O-RAN next Generation Research Group (nGRG)

Research Report

O-RAN Towards 6G

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Executive summary

The next Generation Research Group (nGRG) is a task force within O-RAN ALLIANCE, which focuses on research of open and intelligent RAN principles in 6G and future network standards. At the moment, the nGRG consists of the following active Research Streams (RS):

- RS01: Use cases & Requirements
- RS02: Architecture
- RS03: AI/ML
- RS04: Security
- RS08: nG Research Platforms

RS01 research stream explores the area of 6G use cases and performs an analysis of the potential 6G gaps in the O-RAN standards which are then provided as inputs to other research streams.

RS01 conducted a survey to find out different aspects of future O-RAN development. The survey was conducted, not just to find out interesting use cases, but also to assess different aspects of O-RAN solutions and their future evolution.

Clause 1 provides Motivation and other details of the survey, clause 2 to clause 11 contain details about the survey questions and consolidated answers. Clause 12 contains conclusion of the survey responses.

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List of abbreviations

Table 1 lists abbreviations used in this research report and their definition.

Abbreviation	Definition
3D	Three Dimensional
3GPP	Third Generation Partnership Project
4G	4th Generation
5G	5th Generation
6G	6th Generation
AGV	Automatic Guided Vehicles
AI/ML	Artificial Intelligence/Machine Learning
AR/VR	Augmented Reality/Virtual Reality
CSI	Channel State Information
CU	Central Unit
DT	Digital Twin
DU	Distributed Unit
E2E	End to End
GHz	Gigahertz
HTC	Holographic Type Communications
HW	Hardware
ION	Intelligent Operation Network
IOT	Internet of Things
IIOT	Industrial IoT
IP	Internet Protocol
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
KPI	Key Performance Indicators
LOS	Line of Sight
mMIMO	Massive Multiple Input Multiple Output
MR	Mixed Reality
NCC	Network and Computing Convergence
nGRG	Next Generation Research Group
Near-RT	Near Real Time
Non-RT	Non Real Time
nextG	Next G Alliance
NR	New Radio
NTN	Non Terrestrial Networks
O-Cloud	Open Cloud
OFDM	Orthogonal Frequency Division Multiplexing
O-RAN	Open Radio Access Network
O-RU	Open Radio Unit
PHY	Physical Layer
RAN	Radio Access Network
RIS	Reconfigurable Intelligent Surfaces
RF	Radio Frequency
RIC	RAN Intelligent Controller

RS	Research Stream
RU	Radio Unit
SBA	Service Based Architecture
SDG	Sustainable Development Goals
SDO	Standards Development Organization
SMO	Service Management and Orchestration
STIN	Space Terrestrial Integrated Network
SW	Software
TCO	Total Cost of Ownership
TIRO	Tactile Internet for Remote Operations
THz	Terahertz
TSN	Time Sensitive Networking
UAM	Urban Air Mobility
UE	User Equipment
UN	United Nation
UPF	User Plane Function
uRLLC	Ultra Reliable and Low Latency Communications
XR	Extended Reality

Table 1. Abbreviations Definition

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1 Motivation

The nGRG has been established to bring the O-RAN towards 6G and beyond. One of the key criteria to achieve such a feat is to know what the 6G will be all about. Therefore, it is necessary to look at the future 6G use cases and their requirements. From these usecases and requirements, we can steer the O-RAN research towards 6G, find the gaps in the current O-RAN standards, and enhance O-RAN standards to close the gaps. To achieve this, following questions have been asked:

- What are the 6G use cases and requirements that will impact existing and evolving O-RAN?
- What are the wanted functional and non-functional capabilities in 6G?
- What gaps are between requirements and wanted system capabilities in current O-RAN architecture and standards?

Use cases for technologies not yet developed are difficult to pinpoint, however the 6G literature and O-RAN Alliance members all are ripe with interesting, thought provoking and out-of-the box ideas. Use cases are meant to be for End users, Machine, Service, Network, Biological and other system based. Use cases are usually based on needs or based on enablement of new technologies.

To collect information about interest of O-RAN members in use cases towards 6G a survey was conducted during October and November 2022. This research report is based on the conducted survey.

The survey consists of many parts which are listed below:

- Categories of use cases
- Prioritized use cases from ITU-T and Next-G Alliance
- Concerned domain for 6G architecture
- Interested work area in O-RAN architecture
- Need of new air Interface
- 6G network and O-RAN components
- Priorities of network layer
- Tools for 6G network
- Security in 6G network
- Resiliency in 6G network

From the survey, 14 responses that are unique and complete are analyzed in the following chapters.

2 Categories of use cases

The first part of the survey has looked at categories of use cases which is of interest towards the 6G. Use cases can be enabled by development of new technologies, while the requirements are coming from end users, biological, physical, and cyber-systems, and from arising previously unmet demands. This survey question aims to find out which category of use cases will be prominent for 6G. To that end, 13 categories of use cases were identified. They are listed below:

1) Quantum systems:

   The impact of a feasible quantum computer is being speculated for future networks and it will have deep impact on computing, communications, security systems and biological research.

2) Privacy and security:

   Key user demands in the current environment are privacy and the security of financial and personal data in all facets of life. These will be built into the systems natively going forward rather than afterthoughts.

3) New public safety and government applications:

   There is a broad spectrum of new applications that 6G will enable and different areas of research have already taken off. This includes new laser technologies, innovative applications for public safety, and military use cases.

4) Specialized vertical industry sectors:

   There is already large interest in many specialized vertical industry sectors for 5G systems. Next generation systems will support even more challenging verticals across areas such as agriculture, automotive, healthcare, smart factories, smart cities, education, media, entertainment etc., addressing societal and environmental goals.

5) Real time analytics:

   With the upcoming 6G and even 5G applications, there is an arising requirement on real time analytics. Therefore, it will be necessary for processing of the real time RAN Intelligent Controller (RIC) to take care of the real time applications and optimize the network quickly.

6) Limits to Moore’s law:

   There are multiple technology trends in the compute and storage spaces. Many of them are poised to have a huge impact on how we develop telecom software systems. Limits to Moore’s law will start impacting compute and memory paradigms.

7) Resilience by design:

   The system resilience as part of bouncing back from any major or minor disruption will be built into the system design of 6G.

8) Automation/Autonomics:

Automation and Autonomics will be part of all system functions, maturing the existing trend.

9) Sensory and brain experiences:

   The new applications will involve human brain with a broad set of new devices and gadgets. This will help our perception using biological, physical, and cyber systems including holographic applications.

10) AI/ML in every part of the network:

   AI/ML applications are part of current network as an operational layer and work on near-real time fashion. 6G is envisioned to be pervasive with AI/ML capabilities designed natively in wireless air-interface all the way to management and orchestration layer. The AI/ML applications in 6G will be comprehensive and expected to operate in real-time manner.

11) Beyond 5G, extreme-edge or edge centric networks:

   Beyond 5G networks will likely be extreme-edge or edge centric and data flow-based across the network.

12) Softwarization and Disaggregation:

   We will continue to see a trend towards softwarization and disaggregation of network elements into more granular microservices that can be spun up on the fly and operate relatively independently. Software defined elements and systems and network functions virtualization will be the underlying technologies beyond 5G.

13) 6G Spectrum towards sub terahertz (THz):

   It is likely that 6G will push the spectrum envelope to the sub THz region enabling throughputs up to 100 times that of 5G. Typical range includes 0.1 THz to 10THz, corresponding to 3 mm to 30 µm wavelength. Novel ways of using dynamic and reconfigurable spectrum will be a key enabler for successful deployment of higher communication bands. The sub THz bands anticipated for 6G must co-exist with the technology in lower frequency bands, as lower frequency bands will continue to be the wireless connectivity backbone for wide-area coverage. So, like the 5G extension into millimeter wave, extension to very high THz frequency bands is a complement to lower frequency bands by providing extreme traffic capacity and extreme data rates through very dense deployments.

The survey results are shown in Figure 2-1, and it is clear that the AI/ML in every part of the network is of interest for almost all survey participants. This is followed by the Real-time analytics, Softwarization & disaggregation and Beyond 5G edge centric. Privacy & security, Automation/Autonomics and 6G spectrum towards THz communication follow the most selected categories.

Considering THz communication was receiving attention for supporting Tbps-level data-rate in the very early days of 6G R&D, it is observed from the survey results that interest in THz communication is reduced significantly. Due to its high-frequency characteristics, THz band is not suitable for the general mobile communication and is expected to be utilized for specific areas such as short-range communication and sensing.

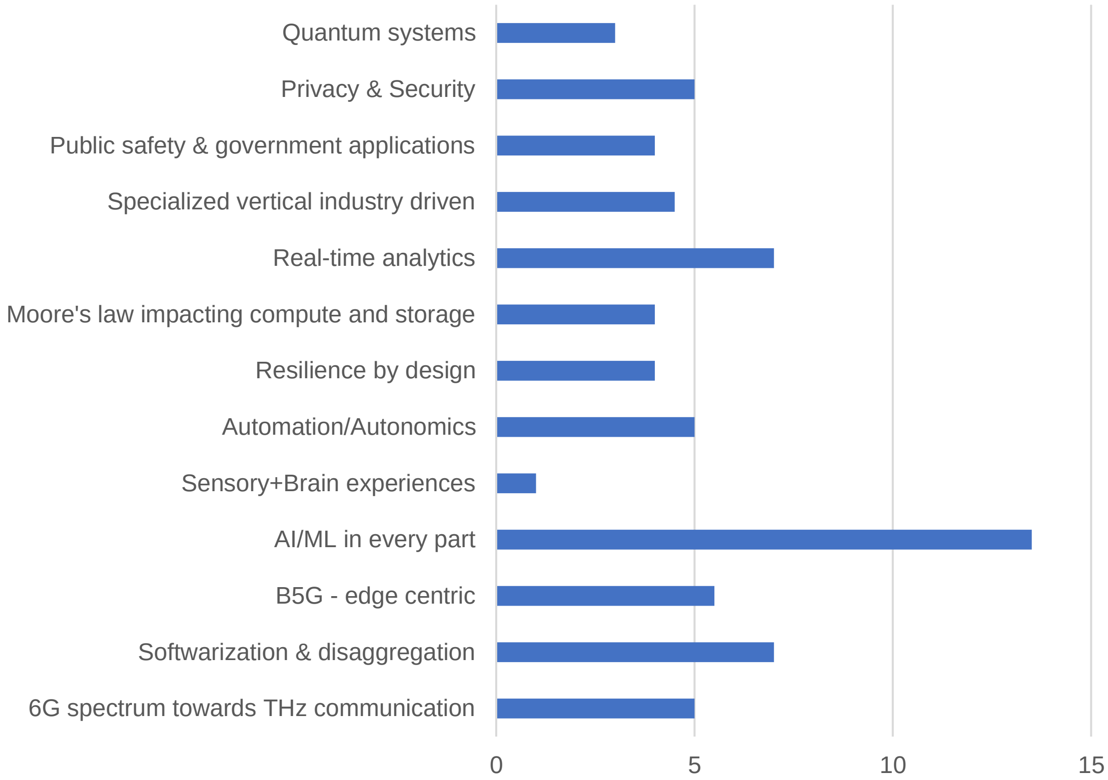

Figure 2-1 6G use case categories of interest

2.1 Additional use cases

Apart from the use case categories mentioned above, few additional use case categories of interest were identified by member companies of O-RAN. Some of them are described below.

2.1.1 Sustainability and energy efficiency

Sustainability and energy efficiency should be basic design criteria for future systems to fulfill UN's Sustainable Development Goals (SDG) targets. Due to ever increasing amounts of transmitted data, particularly due to bandwidth-intensive service types (video streaming, AR/VR, holographic communication etc.) and need for operational data (e.g., for AI/ML, computing, digital twins), the energy/bit consumption must be drastically decreased or to stay at least on par with the current power consumption. In addition, mechanisms to reduce energy consumption, such as zero watts for zero load, and dynamic sleep modes of network components, according to traffic loads, are needed, especially in the RAN. Furthermore, the use of renewable energy as well as circular economy, to extract and restore value, such as reusing, repurposing, and recycling, across the lifecycle has to be considered.

2.1.2 Ease of network operation

There will be various frequency spectrum and deployment scenarios in 6G including those of 5G and it will be very time and cost-consuming to set the network parameters manually in that environment. Also, the existing communication system has some critical challenges in network management and operation because of too many configurable parameters and inter dependency between these parameters, which affect the implementation and performance of the system. From these perspectives, AI/ML can be a key technology to make the overall system more efficient in terms of system performance as well as management and orchestration.

2.1.3 Coverage extension technologies

Coverage extension technologies will be very important in 6G. Upper mid-band (7~24 GHz) and sub-THz band (92~300 GHz) are being considered as the major spectrum candidates for 6G communications at this point. However, if the existing radio technologies are applied in the upper mid-band or higher frequency bands, the investment cost for 6G will increase drastically. This is due to the need of denser deployment or line-of-sight (LoS) scenario to compensate for the reduced coverage and overcome propagation challenges caused by the high frequency communication. So, it is critical to develop radio technologies to extend coverage in high communication bands by leveraging technologies such as extreme mMIMO or investigating advance antenna distribution systems like reconfigurable intelligent surfaces (RIS).

2.1.4 Robotics

The communication environment in 2030, e.g., in cities, roads, industrial and mining sites, is predicted to include a high number of autonomous mobile robots, drones, automated guided vehicles (AGV). Key requirements will be to provide safe, reliable, and collision-free, and efficient communication. Here, 6G networks can play a crucial role by enabling traffic management of connected robotic vehicles via a central coordination of robot trajectories, taking into account an aggregated set of data containing trajectories of other robots and unconnected objects. Examples include security robots, assistant robots, cleaning robots, delivery robots and personal robots. Negotiation of paths through stated intentions from robots can ensure collision avoidance, while the homogenized wireless connectivity quality with the user centric network allows the robots to be constantly monitored and operated from the cloud to keep people safe.

Joint sensing and communication can play a key role in tracking, detection, localization, and interaction. By collecting, processing, and distributing sensor data from all connected nodes in the network (robots, base stations, etc.) and dynamic mapping of the sensed data in high precision 3D models and maps, the robots can effectively see around the corners and plan their future paths. This can be achieved without the need to carry many onboard sensors by relying on the larger network capable of sensing. This allows for smaller, less expensive, and lighter robots that can be used for new types of autonomous transport. Traffic can be made easy and safe for connected robots and humans navigating through the busy connected city.

3 Prioritized use cases from ITU-T and Next-G Alliance

There are already several organizations looking into use cases of the future networks towards year 2030 and the upcoming 6G. In particular, ITU-T [1], Next-G Alliance [2] have looked into the upcoming use cases. The ITU-T has defined seven prioritized use cases, namely:

- Holographic Type Communications (HTC)
- Tactile Internet for Remote Operations (TIRO)
- Intelligent Operation Network (ION)
- Network and Computing Convergence (NCC)
- Digital Twin (DT)
- Space Terrestrial Integrated Network (STIN)
- Industrial IoT (IIoT) with Cloudification

Another organization which has defined future use cases is the Next G Alliance [2]. In general, there are four main categories of use cases:

- Network Enabled Robotic and Autonomous Systems
- Multi-Sensory Extended Reality
- Distributed Sensing and Communications
- Personalized User Experiences

The survey participants have been asked to prioritize and select use cases of their interest from these 11 use cases from ITU-T and Next-G Alliance.

3.1 ITU-T use cases

The responses of companies have provided their priorities to ITU-T use cases but on top of that they have also added additional use cases of their interest, as shown in Figure 3.1-1. The ITU use cases with highest priority are XR/HTC, DT and NTN/STIN, which are followed by the rest of NCC, ION, IIoT and TIRO. However, other use cases have been mentioned, namely AI, Massive communication, and Robotics, each getting at least two votes.

The prioritized use cases XR/HTC, DT and NTN/STIN are currently areas of significant development in the 6G research.

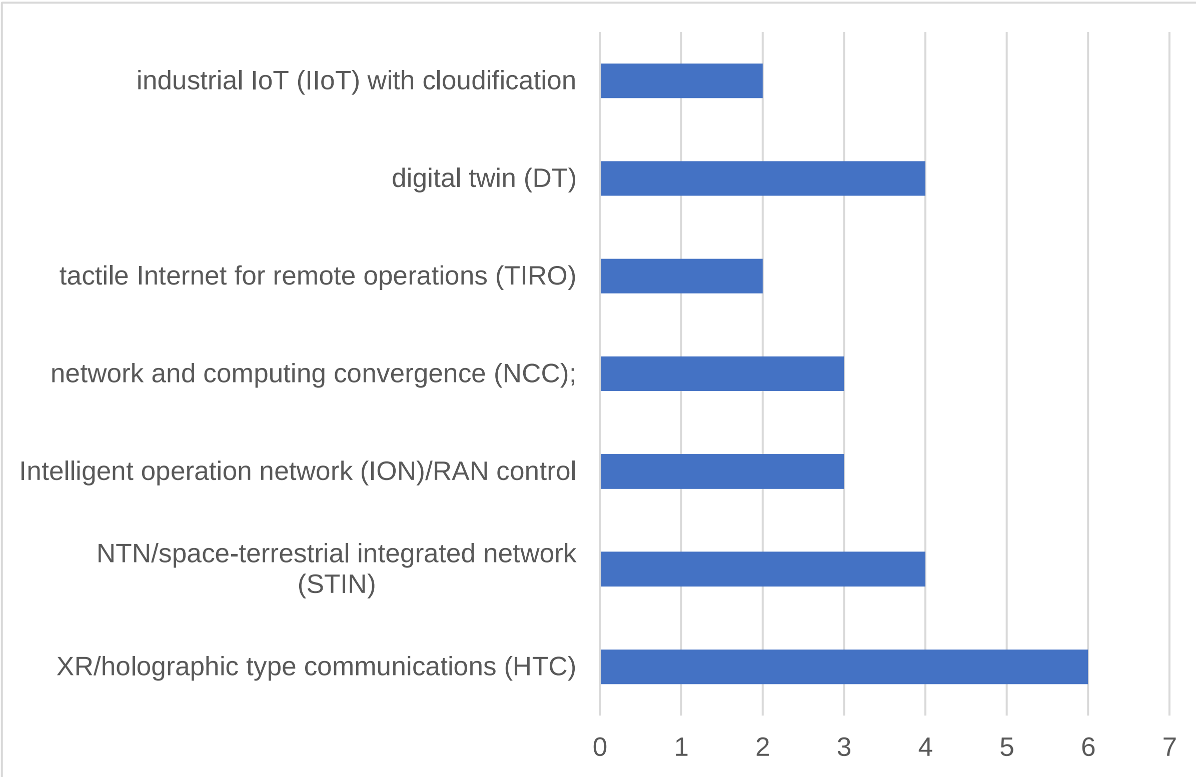

Figure 3.1-1 Prioritization of ITU-T use cases

3.2 Next-G Alliance use cases

Similar to ITU-T prioritized use cases, responses on Next-G Alliance use cases have been evaluated. Again, there have been additional use cases of interest proposed by the companies participating in the survey. From the responses, the most prioritized use cases (in descending priority) are Network Enabled Robotic and Autonomous Systems, Multi-Sensory Extended Reality, XR/HTC, Personalized User Experiences and Distributed Sensing and Communications.

3.3 Additional use cases of interest

From the responses of the participating O-RAN members in the survey, additional use cases of interest have been determined, as follows:

- Autonomous vehicles/systems
- AI
- Massive communication
- Sensing, context awareness and localization
- Network for sensors
- IP breakout (UPF) and RAN control (near-RT, RT RIC) interactions
- uRLLC and TSN for private networks and industrial applications
- Integration of cellular and Wi-Fi – seamless connectivity
- User-centric network

- Global connectivity
- Extreme communications
- Versatile integrations and intelligent customization
- UAM (Urban Air Mobility)
- Energy Efficiency
- Scheduler profile adaptation
- Spectrum sharing in lower and mid bands
- RAN slicing
- Extreme communications
- Versatile integrations and intelligent customization
- Metaverse based Remote Management
- Metaverse
- UAM (Urban Air Mobility)

Next sub clause explains few of these interesting use cases.

3.3.1 XR/HTC

Human centric extended immersive and 3D reality (encompassing VR, MR and AR) and holographic telepresence are expected to eventually become the norm for both work and social interactions. It will be possible to make it appear as though one is in a certain location while really being in a different location – for example, telepresence for care, meetings and gatherings, inspection, gaming, etc. We will have systems that will combine facial expressions with a virtual self within the digital representation of the physical world. Merged reality telepresence experience will be enabled by wearable devices, such as smart contact lenses or glasses, and those embedded in our clothing, skin patches and bio-implants. We will have multiple wearables that we will carry with us, and they will work seamlessly with each other, providing natural, intuitive interfaces. Touchscreen typing will likely become outdated and be replaced with more intuitive interfaces such as gesturing, talking, and eye tracking. The devices we use will be fully context-aware and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new human–machine interfaces will make our telepresence interaction much more intuitive and efficient.

3.3.2 Intent-driven autonomous network management

Traditional network and service management is done by human experts manually as well as automated scripts and functionalities to monitor, tune and decide configuration requirements for different services. This approach met the needs of the previous generations of networks quite efficiently. However, the rapid need for evolution and the diversified service requirements from industry verticals make it difficult to keep up and train the experts with the required expertise in a timely and cost-efficient manner. Autonomous network management has attracted significant attention from the networking community as a possible solution to address these challenges and improve the process of network and service provisioning for a diverse set of users and service provider requirements. Operators' diversified service intents and objectives can be converted into optimized network configurations without individual tasks having to be coded and executed manually. This relies on high levels of intelligence that can be evolved and assessed in the virtual service environment created by the digital twin.

4 Concerned domain for 6G architecture

This survey question was aimed to find domains in 6G architecture which is of main interest and needed expansion in current architecture. Possible options were:

- Transport
- Core
- RAN
- Management, Orchestration and SMO
- Services
- Others - Digital Twin, AI, Security & privacy, Service Based Architecture (SBA) and Energy efficiency

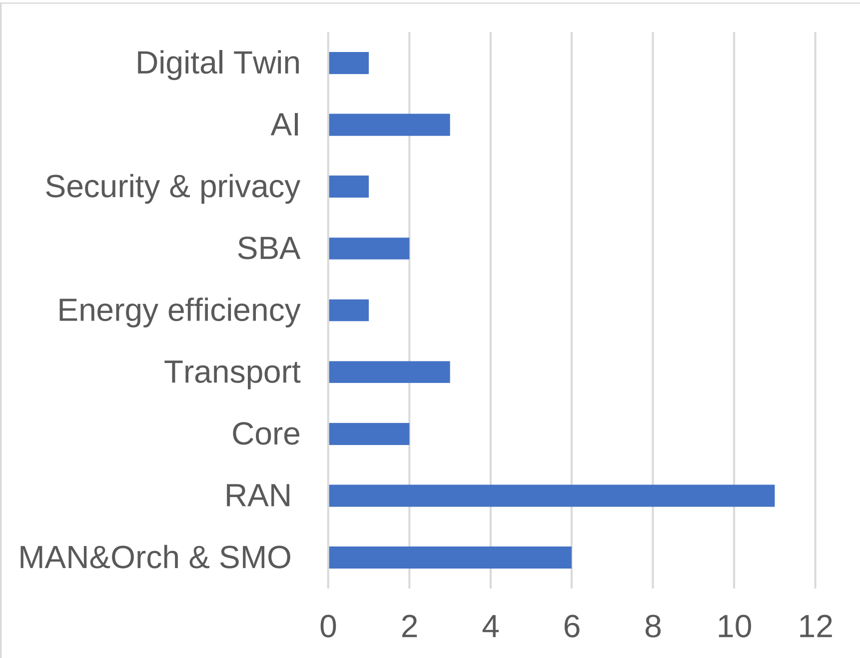

Figure 4-1 6G Architecture Domains of Concern

Figure 4-1 shows summary of responses related to concerned domains for 6G architecture which needs improvement and expansion.

Clearly RAN domain needs improvements in current architecture. For 5G, 3GPP has studied eight functional split options in gNB as stated in TR 38.801 [3]. Finally, 3GPP focused on the high-layer split (between CU and DU) only and the low-layer split (between DU and RU) is left for implementation, which makes it difficult to support multi-vendor interoperability between DU and RU. However, nearly all 5G deployments use separate DU and RU equipment (i.e., low-layer split). Furthermore, RAN architecture design is focused only on gNBs, and AI-related nodes are not considered at all (e.g., SMO, RIC). Introducing AI into RAN has not been a part of 3GPP standards. Recently, 3GPP started to study AI-based Air Interface in Rel. 18 such as CSI feedback enhancement. In 6G, standard interface for low-layer split should be defined. Moreover, AI-related nodes, e.g., RIC, should be defined in 6G RAN Architecture with standard interfaces and their trustworthiness has to be proven.

6G architecture should be based on SBA principles, while 3GPP and O-RAN architectures should not diverge or become incompatible.

5 Interested work area in O-RAN architecture

This survey question tried to find out in which arears of O-RAN architecture companies are interested to build solutions. Building solutions end-to-end or target a particular area to build solution.

Possible options were:

- Automation/Autonomics on RAN interacting with other domains
- Interested in just xApps and rApps
- Need new functions/Interfaces
- Others

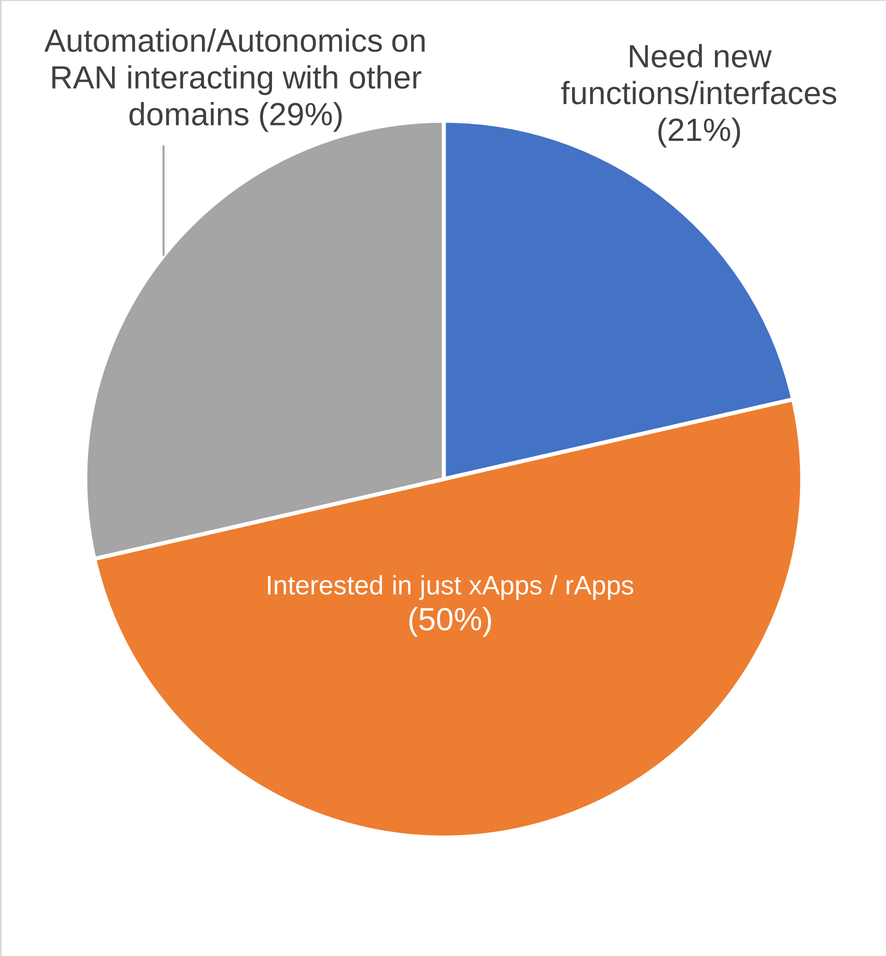

Figure 5-1 Interested work area in O-RAN architecture

Figure 5-1 shows the results of survey question related to interested work area in O-RAN architecture. Interestingly 50% of the participating companies are interested in building solutions around xApps and rApps. Automation on RAN interaction with other domains emerges as the next area of interest followed by the need for new functions and interfaces.

There were a few more areas of interest suggested by member companies, that are described in the following sections.

5.1 Network automation

Network automation including network function and service function orchestration and operation have to be optimized across all domains. Intent driven autonomous network management improves the process of network and service provisioning based on high-level user intents for a diverse set of user and service provider requirements for industry verticals using high levels of intelligence.

5.2 Common SMO

There is need to have common SMO which should include management functions for core, transport, and other network nodes to enable full automation and cross domain optimizations.

5.3 Customization at each node

Study scope and opportunities for customization at each network node (RAN functions, Near-RT RIC and SMO etc.) to enable better coordination between Apps and RAN nodes.

5.4 AI/ML native architecture

AI/ML can be a key technology to make the overall system better in terms of system performance and energy efficiency as well as automated management and orchestration. O-RAN architecture needs to be AI/ML native architecture including SMO, non-RT RIC, near-RT RIC, etc.

5.5 Need of new functions and interfaces

There is need of new functions in near-RT RIC and new interfaces, such as intra-RAN connecting existing O-RAN nodes with new functions or physical RAN and its Digital Twin.

5.6 Need of software and hardware

Softwarization is a key, but it is necessary to identify what needs to be on hardware and what can be softwarized to support a sustainable 6G architecture.

6 Need of new air interface

The research on the air interface is looking into its evolution towards 6G. As this is directly impacting O-RAN there is an open question whether companies see that 6G new air interface will address their use cases or there would be need for additional software or hardware specialized for new frequency ranges.

6.1 Software vs hardware

From the survey, 8 companies think that it will be necessary to rethink the hardware (white boxes), while 5 companies believe that new software will be enough as hardware is keeping up with the requirements anyway.

The need of new hardware comes from the need of cost-effective solutions for the vertical markets. However, in addition to the hardware, compute for 6G needs to be as close to the edge as possible to support improved total cost of ownership (TCO), especially for energy efficiency and to deliver sustainability to the industry.

6.2 Revolution vs evolution

There are several companies that believe it will be necessary to develop both novel software and hardware to support 6G architecture for new use cases, and also, to support new frequency ranges. There is also survey response suggesting that 6G will not only be about new air interface, as it is expected to see upgrades of all aspects, including system architecture, SW/HW platform/infrastructure, transport network, management, and operation, etc.

On the other hand, there is a view of currently not seeing the need for a new air interface specification as just relying on NR should be sufficient. This is due to possible extensions for new bands that may come between 6 GHz and 24 GHz, having mainly O-RU impacts. Extensions to (sub-)THz bands, if required and finally justified by customer service demand, may also impact the waveform to be used (e.g., single carrier instead of multi-carrier Orthogonal Frequency Division Multiplexing (OFDM)), but framing/bandwidth and similar issues can be adapted to existing NR definitions.

6.3 Novel services and deployment

Further air interface extensions may address joint communication and sensing by addition of sensing signals in the NR framing, which can be optimized in a way that they can be used for both communication and sensing purposes at the same time, i.e., going beyond the approach currently under discussion in a 3GPP Rel-19 study.

On general deployment and hardware requirements, there is usually the need to rethink SW and HW for cloud-native implementation of RAN functions, especially decoupling SW and HW in a more proper way. Especially with respect to HW acceleration for computationally intensive functions like NR PHY layer or AI/ML algorithms and supporting more energy efficient realizations. For extreme throughputs, also xHaul interfaces/transport protocols might have to be revisited.

7 6G Network and O-RAN components

The mobile networks of 6G, legacy deployments and O-RAN components will have to coexist. Therefore, there is a question whether the 6G network of the survey participants will include only 3GPP deployments, or combination of O-RAN components with 3GPP and legacy deployments.

From the answers, as illustrated in Figure 7-1, we see that majority (86%) of responses believe that there will be a mix of O-RAN components as well as 3GPP and legacy deployments, whereas only 14% believe that the 6G mobile network will be only 3GPP based.

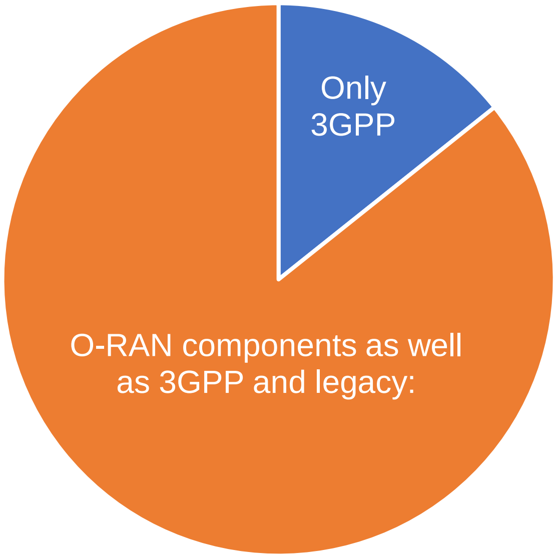

Figure 7-1 What will your 6G network include?

Reponses, where a combination of O-RAN, 3GPP and legacy (or brownfield) deployments will coexist have several reasonings on the need of such combined deployments. One aspect is that O-RAN will not supplant legacy 4G/5G deployments, so the SMO and the RICs must talk to legacy components to maintain network monitoring and visibility. This could lead to user-centric communication due to focus being on providing connectivity irrespective of communication technology and sustainability (efficient use of existing deployments) via control and management of 3GPP based 6G systems by O-RAN RICs. Therefore, 3GPP and O-RAN coexistence can be achieved in a way that 3GPP will standardize 6G network and O-RAN will complement 3GPP with additional standardization, and hence it is expected that 6G network will include O-RAN components as well as 3GPP deployments. One of the main enhancements could be additional open interfaces and components related to AI-native RAN architecture such as SMO and RIC.

The transition towards 6G will likely happen in a phased manner, i.e., it is expected to have some legacy 3GPP deployments in the near future. This is supported by the fact that legacy systems (assumed in the survey to mean 4G and earlier) will still play a role to fulfill long-term contracts of existing customers, thus, different system generations will probably be still in operation when 6G will be introduced. The O-RAN architecture is based on 3GPP and extends it. Therefore, there would certainly be some overlap in deployments where higher functional splits based on O-RAN specifications may be deployed with multi-vendor components in one part, whereas in other parts of the network RAN disaggregation is only on a single vendor basis.

Nevertheless, all these deployments will be following 3GPP and/or O-RAN rules with respect to interfaces, nodes and signaling procedures.

A couple of responses have focused on the need to operate a very comprehensive network and to do research and experiments to evaluate these mixed deployments, as some enhancements may be needed for O-RAN to enable such combined deployments.

8 Priorities of network layers

This survey question was aimed to find priorities of network layers which are of main interest with possible options of:

- Integrated models across multiple layers (E2E)
- Service layer
- Ethernet / switching
- Physical layer
- IP

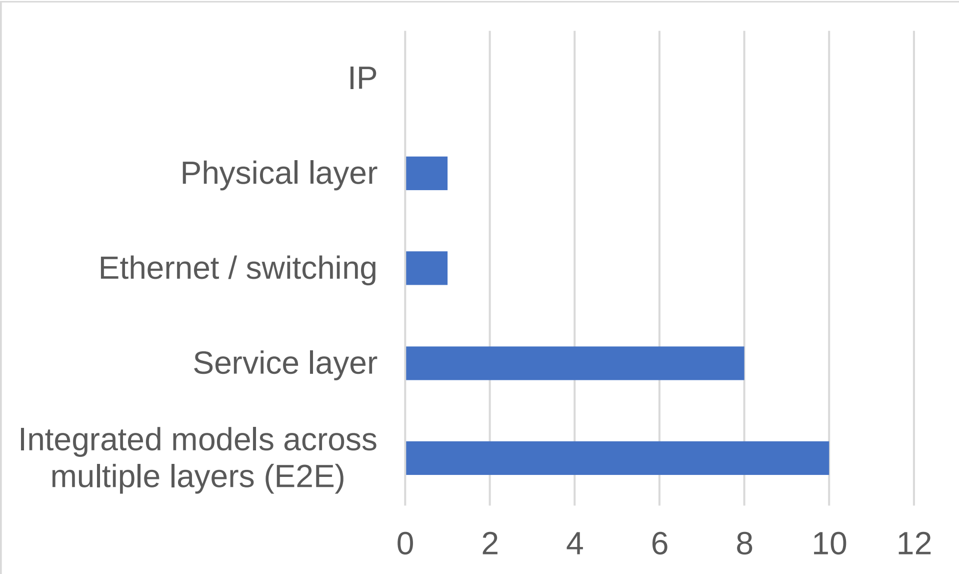

Figure 8-1 Priorities of Network Layers

Figure 8-1 shows the result of survey question related to priorities of network layer.

According to the survey results, the most prioritized component for consideration in 6G networking is integrated models across multiple layers (E2E), with ten votes. This emphasizes the importance of ensuring seamless connectivity and interoperability across different network stack layers, all the way from the physical layer to the application layer. However, the level of integration required will depend on the implementation effort required and the benefits that can be achieved through tighter integration. Therefore, it is important to strike a balance between the level of integration required and the achievable benefits.

In the context of O-RAN, the advancement of O-Cloud is a key concept that enables the benefits of integrated models across multiple layers. Leveraging AI at network components of multiple layers on the O-Cloud can help to optimize network performance and improve network efficiency.

In terms of equipment, disaggregation, openness, and modularity of network equipment will make it possible to handle multiple layers with a single piece of equipment. This will reduce cost, space, and power consumption.

The service layer received three votes, indicating that respondents recognized the importance of a flexible and scalable network platform to provide a wide range of services to meet the diverse needs of users in the 6G era.

Ethernet/switching and physical layer received one vote, suggesting that while these components are important, they may not be as critical as integrated models across multiple layers and the service layer in 6G.

9 Tools for 6G network

The move towards 6G will need tools for a successful deployment, which has been investigated in a question whether end-to-end (E2E) tools, E2E service modeling, RAN design tools or some other tools will be needed.

The answers show that there is no consensus on the needed tools, as shown in Figure 9-1. The results are almost homogeneously distributed between all options.

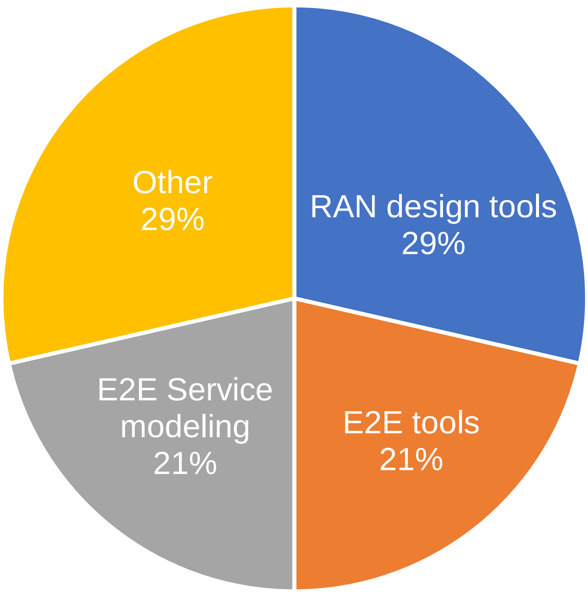

Figure 9-1 What tools will be needed in 6G framework?

Even though there are 4 categories, most companies think that it is too early to speak about the needed tools, as they will arise as a natural consequence of the 6G architecture development, functional requirement definitions and the upcoming use cases that will be needed to be served. Thus, it is important to ensure that we are open minded and not missing out on new opportunities. On the other hand, the required tools will likely consist of many E2E tools to ensure the scalability and sustainability of mobile networks.

The need of E2E tools also come from the deployment/orchestration of network functionalities for customer service provisioning and network operation. How those E2E tools are finally created, i.e., whether they consist of tools/modules related to different domains (e.g., RAN, core network, transport) that interact with each other, is up to the implementation. For features like network slicing, E2E tools are already required today to orchestrate network functions across available domains according to the requirements set by the slice customer (service area, KPIs, number of UEs, etc.). This also requires knowledge about the network topology, HW characteristics, the available and occupied SW/HW resources, etc., as well as knowledge about the available RF coverage for different RAN frequency layers.

Therefore, integrated network operations/maintenance with real-time security operations (e.g., to see network degradation, whether root cause is HW equipment or SW issue(s) or network attack) must be determined at the time of the event, not after the fact.

With the move towards 6G, ray tracing will play a much bigger role to enable the simulation of many 6G relevant technologies, such as joint sensing and communications, user positioning, and reconfigurable intelligent surfaces. There is also need for better channel models for THz as well as very large antenna arrays for which the plane wave assumption does not hold.

10 Security in 6G network

The security is a key building block for success of 6G, as more companies are looking into secure connectivity. The outcome of the survey question is well aligned with this as shown in Figure 10-1. Majority (86%) of companies believe that security needs to be handled directly in the design phase, while only 14% of companies believe that it can be leaved to vendors to work the solutions based on the requirements.

The responses state the strong believe in “security by design” principle and that security cannot be ignored in any phase. The motivation is that the approaches applied in the past, e.g., adding security features on top of other features and functionalities without consolidating them in an early phase, may result in sub-optimal solutions. Especially cross-domain security approaches are seen as necessary to be discussed in the design phase. Later, architectural splits may follow if they are feasible and not reducing the intended security level.

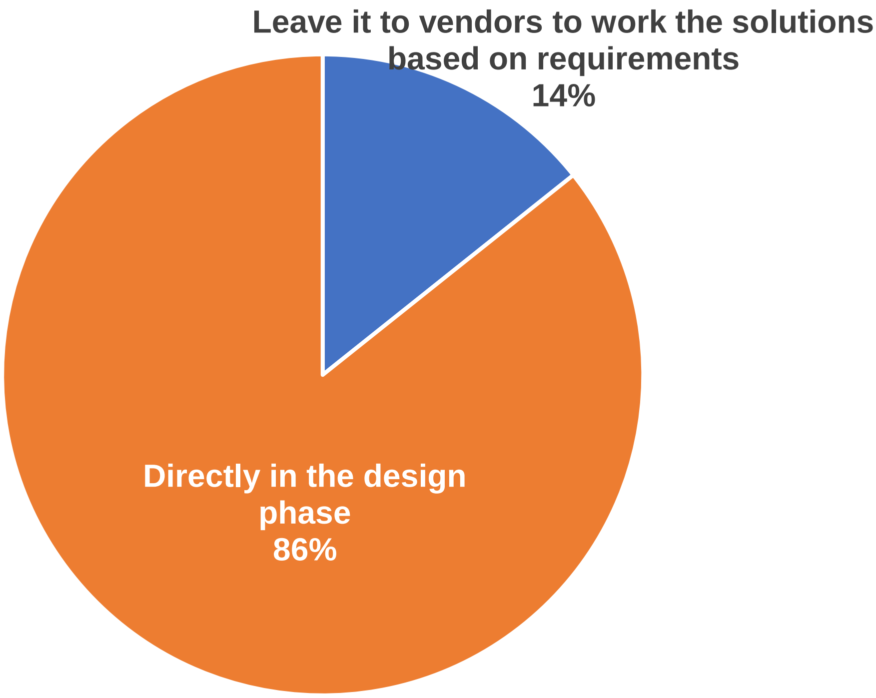

Figure 10-1 How will you handle security in 6G networks?

11 Resiliency in 6G network

As more and more society-critical services become reliant on the cellular network, a key question for 6G is on how to ensure that the network is resilient and can sufficiently and sustainably support service delivery at the appropriate quality levels.

Resilience can be understood in two perspectives. First, resilience is associated with maintaining service quality levels on the network in the face of probabilistically describable adverse events. Second, resilience deals with the preparedness and ability to recover service levels in the face of adverse black swan events.

As shown in Figure 11-1, majority of respondents expect that resilience will be directly incorporated into the 6G networks at the design stage. In particular:

- Resilient networks should ensure functional safety for cellular dependent use cases. Achieving this may require architectural considerations such as statelessness in network design.
- Network and consumer services and applications may require different resiliency levels with 6G software and hardware designed to flexibly adapt to diverging demands.

- Resiliency can be designed into network equipment/functions, and AI/ML can play a role by monitoring several network KPIs and adjusting the network settings accordingly to enhance resilience.
- Additional resilience can come from the overall network architecture/design of implementation (including redundancies in data centers, key nodes, etc.).

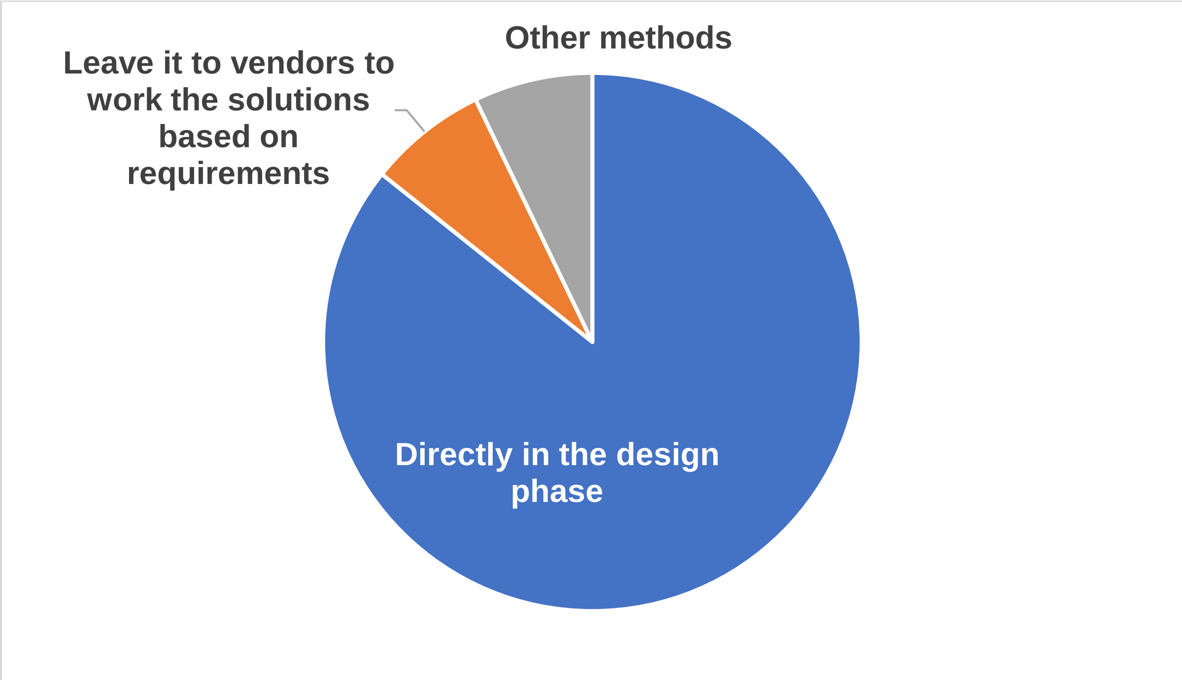

Figure 11-1 How will you use and perform resiliency in 6G networks?

12 Conclusion

The survey result is very useful in defining the path of O-RAN and other SDOs towards 6G. O-RAN Alliance continues to work towards transforming radio access networks towards open, intelligent, virtualized, simplified and fully interoperable RAN. The O-RAN architecture and specifications are built on common 3GPP standards and care about alignment with other industry bodies to ensure compatibility and avoid duplication of work. This survey not only helps O-RAN but also other standards bodies.

Following system requirements and use cases will be of interest for future network.

- AI/ML deployed everywhere (i.e., in all domains) to improve efficiency and trustworthiness of the networks.
- Sustainability and energy efficiency will be a must in new feature design.
- There is a need to develop cost effective solutions.
- Future networks should be based on SBA.
- Softwarization, disaggregation, openness and modularity should be part of the network.
- RAN software and hardware should be cloud native.
- Analytics should be part of architecture and real-time network optimization is needed.
- Network coverage everywhere will be needed.
- Network should be able to support autonomous mobile robots, drones, automatic guided vehicles (AGV) for packet delivery and personal traffic.
- XR and Holographic communication will be part of personal and entertainment communication.
- Digital Twins will be needed for network efficiency and planning.

There is a need to focus on E2E solution covering multiple technologies that 6G network will co-exist with. Additionally, there is a need to have SMO that can manage and orchestrate multiple parts of the network. 3GPP, other SDOs and O-RAN Alliance need to work together for future network. Security, sustainability and reliability need to be considered from design phase itself and not as an add-on later.

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