O-RAN next Generation Research Group (nGRG)

Contributed Research Report

Use Case and Gap Analysis for Radio Quality Assurance

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Contributors:

KDDI

LGU+

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Authors

Akio Ikami; KDDI (Editor)

Amr Amrallah; KDDI

Hyosun Yang; LGU+

Reviewers

Jan Plachy; Deutsche Telekom

Sapna Sangal; Mavenir

Vikas Dixit; Reliance Jio

Hiroshi Miyata; Sumitomo

Daiju C A; Nokia

Bernard Guarino; O-RAN Alliance

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Executive summary

With the integration of advanced IoT and network-enabled robotics into daily life, ensuring stable quality of service (QoS)across the entire service area is paramount for the upcoming 6G. A primary challenge in providing stable QoS in end-to-end (E2E) communications is the variation in radio communication channel quality, particularly the Signal-to-Interference-plus-Noise (SINR). This research report addressed the challenge of maintaining stable radio communication quality. It outlines the motivation for radio quality assurance, analyzes anticipated 6G use cases, and discusses gaps, challenges, and promising technical approaches for the development of O-RAN. Key findings underscore the necessity of a user-centric RAN approach to achieve cost-effective and stable radio quality. This highlights the importance of a RAN adaptability to SINR variations caused by changes in user location. Additionally, the report identifies significant technological gaps, particularly in supporting advanced applications in robotics, mission-critical operations, and Unmanned Aerial Vehicles/Urban Air Mobility (UAV/UAM).

This structure of this report can be summarized as follows:

Chapter 1 provides a brief introduction to the report.

Chapter 2 describes the motivation to assure more stable radio quality over the service area in the 6G era. It highlights the challenges posed by SINR variability and the need for the RAN that can adapt to changes in user's location to provide stable quality of service. It also illustrates the need for a user-centric approach to cost-effectively assure stable radio quality across the entire service area.

Chapter 3 provides a detailed analysis of use cases related to radio quality assurance, with a focus on robotics, mission-critical applications, and UAV/UAM. These cases describe potential requirements and gaps in current technology, emphasizing the need to provide stable radio quality to support advanced tasks as a common factor.

Chapter 4 addresses the gaps in O-RAN to ensure stable radio quality for each user and lists potential solutions for the 6G era. It describes advanced air interface management by RICs such as Multi-TRP/D-MIMO and RIS, as well as the challenges of managing RAN functions in a distributed and hierarchical cloud environment.

Finally, the report is concluded in Chapter 5.

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List of abbreviations

3GPP	3rd Generation Partnership Project
AI/ML	Artificial Intelligence / Machine Learning
AP	Access Point
C&C	Command and Control
DU	Distributed Unit
E2E	End-to-End
LOS	Line-Of-Sight
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operators
NF	Network Function
OFDM	Orthogonal Frequency Division Multiplexing
RAN	Radio Access Network
RIC	RAN Intelligent Controller
RIS	Reconfigurable Intelligent Surface
RU	Radio unit
SINR	Signal-to-Interference-plus-Noise Ratio
SLA	Service Level Agreement
SMO	Service Management and Orchestration
SNS	Social Networking Service
UAV	Unmanned Aerial Vehicle
UAM	Urban Air Mobility
VNF	Virtual Network Function
WI	Work Item

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1. Introduction

Envisioning the 2030s, the 6th Generation mobile communication systems (6G) is expected to closely integrate advanced Internet of Things (IoT) into our daily life, offering network-enabled robotics such as automated delivery robots or autonomous driving vehicles [1]. To enable a wide variety of devices and services*, it is necessary to provide stable communication quality with reliability and higher throughput, that meets the demands, regardless of the user's location. However, the radio communication channel quality, specifically the Signal to Interference plus Noise (SINR) varies significantly within the mobile network service area depending on the user's location and environment, unlike fixed-line communications. The communication channel quality variation is a challenge for assuring stable quality of service over End-to-End (E2E communication. Therefore, this research report considers a radio access network (RAN) that provides the necessary radio communication channel quality in a user-centric manner, considering the varying radio communication channel quality due to impact of environment on the channel propagation and user's device location. In this report, we first explain the necessity and concept of radio communication channel quality assurance in Chapter 2. Then, in Chapter 3, we analyze individual use cases anticipated for 6G related to assuring radio quality. In Chapter 4, from the perspective of O-RAN, we discuss gaps, challenges, and promising technical approaches toward providing stable radio quality independent of location. Finally, the conclusion is given in Chapter 5.

2. Motivation for radio quality assurance

Various consortiums and standardization task groups, such as, NextG [1], NGMN [2], Hexa-X [3], and B5GC [4], have presented potential use cases toward 6G, which are expected to be commercialized around 2030. Among the different use cases envisioned, robotics has been identified as a common theme. For instance, mission-critical applications with remote operations, tasks where robots and cobots can replace human labor, and applications that can utilize the Urban Air Mobility. In these 6G use cases, robots are utilized to perform critical missions which may jeopardizing the safety of human labors. This necessitates robust and continuous monitoring and control of robots via 6G, regardless of their location.

In the pursuit of stable quality of service, efforts are being made to explore network slicing and service level agreement (SLA) assurance in the 5th Generation mobile communication system (5G). In fixed networks, stable throughput is achieved by assigning bandwidth to services and users. Similarly in mobile networks, prioritizing certain users or services for radio resource allocation can enhance throughput of the prioritized users. However, due to inherent variations in radio communication channel quality caused by user's location and surrounding environment, the throughput that can be provided with the same wireless resources varies by user location. Radio fluctuation due to the far user's location from the serving base station is considered the main cause of the long-term fading. This is known as the cell-edge problem which is caused by increasing path loss and inter-cell interference when user moves away from the cell center towards cell edge, leading to degradation of radio quality, as shown in Figure 2-1. While the radio quality is typically high around the cell center (base station), it degrades as users move towards the cell edge. However, a similar issue might happen in case of deploying high cell towers. Techniques such as antenna tilting are necessary to mitigate the issues caused by high cell towers and maintain good radio quality. When attempting to assure quality of service for moving users, such as those using unmanned aerial vehicles (UAVs), urban air mobility (UAM) or even robots, it becomes necessary to allocate excessive radio resources to counteract the cell edge effect, making it difficult to effectively utilize limited radio resources. Therefore, the fluctuation in radio quality depending on user's location becomes a significant challenge in assuring stable E2E quality of service. In other words, it is necessary to assure stable radio quality anywhere within the service area to provide a sufficient level of stable quality of service which are essentially for these use cases.

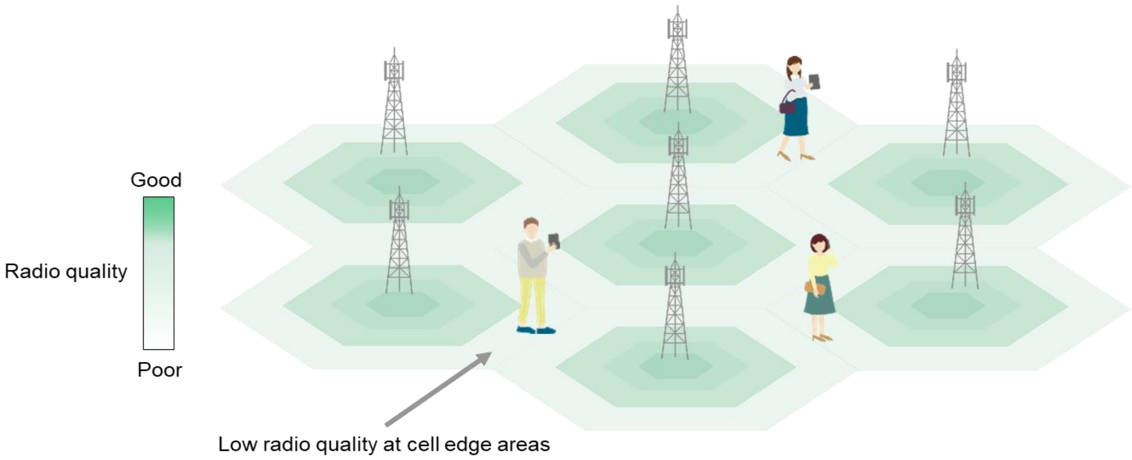

Figure 2-1 Existing radio quality map.

On the other hand, one of the main objectives of O-RAN ALLIANCE is to improve the deployment and operational efficiency of RAN [5]. It is expected that mobile traffic will continue to grow [6], and in the 6G era, it will be necessary for mobile network operators (MNOs) to handle traffic volumes that are multiple times greater than the current levels. However, it is anticipated that 6G will likely continue to use orthogonal frequency division multiplexing (OFDM), as seen in 4G and 5G. While ODFM is expected to be a cornerstone modulation technique, ongoing research into new modulation schemes and potential advancements means that future innovations may also play a significant role.

This issue is also recognized by Next G [7]. To address the burgeoning traffic with limited frequency resources, one suggested approach involves implementing management strategies aimed to maintaining high radio quality in user-centric manner over space and time by potentially coordinating base stations via RAN management. This user-centric approach has been introduced as one of the future technology trends in ITU-R M.2516 [8]. This approach is also related to "user-centric cell-free" [9] in contrast to current cell-centric concepts that provide fixed radio maps. The concept of user-centric RAN, which provides stable radio quality that can satisfy user demands, is illustrated in Figure 2-2. We define a RAN system that achieves radio quality assurance through this user-centric approach as user-centric RAN. User-centric RAN aims to assure appropriate radio quality for the entire area by coordinating surrounding base stations and concentrating high radio quality areas at user's location. In other words, it is akin to spotlighting each user. Considering the new services and scenarios of the 6G era, RANs need to meet diverse and personalized demands. Providing appropriate radio quality in a user-centric manner, both spatially and temporally, not only ensures cost-effectiveness but also enhances spectral efficiency, optimize resource utilization, and improves overall network reliability and user experience.

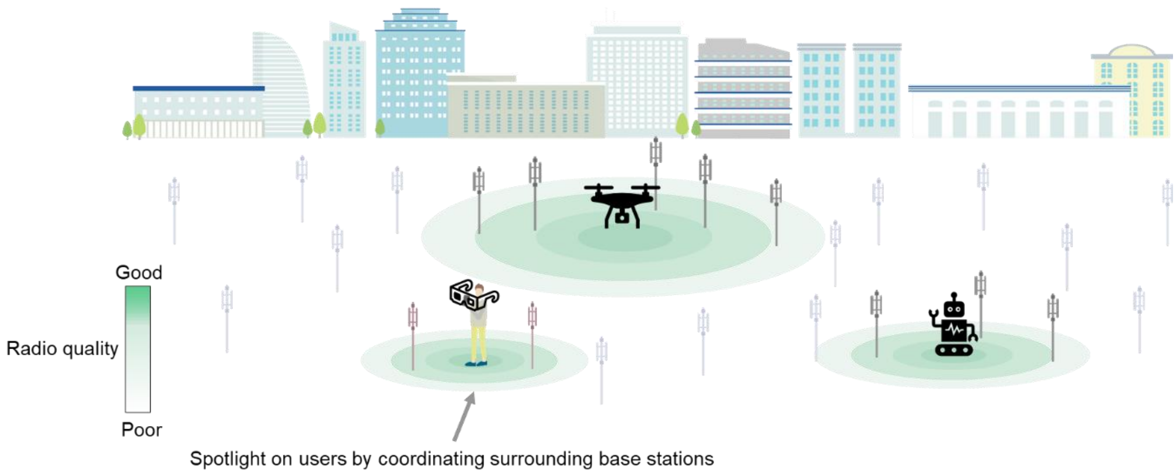

Figure 2-2 The concept of user-centric radio quality assurance.

3. Use case analysis on radio quality assurance

This chapter describes use cases *related* to radio quality assurance. The criteria for selection shall be use cases that require continuous and stable quality of service while on the move, i.e., stable radio quality everywhere. In analyzing the use cases, we surveyed NextG [1], NGMN [2], Hexa-X [3], and B5GC [4] and the 3rd Generation Partnership Project (3GPP) literature [17]. As a result, we listed robots and cobots, mission critical, and UAV/UAM as meeting the criteria of 'stable radio quality everywhere'.

3.1 Robots and cobots

Robotics and cobotics are mentioned as use cases for 6G in initiatives such as Next G [1] and Hexa-X [3], and their application is expected across a wide range of fields, from daily life to various industries. This section will describe use cases in diverse domains.

3.1.1 Description

Home and Swarm Robotics

With the ever-increasing demand for robotics in future applications, starting from simple home applications toward complicated and connected ones for industrial and medical applications, the need for robust wireless connectivity becomes essential for these future applications [8]. Nowadays, we can see some home automation robots everywhere, such as vacuum cleaners or lawnmowers. These small smart devices may take the shape of swarms in the near future to accomplish certain tasks [1]-[4], [8]-[12]. Each robot is equipped with not only video cameras but also many sensors that require real-time signal processing.

Healthcare Robotics

During the last few years, a wide range of healthcare robots have been developed. Moreover, the COVID-19 pandemic accelerated the development of healthcare robotic platforms [13]. Starting from care robot, which is used to provide assistance to patients, to hospital robots which can do different tasks as assisting nurses by performing noncritical tasks, performing some transportation tasks for supplies between different sections, or even do assist in different medical tests and examinations specially during pandemic time as they are not vulnerable to viruses or other microorganisms [14].

Industrial Robotics

On the other hand, the vast development of wireless connectivity has significantly increased appeal of industrial robots. These machines can operate 24/7 and perform risky tasks that might jeopardize human safety, such as dealing with objects of extremely high temperatures or interacting within dynamic environments that demand constant focus and concentration from human workers [4].

Surveillance Robotics

The integration of wireless connectivity in robots has become increasingly influential in security applications as well. These autonomous or semi-autonomous machines, equipped with cameras, sensors, and wireless communication capabilities, can patrol designated areas and provide real-time video feeds to a remote-control center, enabling constant surveillance without the need for human guards on site at all times [2]. They can also be utilized in dangerous scenarios such as bomb detection and disposal, where they can investigate and neutralize threats from a safe distance. Enhanced by artificial intelligence and machine learning, these robots can recognize faces, detect unusual behavior, navigate independently in complex environments, and identify specific objects or substances [22].

Supportive Robotics

Moreover, cleaning and delivery robots, enhanced by wireless connectivity, are becoming instrumental, particularly as a support for aging societies [1]. Cleaning robots can autonomously navigate and perform tasks like vacuuming and sanitizing, reducing the physical burden on seniors. Similarly, delivery robots can transport goods, including groceries or medications, directly to individuals, a service particularly beneficial for those with limited mobility. Both types of robots can be monitored and controlled remotely, providing real-time updates, and assuring their operations align with user’s needs. In this way, the integration of robotics and wireless technology not only automates daily tasks, but also enhances the quality of life and independence for the elderly [4].

Cloud Robotics

The concept of cloud robotics represents a significant leap forward in the field, where robots are no longer limited by their onboard computing power or data storage capacities. By leveraging the cloud, robots can access vast amounts of processing power and storage, as well as a wealth of shared knowledge and algorithms contributed by other machines and developers from around the world [15]. This connectivity allows for more sophisticated analysis, decision-making, and learning capabilities. Robots can now perform complex tasks more efficiently, adapt to new situations, and even collaborate with other robots in real-time to achieve common goals. The integration of cloud computing with robotics opens up new possibilities for scalability, flexibility, and intelligence in robotic systems, paving the way for more advanced applications and services across various industries.

3.1.2 Potential requirements and gaps

1. Seamless connectivity.
2. Stable, reliable, robust, and secure connection to avoid dropouts and to ensure a consistent radio quality without interruptions.
3. Uniform QoS guarantee to be able to transmit high-quality real-time videos at anytime and anywhere.

4. Ultra-low latency and jitter end-to-end communication is mandatory to support real-time control.
5. Advanced wireless security measures should be applied to protect against potential cyber threats.
6. Enhanced wireless system capacity to accommodate the high demands of numerous robots and cobots.

To realize these potential requirements, it is imperative to provide stable wireless quality throughout the service area, which is to say, radio quality assurance is essential. As robots and cobots become increasingly integrated into our daily lives and critical infrastructures, the necessity for uninterrupted and reliable wireless communication becomes paramount. Whether it's a swarm of robots coordinating in a smart home, a healthcare robot navigating a hospital, or an industrial robot operating in a factory, each scenario demands a wireless network that can deliver consistent performance to support the sophisticated tasks at hand. This includes ensuring seamless connectivity for cloud robotics, where the ability to access and process data in real-time hinges on the network's stability. Radio quality stability will enable these diverse robotic systems to operate efficiently and safely, fulfilling the promise of a technologically advanced future where robotics enhances productivity, safety, and quality of life.

3.2 Mission critical

The more stable and reliable radio quality in 6G is expected to enable mission-critical use cases [1], [2]. This section analyzes mission-critical use cases.

3.2.1 Description

Remote Operations in Harsh Environments

Remote operations in harsh environments, which are often mission-critical, involve the control and management of processes or systems from a distance in particularly hazardous or challenging conditions. These conditions can be characterized by extreme temperatures, high air pressure, strong winds, heavy rain, or even atomic radiation. Such operations are common in security related tasks such as boarders control, or industries like oil and gas, electrical power generation, nuclear reactors, and in activities like mining excavations [1]. These remote operations allow for the continuous function and monitoring of critical tasks, reducing risks associated with direct human interaction in these severe environments. With the aid of reliable wireless connectivity, these tasks can be accomplished with a higher level of safety and according to the required performance.

Oil and Gas Industry

Starting with the oil and gas industry, they are among the sectors that frequently confront severe climatic and operational conditions simultaneously. Extraction of oil and gas typically occurs in challenging environments, whether it be the sweltering desert. Take, for instance, the operations in the North Sea at the northernmost part of Europe, where powerful winds and sub-zero temperatures persist nearly year-round. On the other hand, extraction also takes place in the scorching deserts of Middle Eastern countries, which hold some of the highest temperature records globally [1].

Power Grid Management

Remote operations are increasingly important for electrical power grids. Modern power systems require swift responses to outages, making advanced sensors and smart meters vital for real-time data on power generation, transmission, and consumption. Operators can remotely monitor the grid's status and control various components, enhancing stability and preventing blackouts. However, robust wireless connectivity is needed to support the vast array of sensors and controllers for smoother remote operations [1].

Offshore Wind Turbine Monitoring

Wireless connectivity is especially important for offshore wind turbines. Due to harsh environmental conditions, remote operations using advanced sensor technology are utilized to collect real-time data on wind speed, turbine performance, and weather conditions. This data is sent to a remote-control center for analysis, allowing operators to monitor the turbines' status and quickly detect any issues. Remote operations also involve controlling various aspects of the turbines' functionality from a distance, optimizing energy production. Automated functions reduce the need for human intervention. In case of emergencies, remote operation centers can quickly coordinate necessary responses, assuring safety and minimizing downtime [1]-[4].

Nuclear Plant Decommissioning Safety

When it comes to the decommissioning of nuclear power plants, wireless technology plays an equally important role. Decommissioning is a complex, lengthy, and hazardous process that involves tasks such as decontamination, dismantling, and waste management. Wireless networks can facilitate remote monitoring and control of these tasks, improving safety by minimizing personnel exposure to radioactive materials. For instance, robots equipped with cameras and sensors, controlled over wireless networks, can perform dangerous tasks such as cutting and removing radioactive components. In addition, real-time data transmitted wirelessly can aid in tracking and managing radioactive waste. Thus, wireless technology contributes significantly to the safe and efficient decommissioning of nuclear power plants [1].

Mining Excavations

Apart from the need for a robust wireless connectivity for the industrial applications, mining excavations are activities that often take place in harsh and challenging environments, making the use of robust wireless connectivity crucial for efficient and safe operations. In mining excavations, wireless networks play a critical role in monitoring and controlling operations, allowing for the remote operation of drilling rigs and excavation equipment, reducing risks to human operators. Sensors throughout the mine transmit real-time data on various parameters, improving safety and efficiency. Wireless technology facilitates communication among mine workers, particularly in underground mines. Thus, robust wireless connectivity is paramount for mining excavations [1].

Robotics in Search and Rescue Missions

In addition to the various applications for robots aided with wireless technology for industry, they can also be used for search and rescue operations in hazardous conditions, reducing the risk to human rescue workers. These robots can be remotely operated or even autonomous, allowing them to operate in areas that might be too dangerous for humans to enter. The deployment of robots during disasters can significantly improve the effectiveness and safety of rescue operations, making it a promising technology for emergency responders [1].

3.2.2 Potential requirements and gaps

1. Robust and resilient wireless connectivity to be able to withstand harsh operating conditions including underwater and underground operations.
2. Long range connectivity to support long distance operations.
3. Stable, reliable, robust, and secure connection for monitoring and controlling to ensure accuracy and safety.
4. Scalable network connectivity to handle a large number of connected devices.
5. Wireless network should support high mobility for fast interaction in various situations.
6. Ultra-low latency end-to-end communication is mandatory to support real-time control.
7. Advanced wireless security measures should be applied to protect against potential cyber threats. Security is out of scope for radio quality.

To fulfill these potential requirements, it is crucial to ensure stable radio quality across the entire service area, in other words, radio quality assurance is necessary. In the context of remote operations in harsh environments, where mission-critical tasks are managed from a distance, the reliability of connectivity is non-negotiable. Industries such as oil and gas, power generation, and mining rely on robust wireless networks to conduct operations safely and efficiently, often in extreme conditions that are not suitable for human presence. The ability to maintain high data precision, support long-range and scalable connectivity, and provide ultra-low latency communication is dependent on the assurance of consistent radio quality. Furthermore, as we integrate more autonomous robots into search and rescue missions and other high-risk activities, the demand for secure and resilient wireless networks becomes even more pronounced. Therefore, implementing comprehensive radio quality assurance measures is fundamental to the success of these industries and the safety of the personnel involved.

3.3 UAV/UAM

UAVs and UAMs represent the frontier of aeronautical innovation, with a wide range of promising use cases. This section explores the use cases for UAV/UAM that could be realized by assuring more stable radio quality.

3.3.1 Description

Interest started with drones has evolved into UAV/UAM services using cellular networks. Correspondingly, Long Term Evolution (LTE)/5G UAV feature had been specified in 3GPP [16] [17], and commercialization of UAM services is also being propelled by the Korean government. Looking ahead to 6G, it is expected that new use cases and applications for UAV/UAM would emerge, leading to rapid market growth in industries associated with aerial mobility [19][20].

In 6G, it is expected to support anytime, anywhere connectivity. The network coverage will expand to include the sky, sea, islands, and so on. One example of the sky is UAV/UAM, and mobile communication service could be provided by using the terrestrial network.

UAV/UAM is emerging as a new means of transportation that can transport cargo or people in the sky. It requires command and control (C&C) communication with real time and high reliability for safe flight, and uninterrupted broadband service would be beneficial for data transmission and infotainment services.

C&C function for safe flight

For safe flight, UAV/UAM should be controlled in real-time by using C&C signal. The C&C signal is responsible for the management and control of the aircraft, and it includes flight authorization, navigation database management, waypoint updates and more. Therefore, it requires real time, high reliability, rigid authorization.

Data transmission and Infotainment Services

UAV/UAM should be able to collect and transmit information necessary for flight such as video, images, and sensor data. In addition, infotainment services can be provided to flight passenger in UAM. Just as on ground, passengers would like to watch videos, send messages, and use social networking service (SNS) in the air. Hence, it requires high throughput with advanced mobility features to ensure seamless service in the air where the channel characteristic is more unstable and complex than on the ground.

3.3.2 Potential requirements and gaps

1. High data rate for both of the uplink and downlink to support data-consuming transmission such as infotainment data, navigation data, video data, and so on.
2. Scalable network connectivity to handle a large number of connected devices.
3. Wireless network (e.g., cell-free architecture) should support seamless connectivity even in high-speed mobility.
4. 3D network coverage to provide robust connectivity at various altitudes.
5. Ultra-low latency end-to-end communication is mandatory to support real-time control.
6. Advanced wireless security measures should be applied to protect against potential cyber threats.
7. High reliability is required for C&C communication.

To fulfil these requirements, it is essential to assure radio quality while on the move. However, providing services to UAV/UAM using cellular network has the following limitations.

- ✓ Aerial Channel has a higher line-of-sight (LOS) probability than ground.

An aerial device would see radio signal from more cells than a ground device. This causes the aerial device to experience stronger interference from more neighbor cells (i.e., poor SINR).

- ✓ UAV/UAM requires advanced mobility to support mobility with high velocity.

UAV/UAM would experience frequent handover and continuous channel quality degradation due to their mobility with high velocity.

- ✓ Existing cellular networks are optimized only for ground user not for aerial device.

Existing cellular networks are optimized for ground user by down-tilted antennas. In this case, as shown in Figure 3-1, the aerial device is likely to be served by sidelobes of the antenna. Due to the presence of possible nulls in the sidelobes, the aerial device may see a stronger signal from a distant base station. Hence, the aerial device may suffer from unstable radio condition [16]. User-centric RAN can be one of the solutions to solve the interference issue. It can be expected to ensure radio quality by flexibly configuring cells based on the user's location and mobility.

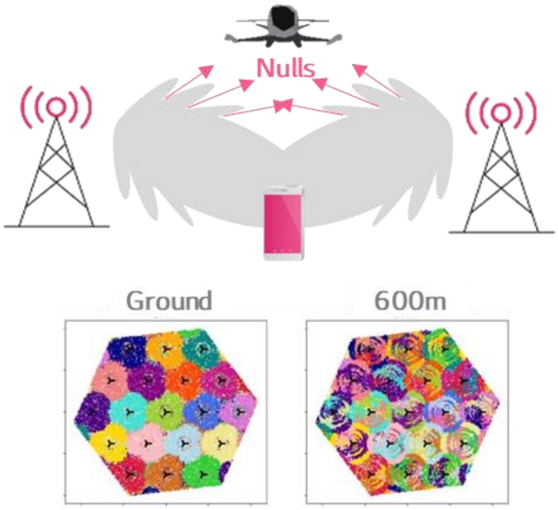

Figure 3-1 Comparison of the cell coverage.

4. Gap analysis for O-RAN

In this section, we describe the gap in O-RAN for assuring stable radio quality for each user, to increase agility to individual user demands, and list the potential solutions in 6G era. In the current O-RAN, Massive MIMO optimization is being discussed as one of the MVP-C features to control the current air interface with RIC. To aim for higher and more stable radio quality, the 3GPP plans to advance studies on the air interface, especially enhancing MIMO technologies. Hexa-X and the Next G have presented advanced air interface technologies to provide more stable radio quality, emphasizing the necessity of coordinated multi access points (APs), specifically multi-transmission reception points (Multi-TRP)/Distributed MIMO (D-MIMO) [17], [18]. From the perspective of O-RAN architecture, it is necessary to study the management of these advanced air interfaces by the RAN Intelligent Controller (RIC) to assure radio quality for each user.

In the 6G era, RAN is expected to become cloud-native, and all NFs will be deployed in the O-Cloud as defined in O-RAN. As the use case scenarios described in the previous section, it is anticipated that not only humans but also various devices, such as robots and UAVs, will communicate, leading to an increase in the spatial and temporal dynamics of RAN resource consumption. Therefore, the efficient use of resources on the virtual infrastructure is expected to be achieved by being more agile in responding to changes in demand. Furthermore, advancements in the air interface by the 3GPP, particularly with the increase in MIMO multiplexes, as well as multi-TRP and D-MIMO, are expected to escalate the computation load for radio signal processing in DU. In response to these evolving dynamics and heightened computation demands,, Hexa-X and Next G have outlined the optimization of virtualized RAN through flexible network functions (NF) management, using wide area and distributed cloud platforms [17], [18]. This on-demand deployment in a fully distributed/decentralized architecture is also described in the ITU-M 2516 [8]. In addition, Hexa-X and Next G have described the dynamic NF placement as a common technological solution to realize this flexible and on-demand virtualized RAN. From the perspective of O-RAN, it is necessary to study the cloud architecture and management required for flexible and on-demand NF management on O-Cloud.

To satisfy assuring radio quality per user in the context of O-RAN, RIC needs to manage the advanced air interface and RAN functions on O-Cloud. Figure 4-1 shows the management for providing stable and continuous radio quality per user by RIC. Since the radio environment for each user changes depending on the user's location and mobility, it is necessary to consider RIC management of coordination of air interface to provide stable radio quality corresponding to these changes. In addition, to address an increase in the spatial and temporal dynamics of RAN resource consumption caused by stable radio quality, we need to consider how RIC manages RAN functions and resources according to user mobility and used services. Furthermore, radio quality assurance is expected to be a widely interlinked control, so architecture and AI infusion need to be studied as well to reduce the overall system complexity. The following section will provide details of the advanced air interface management by RIC and the on-demand RAN functions management on O-Cloud.

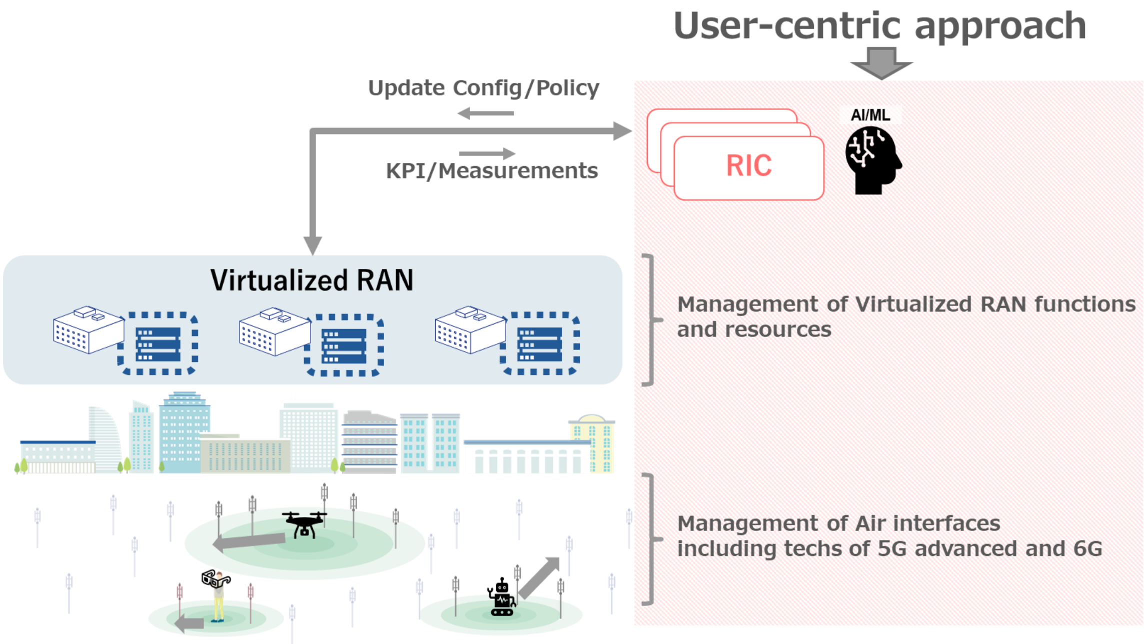

Figure 4-1 RAN management for radio quality assurance.

4.1 Advanced air interface management

This multipoint approach, which we will refer to as Multi-TRP/D-MIMO, leverages the collective signal power of multiple transmission and reception points and spatially distributed APs. Using multiple and distributed APs provides stable radio quality for users even when obstacles, such as buildings or natural terrain, can cause signal shadowing. In addition, coordinated signal processing of distributed APs using MU-MIMO technology reduces interference and improves utilization of the same frequency resources. In 3GPP, Multi-TRP has been recognized as a Work Item (WI) in Release 19, with ongoing standardization efforts to integrate this technology.

In the current O-RAN, Massive MIMO optimization is being discussed as one of the MVP-C features to control the current air interface with RIC. Multi-TRP/D-MIMO, as well as the current air interface, is expected to contribute to assuring user radio quality and saving RAN resource consumption by the management of RIC. Figure 4-2 shows an example of Multi-TRP/D-MIMO management by RIC. As shown in Figure 4-2, the combination of the served APs may be changed according to the user's requirement and mobility. Users which require robust and stable communication can be allocated to many serving APs for both transmitting and receiving. On the other hand, best-effort users can be allocated a minimum number of necessary APs. The required selection of served APs changes as users move, so the RIC needs to control the selection of APs or policies that can adapt to accommodate this change. In addition, the management of efficiently sleeping non-served APs by RIC can reduce the power consumption of those APs. This selective management of served APs not only assures radio quality but also reduces RAN resource consumption for signal processing, leading to a more sustainable RAN operation. For remote control of UAVs/UAMs, etc., response times need to be very short. One example of a possible solution is to deploy the RIC on the same server as the DU or near the server to shorten the control delay.

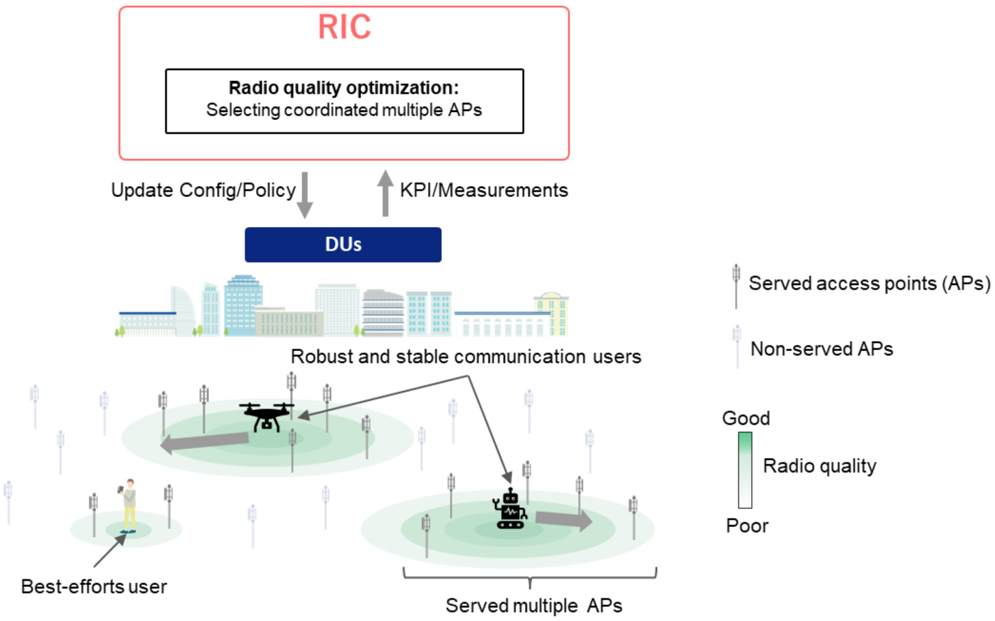

Figure 4-2 Multi point coordination management by RIC.

In the mmWave domain, the Reconfigurable Intelligent Surface (RIS) and advanced beamforming technology have also got attention for 6G [10]. RIS refers to a novel technology that consists of a surface with many small electronic elements that can be programmed to manipulate electromagnetic waves as described in Hexa-X [3]. By adjusting the phase and amplitude of incoming signals, an RIS is expected to effectively control the radio wave reflection and propagation environment for enhanced signal quality and coverage. Although still in its nascent stages, RIS is being explored for its potential inclusion in future 3GPP releases. The focus is on understanding how RIS can be integrated within the existing 3GPP framework and beyond, evaluating its compatibility with current infrastructure and its benefits in terms of spectral efficiency, energy consumption, and overall system performance.

Controlling multiple RIS using the RIC presents several advantages in adapting to user distribution and mobility. The RIC ensures consistent and high-quality connectivity by dynamically managing the angle of reflection in RIS. This approach facilitates the customization of signal paths to accommodate user movements, leading to enhanced coverage, reduced interference, and improved signal strength. The RIC's ability to manage RIS can improve signal propagation characteristics, particularly in challenging scenarios such as urban canyons or indoor environments where signals may be prone to reflection, diffraction, or scattering. Therefore, this RIS management by RIC contributes to assuring radio quality for individual users to meet specific user requirements and usage patterns.

4.2 RAN functions management in distributed and hierarchical cloud

To balance RAN resource consumption and radio quality assurance for each user in diverse services, an on-demand wide-area distributed cloud architecture and the management for the virtualized RAN is indispensable. Dynamic NF placement in the distributed cloud is a technological solution emphasized by Hexa-X and NextG [18], [19]. This technology dynamically deploys and redeploys NFs across the distributed cloud infrastructure, adapting efficiently to fluctuating user demands and distribution patterns. Figure 4-3 shows the on-demand RAN function management using scaling NFs or dynamic NFs placement. As shown in Figure 4-3, A Service Management and Orchestration (SMO) operates by intelligently placing virtualized NFs of Distributed Units (DUs) and Centralized Units (CUs) near end-users when necessary or scaling Virtual Network Functions (VNFs) to optimize RAN performance and resource utilization according to user distribution. In addition, ensuring the required communication quality for each user hinges on the dynamic management of user-VNF associations, allowing the network to adapt to individual needs and maintain optimal service levels.

However, in the current O-Cloud environment in O-RAN, this dynamic and user-centric scaling or placement of NFs introduces the challenge: service continuity, as DUs and CUs are bound to specific cells or cell clusters. Maintaining service continuity during the scaling or dynamic placement process is challenging in the current NFs deployment process in O-Cloud, potentially resulting in a temporary service outage. Due to these challenges, the current virtualized RAN in O-RAN does not achieve adaptability to demand, which is the primary benefit of virtualization. To address these problems, it is necessary to study architectures and interfaces in the O-Cloud that allow NFs to be decoupled from physical cell sites, enabling seamless management of NFs and computing resources across the entire network. Additionally, as some RAN functions are executed on accelerators, it is essential to consider the efficient allocation of computing resources that include accelerators for NFs to support on-demand scaling.

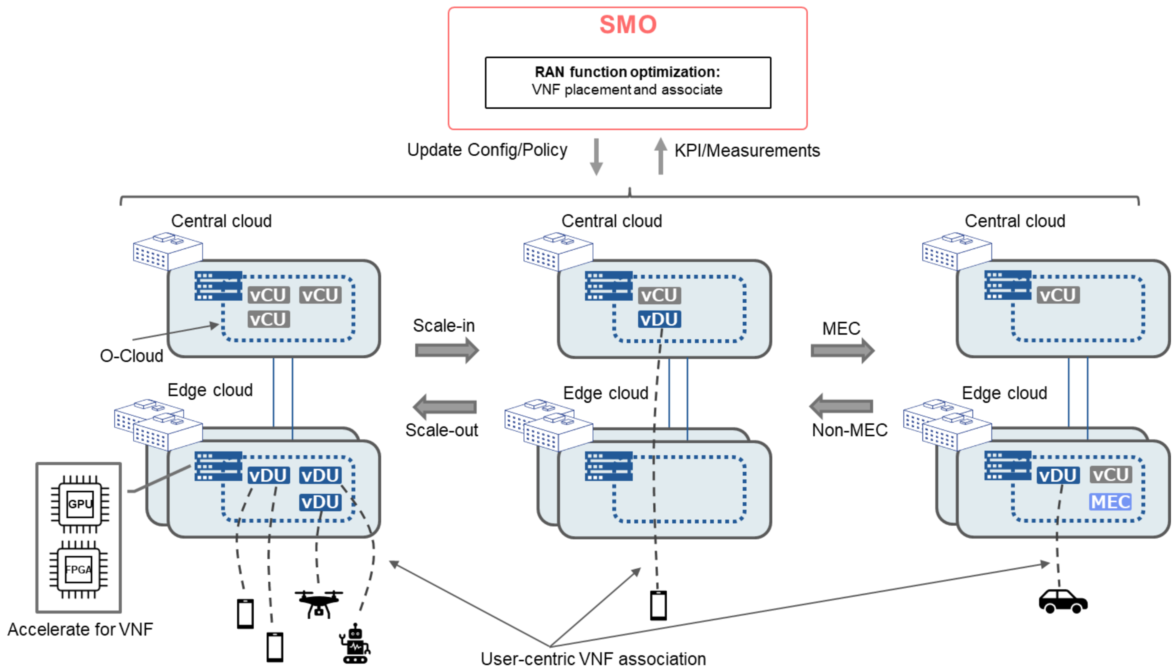

Figure 4-3 RAN function management in distributed and cloud.

5. Conclusion

As we approach the 2030s, the vision of 6G as an integral part of our daily lives and social infrastructure becomes increasingly tangible. The diverse and sophisticated use cases envisioned for 6G—from home and swarm robotics to mission-critical applications and Urban Air Mobility—demand a paradigm shift in how we assure communication quality. This research paper has underscored the critical importance of stable radio quality assurance as a cornerstone for the successful deployment and operation of 6G networks. Through our comprehensive analysis, we have identified the potential requirements for various 6G use cases, highlighting the need for seamless connectivity, uniform radio quality, and the ability to maintain high-quality communication regardless of user location or mobility in the coverage area. In the context of O-RAN, we have explored the gaps and challenges that lie ahead, particularly in managing the advanced air interface and RAN functions on O-Cloud.

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