O-RAN Empowering Vertical Industry: Scenarios, Solutions and Best Practice

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Executive summary

The O-RAN ALLIANCE is committed to evolving radio access networks (RAN), making them more open, smarter, interoperable, and scalable than contemporary deployments. The first white paper "O-RAN: Towards an Open and Smart RAN [1]" introduced key ORAN concepts: (1) Openness to build a more cost-effective network through open interfaces and open hardware, and (2) Intelligence to suit complex, dense, and future ready networks through embedded intelligence in every layer.

The second white paper "O-RAN Use Cases and Deployment Scenarios [2]" introduced an initial set of use cases that leverage the unique benefits of the O-RAN architecture. This includes utilization of machine learning (ML) and artificial intelligence (AI) modules operating through open and standardized interfaces in a multi-vendor network, along with white-box hardware, open hardware reference design, and cloud native deployment through the O-RAN cloudification and orchestration platform, O-Cloud.

The third white paper "O-RAN Minimum Viable Plan and Acceleration towards Commercialization [3]" outlined the Alliance's focus on several key areas to enable and accelerate the introduction of the rich capabilities of O-RAN architecture in commercial networks and to provide a minimum set of end-to-end specifications for selected use cases for the deployment of a secure, multi-vendor interoperable network.

The fourth white paper "Overview of Open Testing and Integration Centre (OTIC) and O-RAN Certification and Badging Program [4]" introduced OTICs and the O-RAN Certification and Badging program, which are key pillars that support O-RAN ecosystem in achieving its mission. It provided an overview of these two key pillars, what they are, how they operate, and their key objectives.

This white paper "O-RAN Empowering Vertical Industry: Scenarios, Solutions and Best Practice" extends the previous white papers and presents the Alliance's interests in industrial engagement to show the benefits of O-RAN architecture in several vertical industries. This white paper starts with the brief introduction to O-RAN Architecture, followed by an analysis of vertical industry use cases and requirements. Opportunities and benefits of O-RAN Architecture corresponding to each use case are discussed in the subsequent section. O-RAN key solutions, field trials and deployments are presented , followed by O-RAN potential enhancement features to further accommodate vertical demands. This white paper concludes with key findings and future visions toward better vertical industry O-RAN network deployment.

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Introduction

The Emergence of O-RAN

Traditional RAN solutions were monolithic and based on specialized hardware. Vendors provided limited control to configure their RAN products via proprietary OAM Interface. There was limited availability of the RAN suppliers, and it was very difficult for new vendors to provide innovative solutions. Because RAN products were monolithic and proprietary, it was difficult to introduce new features. It was hard for operators and independent software developers to gain control over RAN equipment due to proprietary interfaces and licensing restrictions to build new features.

C-RAN forum, founded in 2009 by China Mobile, first proposed to the industry the concept of Centralized, Collaborative, Cloud and Green Radio Access Network (C-RAN). Then, xRAN Forum was founded in June 2016 by AT&T, DT and others with the goal to develop, standardize and promote an open alternative to the traditionally closed, hardware-based RAN architecture. The first public specification, xRAN Fronthaul, was to permit a wide range of vendors to develop innovative, best-of-breed RRUs (remote radio unit) and BBUs (base band units) which can be easily integrated with virtualized infrastructure and management systems using standardized data models.

C-RAN forum and xRAN forum was merged to create O-RAN Alliance on 27th Feb 2018. The idea is to create a carrier-led effort to drive new levels of openness in the radio access network of next-generation wireless systems. O-RAN Alliance is transforming the Radio Access Networks Industry towards Open, Intelligent, Virtualized and Fully Interoperable RAN. O-RAN Alliance is a world-wide community of mobile operators, vendors, research & academic institutions and others operating in the Radio Access Network (RAN) industry.

The O-RAN Alliance and Standardization Progress

As of October 2023, O-RAN ALLIANCE has published 101 Technical Specifications/Reports, covering the key components as well as the relevant interfaces, such as Non-Real Time RAN Intelligent Controller (Non-RT RIC) and Near-Real Time RAN Intelligent Controller (Near-RT RIC), its A1 and E2 interfaces, open fronthaul, O-cloud and so on. Many of the specifications are stage-3 mature and could provide implementable guidance for vendors to develop their products.

More specifically, the O-RAN ALLIANCE MVP (Minimum Viable Plan) provides the prioritized roadmap for O-RAN solutions. In MWC Shanghai 2021, O-RAN MVP has published its first Release “Open” package which includes a series of open fronthaul, open transport, open hardware, open stack, open cloud features, and testing and integration guidelines for Open Testing and Integration Centers (OTIC). Continuing the momentum, in 2022 MWCB, O-RAN MVP delivered the second Release "intelligent" package to industry, with standards which provide solutions to traffic steering, QoS/QoE optimization, network slicing phase I use cases. Security phase I, Open Cloud API phase I will set up a baseline for the security and open cloud infrastructure solution. Then in 2023 MWCB, Release003 was published, with standards offering an end-to-end solution of SMO, Network Slicing and Security, which continued to enhance O-RAN ecosystem. O-RAN Release 004, which is planned to be published in June 2024, will contain Uplink Performance Improvement (ULPI), Energy Savings, Shared O-RU, Security, mMIMO Optimization, RAN Analytics Information Exposure, and SMO solution.

On the base of specifications, O-RAN ALLIANCE also puts the efforts in the area of Test and Integration (T&I). The ALLIANCE is responsible for approving OTIC globally, which is to provide an open, collaborative, vendor independent, and impartial working environment to conduct various T&I activities for vendors and operators. One key role of OTIC is to award Certification and Badges to the products following O-RAN ALLIANCE guidance and principles. With the awards, the products are proved to be either O-RAN specification-compliant or inter-operable with other O-RAN components from different vendors. So far, 17 OTICs have been approved by the ALLIANCE and 14 Certificates & Badging have been awarded, demonstrating the fast progress of the product maturity in the ecosystem. In addition, O-RAN ALLIANCE has been holding Global Plugfest twice a year since 2021. Spanning multiple countries in dozens of labs with 4-5 months duration, every Plugfest provides an environment for participants to collaborate together and conduct T&I activities such as software debug, inter-operability test, performance demonstration, use case validation and so on. The Global Plugfest has greatly accelerated the maturity of O-RAN ecosystem.

Open Source is another key pillar for accelerating O-RAN maturity. The O-RAN Software Community (OSC), which is responsible for the O-RAN reference software development based on O-RAN specifications, has published 8 Releases so far. Much of the software follows the latest O-RAN specifications and has implemented quite a few key O-RAN components such as O-CLOUD, Near-RT RIC, Non-RT RIC etc., which provides the basic reference design for vendors to build their products upon.

The Potential of O-RAN for Vertical Industries

O-RAN, with its innovative approach to RAN architecture, presents a paradigm shift in how network services are delivered and managed, particularly in specialized industry sectors. O-RAN's potential lies primarily in its open architecture, which introduces unprecedented levels of flexibility and customization. This architectural openness allows for a diverse ecosystem of vendors and solutions, facilitating tailored network deployments that can adapt to the unique requirements of different industries. For instance, in manufacturing, O-RAN can support complex automation and real-time control systems, while in transportation, it can enhance the efficiency and safety of intelligent transportation systems.

Furthermore, the integration of advanced technologies like AI and machine learning into O-RAN architecture enables smarter network management. This integration leads to more efficient resource utilization, predictive maintenance, and enhanced security features - all crucial aspects for industries reliant on robust and secure communication networks. The ability to implement network slicing, where multiple virtual networks operate on the same physical infrastructure, allows for dedicated and optimized services catering to specific industry needs.

Energy efficiency is another significant aspect of O-RAN's potential in vertical industries. The white paper highlights how O-RAN's design and operational efficiencies can lead to reduced energy consumption, aligning with the global push towards sustainable and eco-friendly industrial practices.

In summary, the potential of O-RAN for vertical industries is vast and multifaceted. Its ability to offer customized, efficient, and sustainable network solutions positions O-RAN as a key driver in the next wave of industrial digital transformation.

Objectives and Scope of the White Paper

This white paper has been crafted with the fundamental objective of delineating the role and impact of O-RAN technology across a spectrum of vertical industries. It seeks to underscore the significant contributions of O-RAN in driving innovation, operational efficiency, and enhanced capabilities within sectors such as manufacturing, transportation, energy, and emergency response. The document delves into the advantages offered by the O-RAN architecture, characterized by its open, intelligent, virtualized, and interoperable nature. These encompass aspects of customization, scalability, network slicing, cost efficiency, enhanced security, improved energy efficiency and so on.

A key focus of the white paper is on presenting real-world use cases and requirements from different industries, thereby illustrating the potential of O-RAN in facilitating their digital transformation. It also provides an in-depth exploration of O-RAN's solutions and best practices, supported by insights from field trials and deployments that exemplify the practical application of this technology in various industry settings.

Furthermore, the paper discusses potential future enhancements and challenges in O-RAN technology, outlining innovative features and addressing existing hurdles. This discussion aims to chart a course for the ongoing development and broader adoption of O-RAN in diverse industrial applications. The white paper serves as a comprehensive resource for industry stakeholders, policymakers, technical personnel and academic, offering a detailed understanding of O-RAN's capabilities and guiding future innovations in this evolving field.

Vertical Industry Use Cases and Requirements

In this chapter, we delve into the real-world use cases across a variety of industry sectors. We aim to provide a detailed examination of unique requirements in industries such as manufacturing, transportation, energy, and emergency reaction, highlighting the versatility and adaptability of O-RAN solutions.

Manufacturing

The industrial network requires the utilization of next-generation information technologies such as 5G, cloud computing, IoT, big data, and artificial intelligence to eliminate barriers between people, machines, objects, and services, creating digitized models and digital twins throughout the entire product lifecycle. These technologies drive efficient operations and promote innovation in production methods and business models through data-driven solutions. The primary use cases for 5G manufacturing networks currently are:

Industrial Control: To meet the demand for flexible production for high-end equipment manufacturing customers, it is necessary to provide industrial automation wireless communication product solutions. These solutions ensure flexible deployment and stability, especially to support reliable communication between controllers and devices[5].

Wireless Data Acquisition: During the digital upgrade and transformation process of industrial plants, a large number of different types of equipment such as production equipment, video surveillance, and sensors need real-time information statistics. However, due to the low level of digitalization of the production line, it is challenging to monitor and analyze the production capacity effectively, which is essential to achieving intelligent production control. Therefore, wireless data acquisition is needed to collect and transmit real-time data from these devices for analysis and optimization.

Vision-based Remote Control: With the large-scale expansion of industrialization, equipment is relatively independent and geographically dispersed, making it difficult to monitor and manage efficiently. Scenarios such as tower cranes at industrial sites and unmanned driving for mining trucks require high data rate uplink capable of carrying a large amount of video feedback, as well as stable latency performance, which is necessary for reliable remote control.

Smart Logistics: The demand for smart logistics to reduce overall costs and increase efficiency is growing. It is necessary to significantly improve labor productivity and space utilization efficiency. For high-density warehouses, wireless communication requirements are stricter. Mobile devices need to move across the entire warehouse at high speed. Stable and reliable communication are needed to ensure communication between mobile devices and the control system. Some of these requirements include:

1. Low-latency and reliable communication: For mission critical applications like industrial control, reliability is essential to provide consistent low-latency wireless communication, as any disruption or delay can result in significant losses.

2. Edge AI: Factory-level AI techniques, via digital twins, are expected to improve operational performance and minimize maintenance. Edge AI services enable end-to-end operational intelligence like Automated Guided Vehicle (AGV) fleet management etc.

3. Cost effective: As private sectors tend to be cost sensitive, lowering cost can be achieved in terms of reducing cost per bit by increasing spectral efficiency and reducing deployment cost. In O-RAN architecture, manufacturers are able to select and integrate components from different vendors, creating a more cost-effective network that best suits the needs through open interfaces and open hardware.

Transportation

Intelligent Transportation Systems (ITS) are advanced applications that aim to provide innovative services related to various modes of transport and traffic management, enhancing the safety, efficiency, and sustainability of transportation networks. These systems leverage digital technologies, such as connected sensors, communication networks, and data analytics, to monitor and manage traffic, optimize transportation infrastructure, and support new mobility services.

Intelligent Transportation Systems encompass a wide range of applications designed to address various challenges, such as congestion, pollution, and safety concerns. Some common ITS applications include:

Traffic management: ITS can help monitor and manage traffic in real-time, using connected sensors and communication networks to collect data on traffic conditions, vehicle speeds, road occupancy, road services and detouring situations. This data can be analyzed and used to optimize traffic signal timings, manage traffic flows, and provide real-time information to drivers, helping to reduce congestion and improve overall traffic efficiency.

Connected and Autonomous Vehicles: ITS can support the development and deployment of connected and autonomous vehicles, which rely on advanced communication and sensor technologies to navigate, communicate with other vehicles, and interact with transportation infrastructure. Reliable, low-latency connectivity solutions are needed to help facilitate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, enabling safer and more efficient transportation systems. Some of these requirements include:

1.High-capacity connectivity: Many ITS applications, such as connected and autonomous vehicles, require high-capacity communication networks to transmit large volumes of data in real-time.

2.Low-latency and reliable communication: Real-time communication is essential for many ITS applications, particularly those related to traffic management, public transportation optimization, and connected and autonomous vehicles. O-RAN's SLA assurance capabilities can help facilitate real-time communication between road participants, enabling more responsive and efficient transportation systems. In congested networks for high-traffic environments, O-RAN techniques such as network slicing can be applied.

3.Edge processing: Given the large amount of sensed data that needs to be processed in real-time, and decisions need to be made at tens to hundreds of milliseconds, O-Cloud as computing infrastructures can serve as edge processing nodes, allowing local data analysis and decision making with shortened latency while reducing backhaul load and data leakage risks.

Energy

The smart grid reflects the evolution of energy industries worldwide. It encompasses power generation, transmission, distribution, storage, and utilization within a comprehensive system, utilizing IT and automated control technology to optimize all aspects from generation to utilization, through bidirectional communication. The wireless communication use cases for smart grid control includes:

Power Distribution Network Protection: By collecting current phasor data of the distribution network, the system can promptly understand the condition of transmission lines, quickly diagnose faults, accurately pinpoint their locations, and isolate fault areas or equipment. This allows for a swift restoration of power.

Advanced Metering: Using smart meters, the system conducts detailed collection of power consumption information to meet intelligent power consumption and personalized customer service needs. For industrial and commercial users, intelligent data analysis provides support for energy efficiency management.

Drone Patrol Inspection: This primarily involves inspecting the physical characteristics of transmission lines between grid structures, such as bending deformation and physical damage. This scenario is typically used for long-distance, outdoor, high-voltage transmission. Typical applications include forest channel detection, icing monitoring, forest fire monitoring, and external damage warning detection.

The Smart Substation: Robots conduct daily inspections, returning data to the control room. Advanced AI technology is used to analyze and evaluate high-definition images and videos, improving inspection efficiency. AI can also verify equipment operation upgrades and cameras can capture abnormal personnel safety situations for prompt identification. The network requirements for these scenarios include:

1. Wide coverage and massive connectivity: Advanced metering services require extensive network coverage and connectivity due to the wide distribution of terminals. Cellular network enabled wireless connectivity provides such wide area communication without physical wires, but factors like interference, capacity and reliability should be considered.

2. Low latency and high reliability: Smart grid control services need real-time communication between protection devices and require extremely high reliability due to sensitivity to latency.

3. Isolation: Especially for control-related services, smart grids require high security levels and need to be completely isolated from other businesses.

4. Edge computing: Patrol inspection services need to analyze a vast amount of image and video data. Combining edge computing with AI technology better meets the requirements of efficiency and quality.

Emergency Reaction

Emergency responses are crucial in dangerous situations as they provide timely rescue signals. Once a signal is dispatched, various actions including automatic emergency alarms, emergency communication, basic communication recovery, and positioning services can be initiated. This section discusses these emergency response applications using the O-RAN architecture, which requires edge processing for resource computation, low-latency communication for prompt responses, data security to safeguard user information, and a deterministic network for emergency communication support. Some common emergency reaction scenarios include:

Automatic Emergency Alarm: For the safety of industrial production and storage environments, automatic emergency alarms are essential. These could include fire, toxic gas, and humidity alarms. In such scenarios, high security levels, high reliability communication, low sensing latency, and quick responses are vital.

Emergency Communication: In situations like fires or earthquakes, emergency communication ensures that victims can communicate or signal for help. This requires a private deterministic network slice for optimal transmission performance.

Basic Communication Recovery: In the event of a disaster, basic communication networks may be damaged. Therefore, the resilience and swift recovery of original communication equipment are critical for basic communication support, reducing disaster impacts on residents.

Positioning Services: Indoor base stations using Ultra-Wideband (UWB) and Bluetooth can provide indoor positioning services during emergencies. They can connect to signal transmitting equipment and display the location of endangered individuals on a positioning platform. Emergency responses require the following:

1. Edge processing: In emergency situations, edge data processing is key. O-Cloud enabled base stations can deploy edge application platforms in containers, providing edge computing services while also serving as wireless communication equipment.

2. Data security: As base stations can function as edge servers, data can be analyzed at the edge, ensuring data security within the base station's deployment scope, such as a factory or office.

3. Deterministic network: When basic communication equipment is damaged, restoration of the communication network is urgently needed. Base stations with O-RAN architecture in a deterministic network can create a private network slice prioritizing emergency communication, ensuring timely, precise, and swift capabilities.

Opportunities and Benefits of O-RAN Architecture

Introduction to O-RAN Architecture

The high-level view of O-RAN architecture consists of the O-RAN NFs (Network Functions), an SMO (Service Management and Orchestration) framework to manage the O-RAN NFs and an O-Cloud (O-RAN Cloud) that may host many of the O-RAN NFs. Figure. 1 below shows the interfaces - A1, O1, Open Fronthaul M-plane and O2 - connecting SMO framework to O-RAN NFs and to O-Cloud. As depicted in this figure, the O-Cloud includes the O-Cloud Notification interface [6] which is available for the relevant O-RAN NFs (i.e., Near-RT RIC, O-CU-CP, O-CU-UP and O-DU) to receive O-Cloud related notifications. Figure. 1 below also illustrates that the O-RAN NFs can be hosted on the O-Cloud or on customized hardware.

All O-RAN NFs, except O-RU, are managed via the O1 interface to an authorized SMO framework. The O1 interface exposes management services for the O-RAN NFs that are managed individually or together, as specified in the OAM Architecture specification [7]. The Open Fronthaul M-plane interface, between SMO and O-RU, supports the O-RU management in hybrid mode, as specified in [8][9]. O-RAN NFs instantiated on the O-Cloud may utilize the APIs exposed by the Accelerator Abstraction Layer (AAL) defined in [10].

The Near-RT RIC in the figure below provides RAN analytics information services via the Y1 service interface [11]. These services can be consumed by Y1 consumers after mutual authentication and authorization by subscribing to or requesting the RAN analytics information via the Y1 service interface.

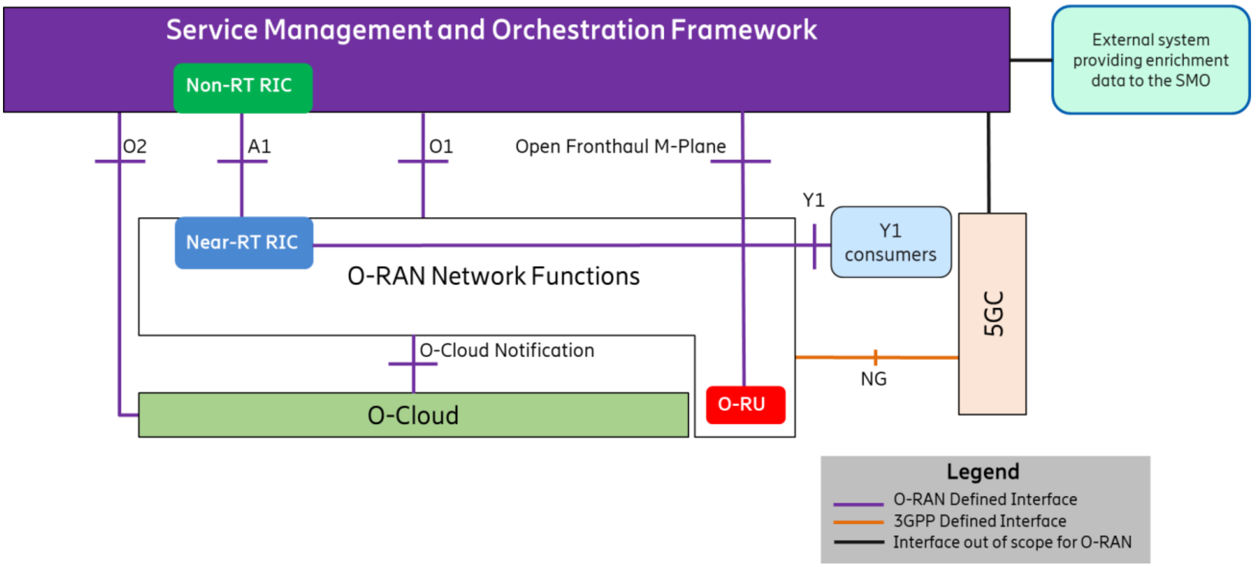

Figure. 1: High Level Architecture of O-RAN

Within the logical architecture of O-RAN, as shown in Figure. 1, the radio side includes Near-RT RIC, O-CU-CP, O-CU-UP, O-DU, and O-RU O-RAN NFs. As stated earlier, the management side includes SMO Framework containing a Non-RT-RIC function. The Non-RT RIC enables Non-Real Time control loops, in which R1 interface enables multi-vendor rApps to consume or produce the R1 services and is independent of specific implementations of the SMO and Non-RT RIC framework. The O-Cloud, on the other hand, is a cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN NFs (such as Near-RT RIC, O-CU-CP, O-CU-UP, and O-DU etc.), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions. The virtualization of O-RU is not supported at the present time.

As shown in Figure. 2, the O-RU provides the Open Fronthaul M-Plane interface to authorized O-DU in hierarchical mode, or to authorized O-DU and SMO in hybrid mode. The O-DU and O-RU are connected via the OFH (Open Fronthaul) interface.

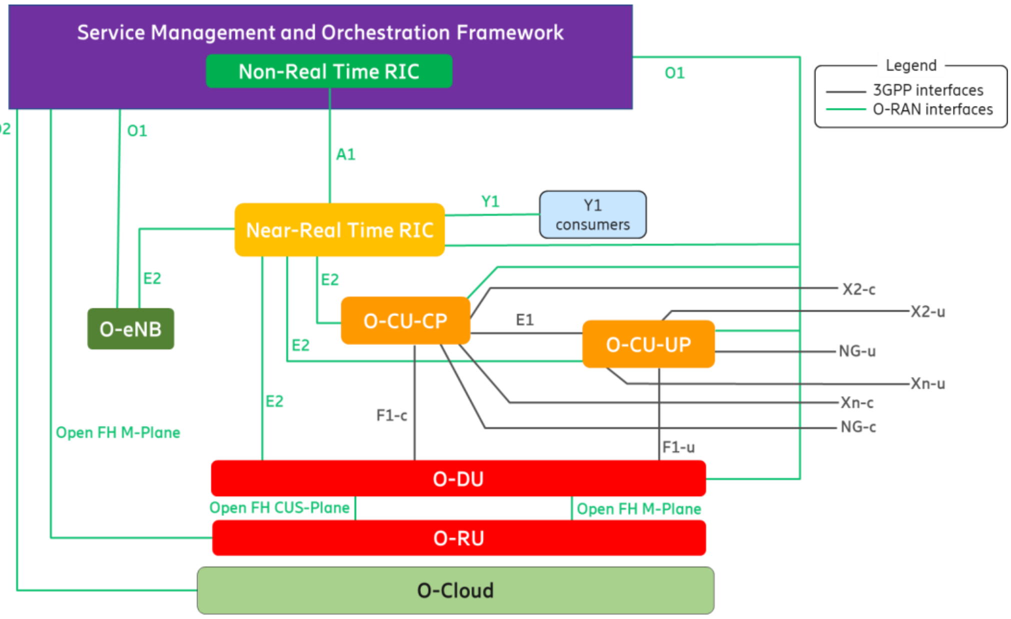

Figure 2: Logical Architecture of O-RAN

Please refer to the O-RAN Architecture Description [12] for more details.

Opportunities for Vertical Industries

This section highlights essential elements that underscores O-RAN's unique advantages in advancing industry-specific network solutions, from customization, scalability, cost efficiency to service reliability and management automation.

Customization and flexibility

One of the most significant opportunities O-RAN offers to vertical industries is the ability to customize and tailor mobile networks to meet specific industry requirements. The open and modular nature of O-RAN architecture allows network operators to select and integrate components from different vendors, creating a network that best suits the needs of a particular industry. This approach enables network operators to develop bespoke solutions that address unique challenges, such as ultra-low latency requirements, high bandwidth demands, and specialized security needs.

To be more specific, with open interfaces, it becomes possible to mix-and-match RAN equipment from various vendors. This allows to introduce and utilize optimal RAN equipment depending on the deployment scenario including industry use considering performance, supported features, schedule and cost.

In the O-RAN specification, Open Fronthaul was the first interface to be opened up and has maturity and advanced implementation. With the open fronthaul, best radio units (O-RUs) for each frequency band and deployment scenarios, e.g., indoor, outdoor micro and outdoor macro, can be chosen regardless of the baseband unit (O-CU/O-DU) vendor. Also, O-CU or O-DU can be replaced with those providing better performance, e.g., capacity and power consumption, without having to swap already deployed O-RUs. Furthermore, as any vendors' O-RUs, O-CUs or O-DUs can be selected, thus cost competitiveness can be improved. As such, continuous network augmentation utilizing best-of-breed products with reduced costs becomes possible.

The O-RAN ALLIANCE also specifies profiles for 3GPP RAN interfaces to achieve interoperability among different vendors. Open X2 enables operators providing 5G non-standalone to introduce 5G NR base stations (gNBs) independent of the vendor providing 4G LTE base stations (eNBs). Similarly, open Xn allows operators providing 5G standalone to introduce gNBs from different vendors in the same geographical area. Open F1 provides similar multi-vendor benefits as the open fronthaul but at the higher layer split between O-CU and O-DU. Other open interfaces such as E2, A1 enable operators providing multi-vendor intelligent components.

Furthermore, O-RAN enables greater flexibility in network deployment and management, thanks to its software-centric approach. Network operators can easily reconfigure network resources, scale capacity, and deploy new features and services through software updates, enabling them to adapt more rapidly to changing industry requirements and market conditions. The open source and white box offering, and reference design repository bring further openness and degree of flexibility and support for vertical industries to customize for or develop their own solutions meeting their special requirements in each individual market segment.

Scalability and optimized network capacity

O-RAN's virtualization and cloud-native principles enable more efficient scaling of network resources, allowing network operators to more easily meet the growing demands of vertical industries. By deploying network functions on commercial off-the-shelf (COTS) hardware and leveraging cloud-based infrastructure, network operators can quickly and cost-effectively expand network capacity and capabilities as needed. This scalability is particularly important for industries with rapidly growing connectivity requirements, such as IoT, autonomous vehicles, and smart cities.

Moreover, O-RAN's software-defined networking (SDN) capabilities enable more efficient utilization of network resources, improving overall network capacity and performance. By dynamically allocating and managing network resources based on real-time demand, O-RAN can help ensure that network capacity is optimized for each industry's specific needs.

Network slicing and dedicated services provision

Network slicing is a key feature of O-RAN architecture, allowing network operators to create multiple virtual networks or "slices" within a single physical network infrastructure. Each network slice can be configured with its own set of network functions, resources, and policies, enabling network operators to provide dedicated and customized services for different vertical industries.

By leveraging network slicing, O-RAN can deliver tailored connectivity solutions that meet the unique requirements of various industries. For example, a network slice for an industrial IoT application may prioritize low-latency communication and high reliability, while a slice for a healthcare application may prioritize data security and privacy. Network slicing enables network operators to offer more differentiated and value-added services, helping them to better serve the diverse needs of vertical industries.

Cost efficiency and reduced capital expenditure

O-RAN's open architecture, virtualization, and cloud-native principles can help reduce both capital expenditure (CAPEX) and operational expenditure (OPEX) for network operators and vertical industries. By enabling multi-vendor interoperability and breaking the traditional vendor lock-in, O-RAN allows network operators to select more cost-effective components and solutions from a diverse ecosystem of suppliers. Additionally, the ability to deploy network functions on COTS hardware and leverage cloud-based infrastructure with customizable software and hardware configuration can significantly reduce upfront CAPEX. Finally, the centralized cloud-based deployment with virtualization and on-demand hardware resource allocation enables resource pool sharing and reusing among multiple physical cell sites and multiple slice services at the industrial workplace. This further greatly reduce the upfront CAPEX.

On the operational side, O-RAN's software-centric approach can lead to more efficient network management and lower OPEX. The use of AI and machine learning algorithms for automated network optimization, predictive maintenance, and security enhancements can help reduce manual intervention and associated labor costs. Furthermore, the ability to quickly deploy and scale network resources through software updates can reduce the time and cost associated with network expansions and upgrades.

Enhanced security and privacy

As vertical industries become more reliant on mobile connectivity for critical applications and services, ensuring network security and data privacy is of paramount importance. O-RAN's open architecture and software-centric approach can help enhance security and privacy for vertical industries in several ways.

First, AI and machine learning algorithms integrated into O-RAN architecture can be leveraged to enhance network security by enabling real-time threat detection, automated incident response, and proactive security measures. These capabilities can help network operators and vertical industries better protect their networks and data from evolving cyber threats.

Second, the use of open interfaces and multi-vendor interoperability encourages a diverse ecosystem of suppliers, which can lead to increased innovation and the development of more secure and robust solutions. By avoiding reliance on a single vendor, network operators can reduce the risk of potential security vulnerabilities associated with proprietary solutions.

Service reliability and sustainability

Service reliability and sustainability are important for vertical industry applications which normally requires highly secure and robust always-on services where the cost from network down-time is barely affordable. O-RAN's virtualization and cloud-native principles enables fast self-healing and seamless failover and resiliency in occasion of system and sub-system failures in both software and hardware domain through various advanced auto-healing technologies available in the cloud framework. The shared O-RU in O-RAN further protects the network by enabling seamless failing over from serving O-DU to standby O-DUs even the O-DUs are implemented as PNFs and from different vendors. The micro-service architecture further improves robustness of the system to sub-component/service failures.

Moreover, frequent software and hardware upgrading without interrupting and impacting network performance is vital for vertical industries' network. The cloud framework and Shared O-RU Resiliency feature enables seamless rolling upgrade of all network components, services, and micro services to avoid service downtime during hardware and software maintenance to track the rapid changing industry requirements and market conditions.

Management and orchestration automation

Network Automation including network function and service function orchestration and operation have to be optimized across all network domains at the fine granularity dedicated for each vertical industry's requirements. The O-RAN architecture enables 3rd party, operators or vertical industry developed applications (e.g. xApps and rApps) to manage and optimize the network via standardized API interfaces, which is vital to meet the highly diversified and rapid changing service requirements from the vertical industries.

Furthermore, O-RAN architecture targets to enable intent driven autonomous network management and orchestration which further improve the process of network and service provisioning based on high-level user intents for a diverse set of user and service provider requirements from the vertical industries using high levels of intelligence, which brings network automation to the next level.

Energy efficiency

RAN is responsible for the majority of the Energy Consumption (EC) of a mobile network, and the O-RU consumes the largest part of the energy consumption of the RAN. The potential depletion of fossil fuel-based energy resources and the urgent need to reduce CO_2 emissions make energy saving a strategic goal for both network operators and vertical industries, in addition to the significant energy related OPEX reduction.

The centralized cloud-based deployment with virtualization and on-demand hardware resource allocation enables resource pool sharing among multiple physical cell sites and multiple slice services in the industrial workplace. This greatly reduce the energy consumption compared with conventional networks which allocate dedicated hardware close to the cell site that consume significant amounta of energy even when the network is not used. These are further optimized with RAN intelligence empowered by advanced AI/ML technologies to bring energy consumption to a minimum everywhere in the O-RAN network. Furthermore, diversified supply chain enabled by O-RAN allows operators and vertical industries to select energy efficient hardware and innovative solutions meeting their energy budget.

Benefits of O-RAN for Manufacturing

One network adapts all

In manufacturing factories, there are various application scenarios such as remote monitoring, industrial control, etc. Different application scenarios have different network quality requirements. The capability of Network slicing and dedicated services in O-RAN can support the demand for one network with multiple uses. By the network slicing capability of O-RAN, different applications can be provided with different network slices. For example, high bandwidth network slices can be provided for remote monitoring, and ultra-low latency guarantee can be provided for industrial control. Network slicing can isolate different network resources and allocate corresponding resources for particular applications.

Real-time positioning

In industrial scenarios, it is necessary to have real-time knowledge of the location of personnel and materials. On one hand, it can be used for production material scheduling and management, and on the other hand, it can be used to avoid safety risks. By using the Open Interfaces of the O-RAN architecture to access the network's communication capabilities, 5G networks can be reused for real-time positioning, reducing the cost of deploying other networks on-site.

Energy saving

Utilizing the capabilities of O-RAN's Near-RT RIC and Non-RT RIC AI capabilities, the network could learn the operational production cycles within each factory, leading to a proactive, adaptive and customized energy saving policy.

Benefits of O-RAN for Transportation

Traffic management and optimization

O-RAN architecture can also benefit traffic management and optimization applications by providing the reliable and low-latency connectivity necessary for real-time traffic monitoring and control. By leveraging O-RAN's open architecture, transportation authorities can more easily integrate and deploy traffic management solutions within O-RAN architecture, such as adaptive traffic signal control systems, real-time traffic monitoring, and dynamic routing applications.

These solutions can help optimize traffic flow, reduce congestion, and improve overall transportation network efficiency. Additionally, O-RAN's support for edge computing enables the rapid processing of traffic data, ensuring that traffic management systems can adapt quickly to changing traffic conditions and implement real-time optimization strategies.

Connected and autonomous vehicles

Similarly, O-RAN is instrumental in advancing Connected and Autonomous Vehicles (CAVs) by providing reliable, low-latency communication for effective interaction between vehicles, infrastructure, road side unites (RSUs) and other road users. This can be achieved through SLA assurance policy generated by Non-RT RIC, Near-RT RIC and RAN slicing. The edge computing capabilities of O-RAN enables the rapid processing of vehicle data, ensuring that CAVs can make real-time decisions and respond quickly to changes in their environment. Such as virtualizing RSU into vRSU, which could be deployed into O-Cloud alongside RAN functions.

Enhanced public safety and security

By leveraging O-RAN's network slicing capabilities, transportation authorities can create dedicated and isolated network slices for public safety and security applications, ensuring that these critical services receive the necessary network resources and quality of service. This dedicated connectivity can help improve response times, enhance communication between emergency personnel, and ultimately, save lives. This is crucial for emergency response services, such as ambulance and police communications, ensuring that critical information can be transmitted rapidly and accurately during emergency situations.

Benefits of O-RAN for Energy Industry

Patrol and surveillance enhancement

Due to the wide range of transmission lines in smart grid, frequent handover occurs during patrols and other businesses. The O-RAN architecture ensures network access while reducing the interruptions of signaling during handover by cloud and centralized deployment of O-CU. At the same time, the Non-RT RIC and Near-RT RIC platform provided by the O-RAN architecture, combined with AI algorithms, can assist in QoS optimization for video surveillance services, ensuring that system resources can be prioritized in case of emergencies such as fires. In addition, the O-RAN architecture can also support network slicing, providing guarantee for differentiated smart grid use cases.

Flexible base station deployment

Different smart grid scenarios have different network requirements. For example, power distribution network's differential current protection requires low latency and high reliability, while advanced metering requires wide coverage and connectivity. The O-RAN architecture divides the original base station functions into O-RU, O-DU, O-CU-CP, and O-CU-UP, allowing for flexible deployment of different functions in different locations. For services with low latency requirements, all functions are uniformly deployed near the terminal, but for the massive connectivity, the O-CU can be centrally deployed. Meanwhile, due to the virtualization of RAN functions based on cloud platforms, functional iteration and protocol stack configuration can be achieved through software updates, with strong scalability.

Remote control and video surveillance processing

Smart grid control services require high security, while large video surveillance services require real-time processing and feedback, for which User Plane Function (UPF) and Multi-access Edge Computing (MEC) functions shall be deployed at the edge. On the one hand, real-time processing is achieved via offloading data locally. The O-RAN architecture is based on the concepts of cloud and openness, making it easier for MEC and UPF to be deployed on a common platform, achieving fast and secure processing for smart grid enterprises.

Benefits of O-RAN for Emergency Reaction

Emergency alarm system automation

In Automatic Emergency Alarm Systems, various sensor data collected by IoT sensors need continuous monitoring. To rapidly process this data, the system can be deployed at the base station of O-RAN architecture, which provides ultra-low latency response and enhanced data security. Thanks to the O-Cloud platform of the O-RAN architecture, edge applications are flexibly deployed in a containerized manner using the spare CPU cores and memory of the base station.

The system deployed at the base station not only alert users through alarms but also trigger policy responses promptly through the edge service platform to minimize security risks. Moreover, the emergency reaction process can notify corresponding mobile users through their wireless terminals.

Communication assurance

Communication assurance comprises emergency communication assurance and original communication assurance. For emergency communication systems, network performance can be optimized by continuously monitoring E2 node data and air interface data and training the A1 policies using the Non-RT RIC platform of the O-RAN architecture. When communication equipment is damaged, the flexible deployment capability of the O-RAN architecture can be demonstrated as the base station software can be deployed on any available server.

For original communication systems, the open architecture and interface of the O-RAN can benefit different manufacturers' wireless equipment. For instance, when the O-DU and O-RU of the same manufacturer lose their connectivity, they can connect to the O-RU of another manufacturer to rectify the network connection problem. Moreover, any communication maintenance personnel, not necessarily the maintenance personnel of the equipment manufacturer, can easily process communication equipment problems.

O-RAN Key Solutions and Best Practices

Key Solutions

Slicing for customized services

Network slicing is a key feature of O-RAN architecture, allowing network operators to create multiple virtual networks or "slices" within a single physical network infrastructure. Each network slice can be configured with its own set of network functions, resources, and policies, enabling network operators to provide dedicated and customized services for different vertical industries.

Slicing within a dedicated network for a single industrial site, e.g., a smart factory, enables converged network solution with performance assurances for each type of communication service in the site. For example, there can be one slice for guest users, one slice for internal users with enhanced security, one slice for production line robots in the factory requiring low-latency, and one slice for emergency calls for users with critical missions that require guaranteed service quality etc.

Edge computing for low-latency applications

Low-latency applications are becoming increasingly important across various vertical industries, as organizations seek to optimize processes, enhance user experiences, and harness the potential of emerging technologies. Edge computing plays a critical role in enabling these low-latency applications by reducing the time taken for data to travel between devices and data centers, allowing for faster decision-making and response times.

Some examples of low-latency applications across vertical industries include Financial Services and Media/Entertainment. In the financial sector, low-latency communication is critical for high-frequency trading, fraud detection, and risk management. Edge computing allows for the rapid processing of financial data and real-time decision-making, helping financial institutions respond to market fluctuations and mitigate potential risks more effectively. In the media and entertainment industry, low-latency communication is essential for high-quality streaming, virtual reality experiences, and online gaming. Edge computing enables faster content delivery and improved responsiveness, ensuring a smooth and immersive experience for users.

Data processing and analytics at the edge

In addition to reducing latency, edge computing also offers benefits in terms of data processing and analytics. By processing data at the edge of the network, operators can reduce the volume of data that needs to be transmitted to centralized data centers, resulting in reduced bandwidth requirements and lower operational costs. This is particularly beneficial for applications that generate large volumes of data, such as IoT devices and video surveillance systems.

Furthermore, edge computing enables real-time data analytics, allowing organizations to gain valuable insights and make data-driven decisions more quickly. This capability is essential for various applications, such as predictive maintenance in industrial settings or real-time traffic management in smart cities.

Enhanced security and privacy

Edge computing can also enhance security and privacy for various applications and industries. By processing data locally at the edge of the network, operators can minimize the risk of data breaches and unauthorized access, as sensitive data does not need to be transmitted across the network to centralized data centers.

Additionally, edge computing supports data processing and storage in compliance with regional data privacy regulations, such as the General Data Protection Regulation (GDPR) in the European Union. This compliance is crucial for industries that handle sensitive information, such as healthcare and financial services.

AI-driven network optimization and automation

In response to the diverse service and business demands of the industry, O-RAN architecture offers a platform that can facilitate AI-driven network optimization and automation. This enables industry consumers to express their network optimization intents through a declarative language, without requiring an in-depth understanding of the complex network details and operations. These intents, which essentially encapsulate the goals, requirements, and constraints of network optimization, place emphasis on "what" rather than the "how". The latter is taken care of by O-RAN components, thereby providing a resolution for network optimization issues. This approach of intent-based network management and optimization propels network automation, leading to a decrease in network operation labor costs and an enhancement of network optimization efficiency.

When the Non-RT RIC and Near-RT RIC receive network optimization intents, they can utilize advanced AI tools to translate these intents into specific network optimization policies or controls, such as network parameter configurations and network procedure controls. They can provide continuous closed-loop assurance by monitoring, analyzing data, and making AI-based decisions, thereby fulfilling network optimization objectives. The AI capabilities encompass dynamic prediction and intelligent decision-making, supporting a multitude of scenarios like traffic prediction-based energy-saving, UE trajectory prediction-based mobility optimization, reinforcement learning based network parameter configuration decisions, and so on.

Pre-scheduling control for industrial vision monitoring

AI-driven network optimization is exemplified by industrial vision applications, which utilizes Non-RT RIC, Near-RT RIC, E2 nodes in the O-RAN architecture, plus an industrial vision server (MES). By leveraging AI algorithms, O-RAN-based architecture facilitates the implementation of 5G adaptive pre-scheduling parameters configuration by dynamically adjusting the scheduling start time in line with the actual image data transmission characteristics, leading to the high efficiency of industrial vision.

Power saving control by O-RU sleep and O-CU/O-DU power control

Another example of AI-Driven Network Optimization and Automation is power saving control by O-RU sleep and O-CU/O-DU power control. As stated in the Energy Efficiency section, power savings can be achieved through optimization with RAN intelligence enhanced by advanced AI/ML technology. The key is to maximize power savings while satisfying QoS/QoE.

For example, AI can be used to predict traffic demand, optimally allocate resources considering QoS/QoE variations, and control O-RUs to maximize power savings. These efforts to reduce power consumption are expected to have a significant effect not only on the public 5G network but also on the industrial 5G network. For example, in a smart factory, since information (size and frequency) from various devices exists on the network and various service applications are operated, the strategy of how to utilize limited resources is very important. Therefore, it is expected to improve productivity and reduce power consumption by intelligently allocating resources in consideration of work efficiency in the factory.

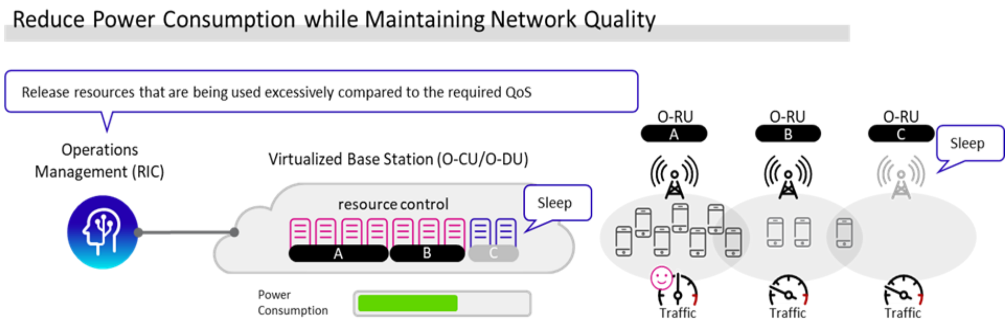

Figure. 3 Balancing Low Power Consumption with Network Quality and QoE

The AI/ML technology includes time series prediction technology that considers crucial periods of time and prediction uncertainty to forecast traffic demand, and multi-agent reinforcement learning that each AI agent processes the data in the divided area. Using open data from the city of Milan, a O-RU sleep simulation using AI on roughly 1000 O-RUs is conducted. As a result, the load distributed to the active O-RUs did not exceed the threshold value that causes quality degradation, and the benefit of putting 50% of O-RUs into sleep mode on daily average is achieved. This translates into an annual reduction in power consumption of about 45.6 MWh per 1,000 O-RUs. Although this simulation is targeted at public 5G network, it is possible to estimate the effects for industry by scaling the number of base stations, fitting base station power parameters, and adapting to traffic models for industry.

Application-aware RAN Optimization

In addition to conventional policies of improving the average quality of experience (QoE) at each mobile coverage area, there is an increasing need to strengthen policies that precisely adhere to QoS requirements per communication session and in real-time to enable the stable use of applications at high-performance levels (work speed, productivity, etc.). This section introduces an application-aware RAN optimization technology that can support such policies based on O-RAN architecture.

Here, the industrial use case to ensure the uninterrupted transport of materials at the factory or warehouse floor by means of Automated Guided Vehicles (AGVs) is considered. Communication services for those remote-control applications need to fulfill stringent requirements, especially in terms of latency, communication service availability and determinism. In those applications, two-way communication consisting of robot status monitoring and control instructions must be completed at a constant cycle, and the system safely stoped with fail-safe if the latency exceeds a threshold. Safety is maintained by fail-safes, but if fail-safes occur frequently, the facility utilization rate and productivity will decrease. To improve the communication service timeliness and availability, an AI/ML algorithm (xApp/rApp) that can perform the following tasks on a per UE basis in near-real-time: 1) estimating application QoS requirements based on information supplied by the application server, 2) predicting fluctuations in wireless quality by using radio quality information supplied by the O-DU, and 3) proactively optimizing O-DU parameters.

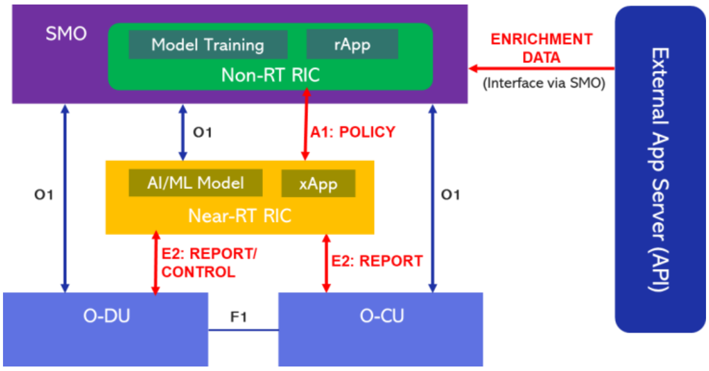

Figure. 4 Application-aware RAN Optimization Architecture

By using mobility, radio propagation, and network simulators, communication service timeliness and availability are evaluated in the context of mean time between failures which is one of the important KPIs defined by 3GPP for this kind of traffic. The proposed method optimizes RAN parameters, including Modulation and Coding Scheme (MCS) and Resource Block (RB) allocation, on a per-UE basis in near real-time. The proposed method is compared with the method of using typical settings for those RAN parameters in public networks. Table. 1 shows the simulation conditions. Figure. 5 shows the simulation results in an environment where the QoS requirements and radio quality vary in accordance with the field conditions (e.g., movement of UE, distance between UEs, etc.). The simulation results confirmed that the QoS requirements are satisfied reliably by the proposed method against the conventional method.

Number of gNB and cell	gNB: 1 cell: 1
Frequency	4.8GHz (n79)
Bandwidth	100MHz
SCS	30kHz
Duplex	TDD
DL, UL ratio	DL:UL = 1:1
Transmission power	23dBm
Floor area	100m x 100m
Floor layout	layout assuming a factory
Number of robots	18 in maximum
Robot running speed	3 m/s in maximum
Traffic per robot	DL: 150Kbps in maximum UL: 1 Mbps in maximum

Table. 1 Simulation condition

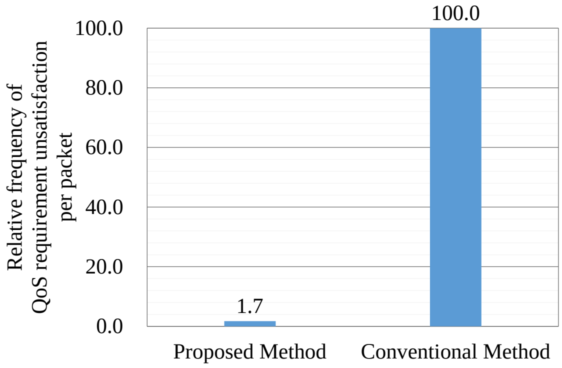

Figure. 5 QoS unsatisfaction improvement

Note: this section is based on results obtained from "Research and Development Project of the Enhanced Infrastructures for Post-5G Information and Communication Systems [13]" (JPNP20017), commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Field Trials and Deployments

Emergency reaction platform

OneNET Platform is a software platform developed by 3rd-party [14], which can provide access capabilities for IoT devices access and edge data computing and forwarding. The OneNET platform can be deployed at the base station enabled by O-RAN architecture in containerized method, where the base station can simultaneously support wireless BBU functions, Near-RT RIC functions and vertical application of IoT enabled by OneNET.

For the emergency reaction, the IoT devices, including intelligent smoke detectors, cameras and etc., can access 5G gateway and transmit collected data to base station by uplink transmission link shown in Fig. 6. Received and processed in OneNET platform in BBU, the downlink transmission link will feedback the control signal to the IoT devices for reacting to the emergency situation. For example, when the detector detects toxic gas and its concentration reaches the alarm threshold, the detector uploads data to the OneNET platform, at which time OneNET issues a signaling alarm to control the emergency alarm devices, and notifies the users and the central cloud managers that an alarm has occurred at a specific location.

However, in the current OneNET platform deployment, the Near-RT RIC platform and the OneNET platform are not yet connected through the Y1 interface, limiting some advanced controlling capability.between the two.

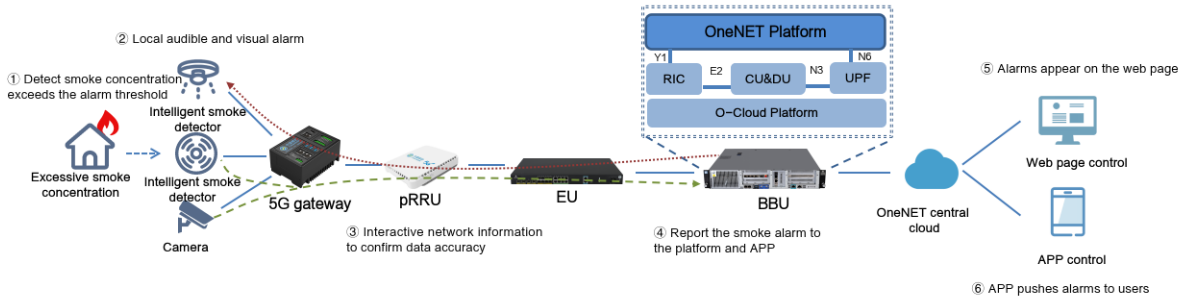

Figure. 6 OneNET Platform Architecture

Security verification

The transformation of radio access via Open RAN revolves around three technological aspects: Open Interfaces, Virtualization, and Intelligence. The "Open RAN Security Report [15]" shows that the use of Open RAN does not fundamentally change the security risks for telecoms compared to traditional RAN, which enables applying O-RAN solutions to mission-critical use cases including industry. The report suggests that adhering to standard specifications can mitigate security risks. Open Fronthaul was chosen as a representative interface for testing due to its maturity, implementation, and coverage of typical connection types and security controls.

Key findings of the report include Open RAN slightly increases the network's vulnerability; Cloud-based infrastructure risks affect both traditional and Open RAN deployments; Concerns about the use of AI, machine learning, and open-source software are neither exclusive to Open RAN nor insurmountable.

Open RAN offers various security benefits including allowing operators to verify security controls, improved efficiency in addressing security issues in cloud environments, and the possibility of automating manual tasks. However, it also presents new security dynamics that require operators to manage, including potential complexity due to more vendors and the responsibility of ensuring a reliable and trusted supply chain.

Finally, the report presents mitigation measures for those deploying or considering Open RAN, emphasizing the need for supplementary controls, adherence to industry standards and best practices, and regular security checks on equipment.

Smart manufacturing

In a factory digitalization upgrade case, the manufacturing factory has 17 production processes on its production line, including different types of equipment such as production equipment, video surveillance, energy consumption measurement devices such as electricity and gas meters, and sensors, which require wireless communication. The factory customer has a manufacturing operations management system, but due to the low digital level on the production line, it is unable to effectively monitor and analyze the production capacity of the production line.

Upgrading the on-site cloud network infrastructure is necessary for data collection of all production factors. The use of wired networks cause problems such as high transformation difficulty, high cost, and complex operation and maintenance. In the process of system upgrading, the customer requires that the production capacity should not be affected, and the transformation should be carried out without stopping the production line.

Through the internal network slice component, O-RAN Vertical Base Station achieves multi-purpose use while ensuring the collection of video data, sensor data, and industrial control information transmission. Different permissions and quality assurance are set for different usages to ensure that all communication needs are met.

Cloud RAN deployment in the industry

In another field trial, a cloud base station integrating computing, networking, and applications is deployed in a factory to verify its capabilities to support intelligent applications. This base station was based on the cloud native platform. The 5G BBU, UPF, and MEC functions were deployed as containers on the same server using COTS hardware. The network was deployed in "one active and multiple standby" mode. The active and standby BBUs were deployed in different rooms, and the RRUs were deployed in dual redundancy mode to ensure that production is not interrupted in case of single point of failures.

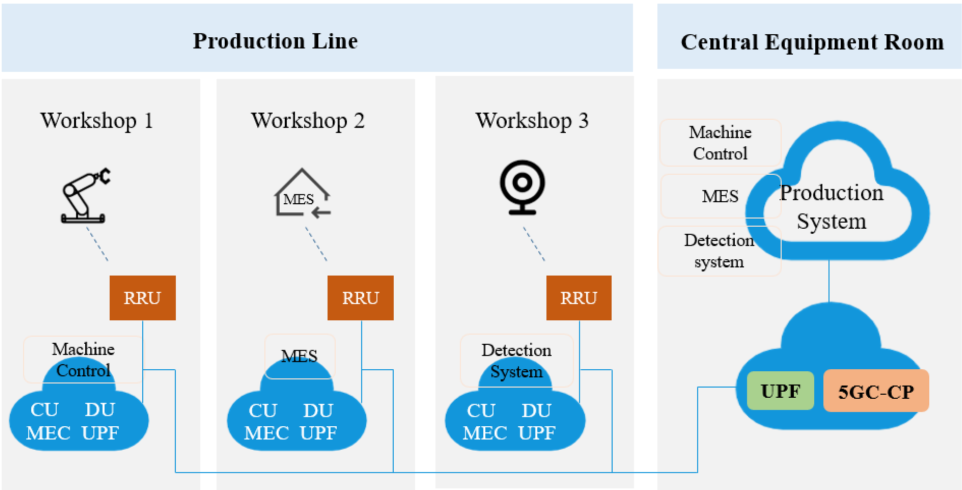

Figure. 7 Deployment Architecture for Industry-Oriented Application Demonstration

1) Manufacturing Execution System (MES)

MES is an information management system for manufacturing. The latency of base station was only 8 ms, lower than the upper threshold (10 ms) for MES transmission.

2) Machine Control

The automatic system installation for a production line requires downlink data rate of over 1 Gbps. This vertical network provided ten 5G 4T4R cells, and the average rate was increased by 1.39 times compared with that of wired network, greatly speeding up the installation procedure and effectively reducing the equipment delivery duration.

3) 5G Intelligent Detection Control

By deploying 5G+AR and machine vision detection applications on MEC Platform (MEP), the system offloaded video data to the local device through the 5G network, reducing the transmission latency. Through intelligent data processing and analysis at the local device, the data about faulty products or components could also be rapidly fed back to the back-end and the production line, so as to control the progress of the production line, improve production detection efficiency and product quality.

AGV connection optimization with Non-RT RIC and Near-RT RIC

In 2022, a cross-vendor integration field trial of RIC platform, 3rd-party apps, and base station was taken. The Near-RT RIC Platform is built on the latest version of ONF RIC; Connection Management (CM) xApp is installed on the Smart Edge Open platform; and the base stations and core network are provided by one vendor.

The CM xApp aims to optimize connection management with AI/ML, it is designed to support customization based on optimization policies to meet various user requirements, such as RAN load balancing, network throughput optimization, higher UE performance at the cell edge, and selection of handover target cells based on UE QoS. The CM xApp formulates connection management as a combinatorial graph optimization problem. It provides a AI/ML solution that uses the underlying graph to learn the graph neural networks for optimal user-cell association.

The equipments and networking deployment for the field trial is shwon in Figure. 8, where the CM xApp, Near-RT RIC Platform, E2 node, and 5G core network are all containerized. The E2 node and the Near-RT RIC Platform are connected via the E2 interface, which complies with the E2AP v2.00 standard. The O-CU and O-DU are integrated on the E2 node, and the three RRUs serve three cells.

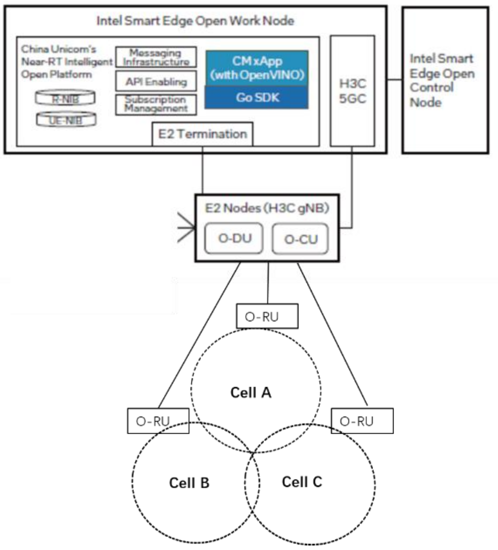

Figure. 8 Field Test deployment

The field trial shows that the Near-RT RIC played an important role with the handover optimization. With the deployment shown in Figure. 8, we obtained the following results:

Optimization Policy	Performance Gain of CM xApp Algorithm over Conventional Max. RSRP Algorithm
Network Throughput	5.7%
Load Balancing	23%
Cell Edge Coverage	231 %

Table. 2 Performance Gain of AGV connection optimization with Near-RT RIC

These results show that with the Near-RT RIC platform and specific xApp, connectivity performance can be optimized to ensure a better business experience.

Potential Enhancement Features

To face the challenges posed by future vertical scenarios, several potential enhancement features are identified to solve various problems. [Disclaimer: potential enhancement features discussed below only demonstrate future trends and valuable options of interest to various vertical industry scenarios, not necessarily reflecting current work in O-RAN ALLIANCE]

Network Digital Twin

The Network Digital Twin creates a realistic digital replica of the physical network using advanced data-driven modeling and simulation technologies. This enables advanced network planning, optimization, automation, and diagnostic solutions at industry sites to efficiently meet each individual vertical service requirement.

It allows for network deployment planning (considering coverage, interference, and load) in a realistic virtual environment. The planning process can be automated, and the network planning results can be optimized and validated with advanced AI/ML solutions and digital twin technology.

The technology can also optimize network performance at a finer granularity by creating a virtual replica of the vertical industry network site (including network elements and the site-specific operating environment) and testing various aspects, such as network topology, configurations, potential changes, and impacts. Energy efficiency can be improved through predicting energy consumption for optimization changes at industry cell sites and site cloud infrastructure, using energy consumption models in the digital twin.

"What-if" analysis using the digital twin as a virtual sandbox helps identify network misconfigurations, link bottlenecks, and security issues for predictive analytics of future network performance. The digital twin also helps assure SLA by monitoring network behaviors and services and suggesting actions in case of sub-optimal performance. It supports closed-loop remediation of network issues by injecting deliberate faults into the digital twin network and generating a rich dataset for ML or other data analytics processes for fault prediction.

It can even generate a large amount of synthetic data for training and evolving the AI/ML models for network planning, network performance, and energy efficiency optimization, network diagnostic, and analytics, without being limited to the data available from the physical network. The digital twin can validate AI/ML control actions and assess performance impact in real-time without affecting the performance of the physical network for AI/ML safety assurance.

Finally, the technology enables intent-driven autonomous network management to improve the network and service provisioning process for a diverse set of user and service provider requirements from the vertical industries, using high levels of intelligence which employ the digital twin to self-evolve and assess provisioning actions.

Communication and Computing Integrated Network

O-RAN architecture adopts the cloud native concept, and RAN functions such as O-CU, O-DU, Non-RT RIC and Near-RT RIC all can be built on the O-Cloud, enabling RAN evolution to a cost-effective radio edge computing platform providing both communication and computing services. It can significantly benefit the vertical industry digital transformation for intelligent manufacturing and better customer service, since the computation consumption task could be realized in a distributed or collaborative fashion with low latency.

CCIN can enhance the computing capability of industry applications at the infrastructure level based on the existing O-RAN architecture, enabling O-Cloud to support diverse computing features, and building a platform that integrates communication and computation. At the network function level, it can further optimize the resource usage of containerized network functions and enhance the nearby forwarding ability of industry data, allowing RAN to have the customized ability to flexibly deploy network functions on demand and forward data nearby to meet industry-specific requirements. The management and orchestration service layer integrates RAN communication and computing services to provide integrated RAN communication and computing services beyond connection for vertical industries.

At the infrastructure level, O-Cloud currently considers using general-purpose CPUs and hardware accelerators to complete RAN protocol stack communication computations. To deploy diverse industry applications in O-Cloud, support for diverse computing features (such as logical computing, parallel computing, etc.) should also be considered. According to business planning, heterogeneous computing resources, such as GPUs/NPUs/TPUs, can be integrated into O-Cloud as needed to support critical applications in the industry, such as AI training/inference, image recognition, and rendering.

At the network function level, the O-CU and O-DU, designed according to the full capacity occupancy of computing resources in the cell, can be further optimized. RAN functions can support dynamic in/out scaling based on the number of users and data traffic dynamics, improving the usage efficiency of computing resources. Considering the data security requirements of the vertical industry, the network function layer enhances local routing capabilities, such as using local UPF or local breakout, to forward application data between O-Cloud nodes with low latency, satisfying the data transmission strategy of industry applications.

At the management and orchestration service layer, SMO can further integrate communication resource management and computing resource orchestration. It can provide external customers with communication, computing, and integrated communication and computing services, and receive business application deployment requirements. Internally, it can match communication resources with computing resources according to business application demands, complete business application deployment, and generate localized SLA assurance policies based on Non-RT RIC and Near-RT RIC.

CCIN empowers O-Cloud computing with RAN communication and enhances communication service performance with O-Cloud. Its shareable computing resources can support diverse business applications in vertical industries. This provides a computing capability platform suitable for sustainable business development in vertical industries, reducing the increased costs brought about by the construction and procurement of computing infrastructure.

Time-Sensitive Networking

In the modern industrial era, various types of industrial equipment and applications are emerging constantly. Due to the inherent requirements of smart factories, the demand for precise control of industrial equipment has reached the nanosecond level. The integration of 5G into Time-Sensitive Networking (TSN) has enhanced both the CN and radio access network(RAN) in 5G, including introducing new components - time converters (DS-TT, NW-TT) in the edge of 5G, defining new QoS attributes for TSN service, enhancing time synchronization inside RAN, and RAN scheduling enhancement.

In the industrial RAN, a variety of services coexist within the network. How to achieve the requirements of different TSN services simultaneously is a significant challenge for 5G. In O-RAN, intelligent components such as Non-RT RIC and Near-RT RIC work closely with the O-CU/O-DU inside RAN, which monitor fluctuations in the wireless network environment in near real-time and utilize intelligent algorithms to predict the behavior of TSN services. They dynamically configure RAN parameters such as semi-static scheduling, QoS related parameters, and PDCP duplication. Moreover, monitoring the delay of RAN or even End-to-End delay in 5G network is also crucial. How to obtain the delay information and ensure deterministic transmission of TSN packets is worth studying. The current discussion in O-RAN WG3 on opening the Y1 interface for interaction with application servers can also be further expanded to communication with TSN-related nodes.

On the 5G CN side, TSN has introduced several new nodes such as TSNTSF, TSN AF, NWDAF, etc. These nodes connect with external TSN nodes to form a TSN system. Both the Near-RT RIC node in the RAN and the NWDAF in the CN have intelligent functions. How to coordinate the intelligent usage of the RAN and the CN, as well as the deterministic network outside the 5G network, to better serve TSN services, is an important topic for future O-RAN vertical industry research.

Service Awareness

In O-RAN, service awareness denotes the network's capability to intelligently recognize, comprehend, and optimize its operation using the external information supplied by Application Servers outside the RAN. This awareness facilitates real-time network adjustments and resource prioritization, ensuring optimal user experiences while promoting efficient resource utilization.

Vertical industries, particularly the manufacturing sector, hinge significantly on deterministic and low-delay communication between devices at each production stage. Given the constrained budgets for enterprise digital transformation, vertical customers are sensitive to costs, emphasizing the importance of spectrum efficiency. To cater to these requirements, cooperation between the Base Station and the Application Server is crucial. For instance, by providing data traffic characteristics for MES analysis, the Near-RT RIC could generate resource allocation strategies (such as pre-scheduling) for optimal spectrum use. The external information could include network-related data like UE-level network service targets, anticipated transmission characteristics, service performance measurements, and so on. Alternatively, it could encompass non-network related data crucial for network optimization, such as UE location information.

However, the current O-RAN architecture does not fully accommodate this type of service provision sensing. Although the SMO external interface and SMO external system have been proposed, the detailed specifications still need to be elaborated. The Y1 interface transmits RAN analytic information to external receivers. Enhancing Y1 to receive analytic information from external data sources is a viable option, but security considerations must be carefully addressed.

Service awareness carries several benefits. Firstly, it could leverage the O-cloud's computing capability to provide more services. Secondly, by accessing more external information related to service data, the optimization algorithms in Near-RT RICs could be refined for improved strategies and policies. Thirdly, service awareness provides vertical customers with more customization options, enabling the creation of more solution-centric networks.

Common SMO and Intelligent Controller

Network management and orchestration need to be optimized across all network domains at a granular level dedicated to each vertical industry's requirements. The O-RAN architecture allows third-party, operator, or vertically made frameworks and applications (e.g., SMO, Near-RT RIC, Non-RT RIC, xApps, and rApps) to manage and optimize the network via standardized interfaces. This capability is crucial to meet the highly diversified and rapidly changing service requirements from the vertical industries. These capabilities are further enhanced with advanced AI/ML technologies enabled by O-RAN standardization. There is a need for a common SMO, which includes management functions for core, transport, and RAN nodes, to enable full automation and cross-layer optimization leveraging the principles of openness, intelligence, virtualization, and interoperability in O-RAN.

Localized CN C/U Plane

In order to fulfill more complex industry scenarios, the network architecture and functionalities are becoming flatterd, with more network functions deployed down to the gNB to reduce latency and increase flexibility. Thanks to the separation of the Control Plane (CP) and User Plane (UP), UP can be deployed on demand, even closer to the edge. The end-to-end latency of 5G industry applications generally reaches below 15ms, which basically meets industrial needs.

On the other hand, edge computing use cases such as traffic offloading still rely on direct control from the Core Network (CN). This asymmetrical localized deployment of CP and UP in specific industries and local IT/CT collaborations can limit the flexibility in configuring networks and hinder efficient application collaborations. In the future, Localized CN may continue to evolve in terms of localized CP and enhanced on-route control of UP.

Regarding localized CP, currently, Local Network Exposure Function (NEF) & User Plane Function (UPF), in collaboration with Edge Application Server Discovery Function (EASDF) in the CN, can already achieve localized traffic offloading, as well as more industry-specific expansion functions based on Local NEF. In terms of enhancing on-route control of UP, to address the challenges posed by the development of Communication and Computing Integrated Network (CCIN) and drawing inspiration from the successful experience of SRV6, in the future, the gNB may have partial Session Management Function (SMF) data routing decision-making capabilities and data on-route control, providing ultra-Real Time integrated services.

Lite O-RU

Each vertical industry requires unique characteristics for its radio access solutions. It calls for diversified customization to cater to the needs of different industry private networks. Moreover, budget control becomes critical considering the limited funds available for information technology transformations in some instances. The ability for agile deployment and ease of use are also key factors, given the pressing requirement for fast delivery.

Lite O-RU displays competitive advantages in several areas. When contrasted with O-RU supporting Split Option7-2x as already specified in O-RAN, Lite O-RU offers a simpler and more cost-effective solution. This is because it demands fewer hardware resources, particularly in situations where multiple O-RUs are connected to one O-DU for an indoor Pico cell scenario. The mature and widely used standardized CPRI with Split Option8 assists operators in connecting with industry customers and exploring the 5G private network. The centralized Low-PHY function in the Lite O-RU solution consumes less power compared to implementing the Low-PHY function in each O-RU.

Lite O-RU presents a feasible solution for many vertical industries. Small antenna number cells are still the common configuration preference of industry customers, and bandwidth concerns related to massive antennas do not pose a problem here. Lite O-RU, when connected with a common rate CPRI link, can support most typical cell configurations, such as cells with 2T2R or 4T4R.

Lite O-RU already has a strong foundation in O-RAN. The open Option8 CPRI spec reference design has already been specified in the Indoor Picocell hardware reference design spec, which includes the CUS-Plane and Management Plane. FHWG7-2->8, supporting hybrid front haul networking between Split Option7-2x and Split Option8, is also defined in the Indoor Picocell with Split Option7-2 spec. These specs can serve as a starting point or reference for Lite O-RU in certain vertical industries.

Conclusion

Key Findings and Insights

The white paper reveals a series of pivotal insights and findings about the role and potential of O-RAN technology in transforming vertical industries. A key revelation is the fundamental impact of O-RAN's interoperability and openness, which fosters a diverse, competitive market and paves the way for innovative, efficient solutions. The flexibility of O-RAN in customization emerges as a significant advantage, allowing industries to tailor network functionalities to specific needs, especially where ultra-low latency, high reliability, and enhanced security are paramount. In terms of network efficiency, O-RAN introduces marked improvements in scalability and capacity through its cloud-native and virtualization principles, leading to more efficient network operations and reduced expenditures. The emphasis on enhanced security within the O-RAN architecture is critical, particularly for industries handling sensitive data, as it contributes to a more robust security framework. Another recurrent theme is energy efficiency, with O-RAN offering sustainable solutions that may significantly lower energy consumption in network operations. The white paper also highlights various innovative O-RAN solutions and best practices, including network slicing, edge computing, and AI-driven optimization, demonstrated through successful field trials and deployments.

The Future of O-RAN in Vertical Industries

Looking ahead, the O-RAN architecture is expected to continue its evolution, further enhancing its ability to meet the specific demands of diverse industries. The open and modular nature of O-RAN, coupled with the continuous innovation in AI and machine learning technologies, is likely to lead to even more advanced and efficient network management and optimization solutions. These advancements will enable O-RAN to address the growing requirements for ultra-reliable, low-latency communications, which are crucial in sectors like autonomous transportation, advanced manufacturing, and smart energy grids.

The commitment to energy efficiency and sustainability will remain a central focus. As industries worldwide grapple with the challenges of environmental sustainability, O-RAN's energy-efficient solutions are anticipated to play a pivotal role in reducing the carbon footprint of network operations. This aspect will not only contribute to the global efforts towards environmental conservation but also offer substantial operational cost savings to businesses.

Furthermore, the ongoing expansion and standardization efforts within the O-RAN Alliance are expected to foster a more inclusive and competitive ecosystem. This will encourage the entry of new vendors and innovators, further driving down costs and spurring the creation of tailored solutions for specific industry needs.

The integration of O-RAN with emerging technologies such as edge computing and the Internet of Things (IoT) will open up new horizons for industry applications. This convergence is poised to enable a new wave of smart applications and services, from intelligent transportation systems to automated emergency response mechanisms.

In conclusion, the future of O-RAN in vertical industries is marked by a trajectory of continuous innovation and adaptation. Its role in enabling smarter, more efficient, and sustainable network infrastructures will be instrumental in shaping the next generation of industry operations, setting the stage for an era of unprecedented digital transformation.

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