Progression of Radio Access Network towards Open-RAN

Varshini AR[1], Vidya C Raj[2]

[1]*PG student, Department of Computer Science & Engineering, The National Institute of Engineering, Mysuru-570008, India*
[2]*Professor, Dean (Academic Affairs) Department of Computer Science & Engineering, The National Institute of Engineering, Mysuru-57008, India*

***

Abstract - *The advent of 5G technology has revolutionized communication, propelled by the transformative concept of Open Radio Access Network (ORAN), which aims to reshape the communications sector. ORAN's innovative architecture emphasizes openness, interoperability, and virtualization, standing in stark contrast to the closed nature of traditional Radio Access Network (RAN) designs. Guided by principles of disaggregation and virtualization, ORAN separates hardware components and enables adaptable, scalable network functions. By dismantling vendor lock-in, ORAN fosters collaboration, diversity, and innovation among stakeholders. Disaggregation drives multi-vendor interoperability, creating a competitive market where network operators can select components from various manufacturers, enhancing flexibility. Virtualization further bolsters performance by transitioning from hardware to software-based solutions, im- proving cost-efficiency, scalability, and agility. ORAN's strategy enhances network flexibility, allowing operators to swiftly meet changing demands and introduce new services. Through its virtualized architecture, dynamic resource allocation optimizes resource usage, enhancing user experiences. ORAN emerges as a transformative force in telecommunications, challenging conventional closed RAN models and offering a dynamic vision for the future of communication technology.*

Key Words: Open Radio Access Net- work (RAN), RAN's evolution, Open-RAN architecture

1.INTRODUCTION

Over the past 50 years, wireless communication technology has evolved significantly, with recent advancements in IoT and real-time applications driving a surge in wireless frameworks. Open Radio Access Network (ORAN) seeks to separate hardware and software components, facilitating adaptable integration from multiple suppliers. IoT emphasizes wide coverage and low power consumption, while real- time applications require low latency and dynamic data processing, necessitating a versatile network. Traditional Radio Access Network (RAN) models fall short of meeting these requirements, urging the need for enhancements. Constructing separate networks for different applications is impractical, prompting efforts to create software-driven, virtualized, intelligent, and energy-efficient mobile networks. Acknowledging the transformational potential of fifth - generation (5G) wireless technology, the telecommunications industry strives for innovation and improved network capabilities to meet growing connection demands. Traditional RAN architectures, reliant on proprietary technology, hinder interoperability and hinder 5G's full potential, thus prompting exploration of virtualization and disaggregation as solutions.

Disaggregation enables separation of hardware components, like baseband and radio units, fostering multi-vendor integration and a competitive market. Simultaneously, virtualization shifts processing functions to software, enhancing scalability, efficiency, and cost-effectiveness. Understanding these principles empowers operators to respond effectively to evolving needs and harness 5G's potential. ORAN, endorsed by players in the telecom sector, isolates hardware and software, allowing top-tier solutions from diverse suppliers to integrate flexibly. ORAN signifies a pivotal shift towards openness, interoperability, and virtualization in RAN design, supporting competition, innovation, and network stability. It forms the foundation for 5G and beyond, promoting cooperation, standardization, and secure operations. Through collaborative efforts, challenges related to interoperability and security are addressed, ensuring the effective deployment of ORAN's promise.

2. EVOLUTION OF RAN

Network infrastructure design's primary objective is secure and efficient device communication. The Radio Access Network (RAN) is a fundamental concept in telecommunications that plays a vital role in ensuring seamless connectivity and effective data transmission between devices and the core network. Network operators are upgrading RANs to manage increased device connections, data traffic, and 5G- based services while optimizing resources and maintaining Quality of Service/Experience (QoS/QoE).RAN's deployment, operations, and maintenance constitute a significant cost, prompting operators to focus on reducing CapExand OpExby creating a flexible RAN that accommodates various deployment options and services. RAN is composed of radio resource management and radio signal transmission/reception. Traditional RANs and Distributed RANs (D-RANs) function independently, but their integrated architecture calls for denser deployment as user connections increase, resulting in higher costs for capacity enhancement. The Cloud RAN (C-RAN) concept emerged as a solution to reduce costs. C-RAN introduced RAN node resource sharing to address the challenges of base station deployment and operation.

2.1 C-RAN

C-RAN, also known as Centralized RAN or Cloud RAN, involves splitting the RAN into separate Remote Radio Units/Heads (RRUs/RRHs) and a centralized pool of Baseband Units (BBUs) in a cloud data center. This architecture supports centralized processing, real-time networking, and scalability, facilitated by a new FH interface connecting BBUs and RUs. However, challenges include single point of failure for BBUs, security concerns, and limitations related to FH overhead, proprietary interfaces, and vendor dependence.

2.2 The virtualized RAN (vRAN)

vRAN utilizes virtualization in addition to the same methodology as the C-RAN. By utilizing the NFV concepts, vRAN decouples the software from the hardware and replaces expen- sive, proprietary hardware with COTS hardware. The coordi- nation of RAN nodes to allocate network resources for various services depending on the requirements of those services is difficult, the complexity of network administration has sub- stantially risen, and a proprietary interface-based deployment leads to vendor lock-in.

2.3 5G Networks

5G's new air interface, New Radio (NR), and the Next Generation RAN (NG-RAN) collectively shape the 5G system. The 5G NR employs physical connections for radio- based communication and operates in two modes: Non- Standalone (NSA) and Standalone (SA), enabling efficient data management and higher data rates. In SA mode, direct connectivity between gNB and the 5GC supports advanced services, while NSA mode facilitates eMBB class services through a connection between LTE, NR, and the 4G CN (EPC).

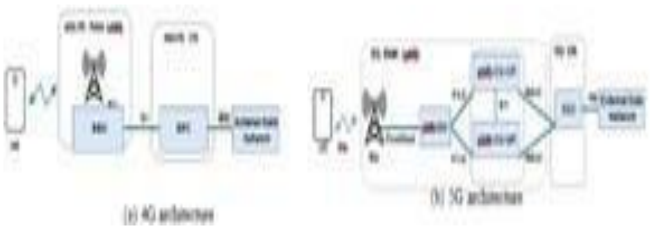

Fig -1: 4G and 5G architectures

Fig 1 illustrates the architectures of both 4G and 5G systems, where 5G's NG-RAN allows RAN disaggregation and configurable functional split options. NG-RAN's deployment supports control plane and user plane separation, enabling flexible scaling and a variety of deployment choices. However, challenges remain in achieving virtualization, software-driven adaptability, interoperability, and energy-efficiency, which the O-RAN Alliance aims to address through open interfaces and virtualized edge computing infrastructure.

3. LITERARURE SURVEY

The concept of ”Open RAN” envisions a future for the Radio Access Network (RAN) with goals including vendor-independent and AI-driven solutions. With the complexity of new use cases introduced by 5G and beyond (B5G) networks, traditional methods impede rapid innovation and standardized AI application. The Open Radio Access Network (O-RAN) alliance proposes an architecture based on disaggregated RAN functions, managed by a RAN controller enforcing decisions via open interfaces. The O-RAN initiative employs machine learning techniques, especially deep learning, to facilitate in- telligent RAN applications that meet Quality of Service (QoS) requirements. In the context of wireless cellular networks, Device-to- Device (D2D) communication holds promise for boosting data speeds, reducing latency, and enhancing efficiency. This technology is examined in the context of fifth generation and beyond (5GB) networks, with a focus on the in-band (IBD) and out-of-band (OBD) D2D modes. Integration of D2D communication with other technologies is highlighted for network performance enhancement, addressing challenges, possibilities, and future directions within the context of 5G and even 6G networks.

4. OPEN-RAN ARCHITECTURE

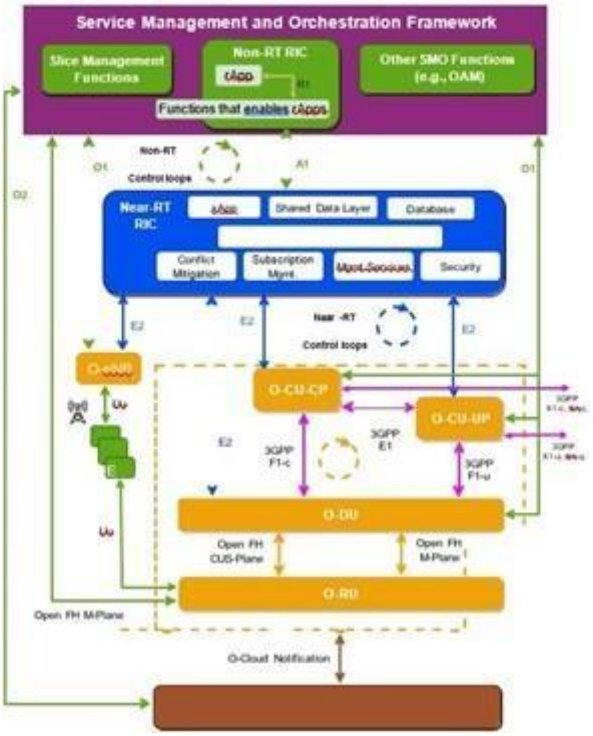

Fig -2: Open-RAN Architecture

The 3GPP 5G System laid the foundation for the O-RAN architecture, enhancing RAN features and introducing open, interoperable interfaces. O-RAN aims to diversify the supply chain, reduce deployment costs, and foster interoperability among vendors. Unlike NG-RAN, O-RAN incorporates new nodes, open interfaces, and cloud infrastructure, allowing for a virtualized RAN with AI/ML-powered intelligent radio controllers. The O-RAN reference architecture includes components like RICs, O-CU, O-DU, O-RU, O-Cloud, O-eNB, and O-UEs, interlinked through various interfaces to form a dynamic network.

4.1 SMO FRAMEWORK

O-RAN's vision for 5G RAN emphasizes adaptability, scalability, and multi-vendor interoperability, with a strong focus on management and automation. The SMO framework plays a central role in managing and orchestrating various O- RAN components, resembling the NFV MANO entity and operating through standardized service-based interfaces to ensure interoperability, while providing FCAPS management functionalities and offering orchestration, workflow management, RAN optimization, and non-RT RIC capabilities.

4.2 O-RU (OPEN-RAN RADIO UNIT)

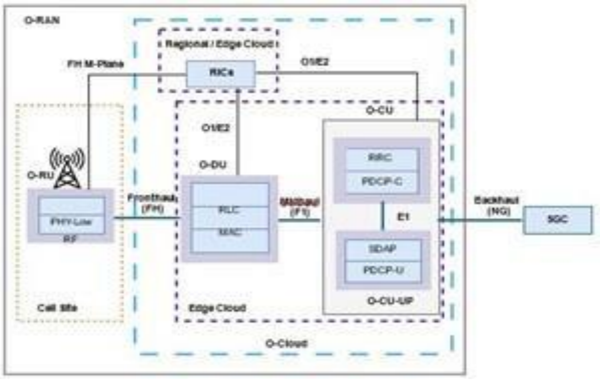

Fig -3: Open-RAN Architecture with Functional Splits

At the physical layer of the network, the O-RU, a radio unit found at cell sites, transmits, receives, and processes radio signals. The radio signals are exchanged between the O- RU and the O-DU in the O-RAN reference architecture using the Open FH interface. The O-RU implements the PHY-Low and Radio Frequency (RF) processing capabilities in accordance with the functional split option 7.2x, as indicated in Fig 3.

4.3 RIC's and Closed -loop control

The O-RAN Alliance aims to leverage AI/ML technologies for automated RAN deployment and operations. It introduces two types of RAN Intelligent Controller (RIC) software-defined components: the non-Real-Time RIC for longer-term operations and the near-Real-Time RIC for more real-time tasks. These RICs communicate through the A1 and E2 interfaces, utilizing control loops to optimize networks with real-time intelligence. The O-RAN architecture provides non-RT, near-RT, and RT control loops, operated by the respective RICs and E2 nodes, addressing varying time scales. These control loops use AI and ML algorithms, along with data from O-RAN functions, to automate operations, create an abstract network view, and enable optimized RAN actions.

4.4 O-DU (OPEN-RAN DISTRIBUTED UNIT)

O-DU is a dynamic logical node in O-RAN, hosting proto- col functions like PHY-High, MAC, and RLC for base station tasks based on functional split option 7.2x. It consists of two logical nodes, one for PHY-High and another for MAC and RLC functions, often implementing the Small Cell Forum's proposed standard interface known as FAPI.

4.5 O-CU (OPEN-RAN CENTRAL UNIT)

O-CU is a logical node in O-RAN that handles protocols like SDAP, PDCP, and RRC, divided into CU-CP and CU- UP using the SDN-inspired concept of control plane/user plane separation. This architectural division allows for scalable and cost-effective solutions using the E1 interface, while edge cloud hosts O-DU, O-CU-CP, and O-CU-UP, with RICs capableof operating in either the edge or regional cloud.

4.6 O-CLOUD (OPEN-RAN CLOUD)

O-Cloud comprises physical infrastructure nodes hosting O-RAN functions, software components, and management tasks. It communicates with O-RAN functions via the O- Cloud Notification interface, with edge and regional clouds hosting RAN functionalities such as O-DU, O-CU-CP, and O-CU-UP based on latency requirements, while non-RT RIC is deployed in regional cloud, and near-RT RIC can be placed in either edge or regional cloud, all managed and coordinated by O- Cloud and SMO.

4.7 O-gNB (OPEN-RAN ENABLED ENB)

An eNB or ng-eNB that supports O-DU and O-RU functions with an Open FH interface between them is called an O-eNB. Additionally, O-eNB offers operations and features linked to the E2 interface, and it is connected to the near-RT RIC by E2-interface.

4.8 UE's

To access services simultaneously utilizing MR-DC, UEs are connected to O-RAN via the Ue interface and can connect to O-eNB and O-gNB. Smartphones used by humans and/or equipment, and vehicles) supporting various vertical services can serve as UEs.

5. IMPLEMENTATION OF OPEN – RADIO ACCESS NETWORK

The techniques and essential components of the Open-RAN implementation include:

1) Define Network Management *:* Specify coverage, capacity, performance, and scalability requirements. Consider current infrastructure and future growth.

2) Planning and Strategy: Determine ORAN scope, evaluating benefits, drawbacks, and costs.

3) Vendor Choice *:* Select multi-vendor components (vB- BUs, RUs, controllers) for interoperability.

4) *Radio Unit Deployment:* Decouple baseband and radio components, flexible placement for coverage.

5) BBU Virtualization: Use SDN and NFV for virtualized baseband processing, scalability, cost-effectiveness.

6) RIC Integration*:* Integrate RIC with virtualized base-band and radio modules for centralized orchestration.

7) Testing Interoperability: Ensure components from different vendors integrate smoothly through open interfaces.

8) Deployment and Optimization*:* After testing, deploy ORAN network, adjust settings for desired quality.

9) Evolution and Upgrades*:* Evolve ORAN with new features, swiftly upgrade network for increased flexibility and benefits.

6. ADVANTAGES OPEN – RADIO ACCESS NETWORK

Disaggregating hardware and software allows O-RAN to create a unified architecture, which has a lot of benefitslike low latency and network slicing. O-RAN offers network automation as well as the following advantages:

1) Agility*:* Due to the unification of the software-enabled architecture, the network is suitable for both current/past and future generations.

2) Deployment Flexibility: Because of software association and dis-aggregation, the network is adaptable for installation, upgrades, and extensions.

3) Real-time responsiveness: The O-RAN software-driven, service-specific network gives real-time services precedence over less important services and adapts its behavior based on the service it is aimed at.

7. OPEN ISSUES AND CHALLENGES

1) Architectural Aspects : O-RAN architecture has evolved since 2018, aiming to align with 3GPP design and improve5G technologies. Adding features, blocks, and functions to enhance functionality is crucial. Future research should ad- dress O-RU termination of the O1 interface, virtualization opportunities, and coordination of multiple near-RT RICs.

2) Performance Aspects *:* Virtualizing O-RAN network services offers a chance to boost performance through dynamic node transfers based on demand and failures. Managing traffic congestion, resource migration, and supporting time-sensitive use cases while maintaining quality and service continuity pose challenges in large and dynamic RAN deployments.

3) Security Aspects: O-RAN Alliance Working Group 11 researches security factors in the architecture, including threat modeling, risk assessment, security requirements, mechanisms, and testing. Security considerations for various entities, interfaces, shared cloud infrastructure, node integration, open-source software, and lifecycle management need further exploration.

4) Energy-saving aspects: As AI and ML techniques utilizing deep neural networks demand high computational power, their integration into O-RAN for new services and RIC automation might raise energy consumption concerns. Balancing advanced AI/ML approaches with energy-efficient designs is important in addressing environmental impacts.

8. RESULTS

The radio unit obtains a special relevance within the context of Open Radio Access Network (Open RAN), resulting from the coordinated efforts of several manufacturers. Each element of its development requires careful attention to detail, which is provided by these firms collectively. The product's name, a unique product number signifying its uniqueness, and a thorough explanation of the factors essential to its operational construct are some of its primary characteristics. This thorough overview also includes current operational status information for the radio device in real-time. The Open RAN philosophy values flexibility, which is demonstrated by the radio unit's programmable framework. Users may precisely modify the functionalities of the radio unit thanks to this adaptive architecture, ensuring a harmonious alignment with particular operational requirements. This adaptability supports the architecture's ability to accommodate a variety of use scenarios. The Open RAN's radio unit software further enhances the radio unit's capabilities by supplementing its hardware components. It provides information about the current Open radio unit software version as well as improved security features, brand-new features, and performance improvements. This software version also adds a user-friendly interface that is adjusted to the requirements of contemporary users and strengthened for compatibility with modern devices. The user interface of the program acts as a conduit for interaction with the features of the radio unit in the real world. Its importance in enabling a thorough assessment of alarm alterations within the larger context of alarm management is especially significant. This crucial task makes sure that changes are transparent ,improving overall management and control of the Open RAN's operational integrity.

9. FUTURE WORK DIRECTIONS

The integration of SDN, NFV, and other technologies into 5G networks poses challenges related to decentralization, transparency, privacy, and security. Blockchain technologyis being explored as a promising solution due to its attributes like auditability, immutability, and distributed architecture. TheO- RAN Alliance is developing Blockchain- enabled RAN (BE- RAN) to enhance security and authentication, aiming to overcome the centralized Certificate Authority's single point of failure. Additionally, the O-RAN Alliance's Next Generation RG (nGRG) is exploring Digital Twin Networks (DTNs) to address the complexity of network disaggregation, offering accurate network simulations to forecast states, offer current status,and facilitate interactions with other network components.

10. CONCLUSION

The Open Radio Access Network (Open RAN) introduces an innovative approach to the telecom sector, fostering open, interoperable, and intelligent RAN solutions while improving performance and cost-effectiveness. This article presents a comprehensive overview of Open RAN's evolution, standardization by the O-RAN Alliance, architecture, security, deployment considerations, and open-source initiatives, while also addressing unresolved challenges and future research directions. It serves as a valuable resource for understanding Open RAN's standardization efforts and guiding further research in the field.

REFERENCES

[1] Azadeh Arnaz, Justin Lipman, Mehran Abolhasan, Matti Hiltunen(IEEE Access [Volume 10] Published in the year 17 June 2022 Toward Integrating Intelligence and Programmability in Open Radio Access Networks.

[2] Zhirong Zhang, Jiangang Chen, Jia Hou (2021 International Wireless Communications and Mobile Computing) Published in the year 28 June 2021 - 02 July 2021 Analysis of the Evolution Scheme of NSA RAN Sharing to SA RAN Sharing.

[3] Huaning Niu, Clara Li, Apostolos Papathanassiou, Geng Wu (2014 IEEE Wireless Communications and Networking Conference Workshop Published in the year 06-09 April 2014 RAN architecture options and performance for 5G network evolution.

[4] Rony Kumer Saha, Shinobu Nanba, Kosuke Nishimura, Young-Bin Kim, Kosuke Yamazaki (2018 IEEE 29TH Annual International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), Pub- lished in the year 09-12 September 2018 RAN Architectural Evolution Framework toward 5G and Beyond Cellular-An Overview.

[5] Nischal Aryal, Emmanuel Bertin, Noel Crespi (2023 26th Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN), Published in the year 06-09 March 2023 Open Radio Access Network challenges for Next Generation Mobile Network.

[6] Bouziane Brik, Karim Boutiba, Adlen Ksentini (IEEE Open Journal of the Communications Society[Volume: 3]), Published in the year 28 January 2022 Deep Learning for B5G Open Radio Access Network: Evolution, Survey, Case Studies, and Challenges.