the link and the throughput improved significantly due to the reduced interference.

3.2. Limitation of Cloud-RAN Architecture

Even though the Cloud-RAN is regarded as a promising architecture for 5G, Cloud-RAN has weaknesses that need to be apparent before implementing Cloud-RAN.

- *Security and trusted problem :* Security and trust are the main problems in Cloud-RAN. The essence of the open-access wireless network can be readily reached by an authenticated or illegitimate person. Apart from conventional wireless network's persistent security problems such as primary user emulation attack (PUEA) and the specimen sensing data falsifying attack (SSDF). Cloud-RAN is also faced with enhanced security and secrecy risks as a result of its communication and self-deployment [17].
- *BBUs bundle together with many BSs in cloud :* Cloud-RAN has an overwhelming risk of missing only a point, meaning if the cloud crashes, the whole network is out of operation. BBU is packed in a cloud along with several BSs. On the other hand, on the optical fronthaul links, which can be up to the 50fold backhaul specification, the Cloud-RAN architecture has a massive overhead [15], [16].
- *Cloud and RRHs latency/jitter:* Most of Cloud-RAN's significant weaknesses are its complex cloud BS operations and the possibility of losing native hardware compatibility. In certain cases [9], there is often a possibility that delayed is enhanced by centralized signal processing.

4. Potential Enhancement Techniques for Cloud-RAN

To overcome the limitation, extensive research is conducted with enchancement techniques such as robust beamforming [18], multi-user MIMO and NOMA [19], massive MIMO [20], mmWave communication [21], clustering [22–24], coalition formation [25], energy harvesting [26, 27], and reinforcement-learning approach [28–32].

- *Robust Beamforming:* This paper suggested a Cloud-RAN architecture involving a beamforming cooperative based on services with imperfect channel state information (CSI). The backhaul connection consists of optical fiber and integrated signal transmission and resource delivery. In considering real-time applications, the sigmoidal SINR function is used to model the usability of consumers. The architecture, a set explained by the application of maximum interference limitation, use of convex relaxation and use the summary ratio form of the objective function is a non-convex utility maximization problem. The highest aggregated consumer utility level is reached under imperfect CSI, limited backhaul ability, and QoS specifications.The overall utility of the proposed Cloud-RAN has shown that it increases for fewer users almost linearly and for a huge number of users, it is sublinear. Furthermore, the aggregate utility is defined in the opposite way proportion by a normalized maximum channel estimation error [18].
- *Multi- user MIMO and NOMA:* A Cloud-RAN analysis including MIMO and NOMA in [19]. The paper suggests a systematic transmission system that will comprehensively resolve both the RRH and the fronthaul interface's implementation and deployment constraints. The model system often takes into account a variety of users, meaning that any device wants to centralize common user functions for a physical layer, allowing them to operate the uplink multi-cell, multi-user joint detection (JD) during the NOMA. A partial NOMA approach with reduced system reliability and a reduced latency is recommended and considered for high efficiency.
- *Massive MIMO:* This paper introduces a modular and scalable RRM approach and a major interruption reduction MIMO precoding scheme [20]. In addition, a non-space-based hybrid precoding scheme with a modular CSI acquisition process. Precoding within the null-space of adjacent victim users executing the proposed scheme has counteracted the intrusion effect

that has resulted in output degradation. Output assessment indicates that the planned architecture should have acquired a better system throughput with a significant number of transmission antennas and was worthy of providing enough SE relative to other excellent precoding schemes.

- *mmWave communication:* Fronthaul and access connect transmissions with the mmWave frequency bands are used in this architecture. A network model focused on stochastic geometry is a review in which RRHs are revised according to an autonomous and homogeneous poisson point process (PPP). Larger antenna arrays are needed to compensate for a fall in the failure and latency efficiency with greater RRH deployment, as a trade-off between intercluster and RRH density can be tested [21].
- *Clustering:* The Cloud-RAN architecture based on multi-cluster interactions is suggested in [22]. The justification for the sale of more RRH clusters in smaller sizes is to minimize the cost and the SE of the machine via a method of RRH clusters. Interference between clusters. The proposed architecture incorporates fronthaul BS, the propagation of BS around RRH, and the compression of the facade, inter-cluster optimization between clusters then shows greater joint performance than intra-cluster and inter-cluster architectures based on TDMA. Also, the [23] Cloud-RAN system integrated with the idea of wireless simultaneous information and power transfer (SWIPT) and proposed a sparse solution to the joint clustering and energy trading. Then, the authors in [24] extend the study to take account the limited-capacity backhaul links of Cloud-RAN in their approach by minimizing the instantaneous energy.
- *Coalition formation:* The paper aimed by [25] is the transmitting of mutual RRHs in the Cloud-RAN by creating the game of the RRH. The author also thinks that RRHs will consider whether to ally with other RRHs so that better outcomes can be obtained. The RRH partnership for consumers would decrease intra-interference which ensures that non-alliance and the grand coalition will have better success matches.
- *Energy harvesting:* The authors in [26, 27] discuss the effect of the implementation in RRHs of the green energy harvester, at RRHs which promising to profit Cloud-RANs retailers and the environment as well. In compliance with the QoS criteria for ITs, the problem is design to reducing the overall cost of electricity trading with the grid as a problem of non-convex linear optimization.
- *Reinforcement learning approach:* Reinforcement-learning based on the conceptual of combinatorial multi-armed bandit (CMAB) technique has been proposed in [28–31] to be incorporated in Cloud-RANs system. Recently in 2021, a smart online energy trading has been proposed in [32] as a prescheduling mechanism to handle the temporal variations of energy demands in Cloud-RANs to further minimize the long term of time-averaged energy cost.

5. Research Direction

The Cloud-RAN has been an invention to meet the 5G wireless network limitation requirements. As a result, high performance, ultra-reliability, latency, cost savings, and support for a wide variety of consumer products are all part of cloud-RAN-green technology research concerns. The fronthaul connection between the RRHs and the BBU cloud would influence the Cloud-RAN performance. The capacity and latency must be high. For this purpose, spectral efficiency (SE), energy efficiency (EE), and numerous QoS network specifiers are optimizing, and the use of effective methods for signal-quantization/compression, large-scale precoding/decoding, MAC frameworks, and the allotment and preparation of resources. In the BBU write in [15], multiuser MIMO is the best candidate for the MAC with high RRH.

Moreover, collaborative clustering of RRH's with cluster-based BBU cloud connectivity can also eliminate front haul burdens, which require a detailed review. Beam shaping architecture for both uplink and downlink minimizes energy consumption and energy use and improves energy efficiency in Cloud-RAN more suited to green technologies [18].

6. Conclusion

The new generation wireless communication network has multiple problems in terms of power and energy use. It is a topic of interest for researchers and academics to research it. This paper proposes the new form of a modern architecture design that efficiently regulates or uses 5G renewable technology resources. The high number of users requires the energy efficiency of the network that is important for researchers. The beamforming 5G green wireless communication system will propose to solve all energy-efficient approaches, such as the creation and preparation of energy savings for the green technology problem. These diverse approaches in extreme energy use situations help sustain the next wave of 5G renewable infrastructure and an energy-efficient network.

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