Using Open Virtual RANS in 5G: Operators' Perspectives and Economic Analysis

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EXECUTIVE SUMMARY

Mobile network operators are engaged in a far-reaching evolution of their infrastructures toward support of 5G. Enabling these deployments involves significant upgrades to their capacities, functionality, and footprints of their networks. Among other parts this involves a substantial evolution of their radio access networks (RANs) with the adoption of 5G New Radio (NR) technologies and the capabilities to support them. The scale of these new infrastructures and the range of technology innovations 5G networks will usher in are stimulating operators to do significant amounts of planning and design to ensure they achieve their goals. These include not only maintaining but in some cases improving the quality of their services while at the same time ensuring they increase their overall efficiency and earn a positive return on investment.

An important option operators have available for enhancing their RANs is to disaggregate, modularize, and virtualize the deployments (which have largely been deployed as tightly bundled, integrated systems in preceding generations of mobile networks). Open RANs are ultimately expected to use lower-cost radio units, based on increased levels of competition for those parts of the deployments. They will also use a more efficient system architecture to support the additional processing 5G infrastructures require. This will provide operators with flexibility to optimize their deployments based on the characteristics of each area they serve. At the same time it will require operators to develop a clear perspective on which architectural options and which types of modularity will serve them best in each of these different environments.

With an eye toward helping operators create the most effective deployments for their 5G RANs, Dell and

Report Highlights

- vRANs are strategic to operators in their deployments of 5G.
- Most operators have a strong preference for using an open vRAN architecture in as many deployment scenarios as they can.
- Operators are strongly committed to the O-RAN Alliance and its work in developing the specifications and the ecosystem for creating a viable, sustainable set of open RAN solutions.
- Their motivations are based on having flexibility in supplier choice, economic efficiency, service innovation, and differentiation.

Intel have done considerable research into the types of infrastructure offerings that will accomplish that. Although this clearly has a number of technical dimensions to address, evaluating the economics of the alternative deployment approaches is an equally critical goal. To add an independent perspective to such analyses and to leverage the depth of architectural design and economic analysis available on the task within its team of analysts, the firms engaged ACG Research to conduct independent interviews with operators about their perspectives toward open RAN deployments and also to develop a robust economic model of the alternatives available to operators in deploying open RANs. The goal of the research is to help operators determine the most effective alternatives they can pursue in deploying their 5G RANs.

Report Highlights

- Operators will use a mix of centralized and distributed open virtual RANs
- 2021 and 2022 will be focused on evaluation, testing and trials. 2023 will be when broader deployments start to materialize
- ACG developed an economic model of alternative open and physical, proprietary RAN deployment scenarios using its Business Analytics Engine (BAE) modeling platform
- Open RAN designs in all cases supply 30% or higher savings in TCO compared with proprietary physical RAN designs
- The amount of savings will vary by operator based on the scale of their deployment

Two Companion Reports

The findings of the ACG research are captured in two integrally related companion reports. This document presents the findings of ACG's in-depth interviews with 5G RAN planning leaders in mobile operators' companies about their perspectives on the design alternatives they have available for their 5G RAN deployments. It specifically explores their perspectives on the timing, benefits, and challenges of deploying open RAN technologies in their 5G infrastructures. A second companion report describes the economic model of 5G RAN deployments that ACG developed in this research. It communicates the results of a comparison of the total cost of ownership for mobile operators of deploying proprietary physical RANs versus deploying open RANs in their 5G networks that was done using the RAN economic model ACG developed.

From the Source: Top Service Providers' Perspectives on Using Open, Virtual RANs in 5G Deployments

In this research we conducted interviews with 5G network planning and engineering leaders in 10 of the world's leading service provider companies that operate in North America, Europe, and Asia Pacific. Several have operations in multiple countries and on more than one continent. Our discussions addressed both business priorities (such as customer and application segments on which they are focusing) as well as technical, architectural, and operational questions on the criteria they are using to determine where, when, and how they will deploy open vRANs in their 5G infrastructures. We prepared a discussion guide for all participants to use in preparing for the interviews, prior to exploring the topics in detail.[1]

Our findings from the interviews are described in a series of sections in this report, highlighting the top considerations operators have in deciding whether and how to use open virtual RANs in their 5G deployments. The sections are:

- Top reasons for preferring an open virtual RAN approach
- Where a centralized, open vRAN will work best
- Where a centralized, open vRAN will not be preferred
- Timing of initiatives
- Top challenges they expect to face in open virtual RAN adoption

Top Reasons for Preferring an Open Virtual RAN Approach

Providers expressed a strong preference for using a vRAN architecture in their 5G deployments and for using an open vRAN architecture as widely as possible as soon as solutions supporting that approach are brought to market. Providers identified five primary reasons about where, why, and how they would like to use open vRAN architectures in their deployments:

- Supplier Choice
- Service Differentiation
- Lower TCO
- Flexible Integration into Operations
- Spectral Efficiency

These are ranked in the general order of importance in which they were described. The importance of each varies depending on the context, but each is influential in understanding the overall direction of the market.

[1] vRAN and Open RAN Reference Information: Note, we have included a short primer on vRAN and O-RAN reference architectures as an Addendum at the end of this paper. We included it to help any reader interpret references and conclusions we have included in our reports. However, if it is material a reader is already familiar with and does not need to review, then diving right into the material is a perfectly workable path.

Supplier Choice

Every operator emphasized that having an increased flexibility in choosing suppliers from whom the multiple components utilized their 5G RANs could be sourced is a strategically high priority for them. To that end, an open RAN design with openly specified interfaces, APIs, and architectures is seen as an enabler of that ability to choose. They expect this flexibility in each major category of function specified in the 3GPP 5G RAN and O-RAN Alliance specifications. There is a strong belief that insisting on such flexibility in the elements they use will contribute to keeping costs lower than they would be if it were not available. Although the level of confidence in achieving the prospective benefits of an open RAN design varies (see the section on Challenges) the desire to test for whether the benefits can be obtained was consistently expressed.

Service Differentiation

In many cases operators believe the programmability of open RANs will help them gain an advantage in bringing new services to market. There are some dimensions on which operators believe they have unique assets that they can leverage to take advantage of this programmability. For example, operators may be able to couple their understanding of subscribers' quality of service entitlements with additional information about their location in creating location-based offerings for subscribers. Additionally, operators' ability to control its subscribers' full user plane path (over both fixed network and radio infrastructure elements) may give them an advantage in leveraging the low-latency capabilities of 5G in certain applications. Operators generally expressed that the programmability of RAN Intelligent Controllers (RICs) in open RAN architectures and the flexibility they will have to co-locate 5G network functions and applications in computing pools in the RAN is likely to provide them with an opportunity in this regard.[2] What the opportunities are will vary in each case, but the ability to leverage this part of the architecture for those purposes was identified as being of likely high value in many of the operators' cases.

Lower Total Cost of Ownership (TCO)

Operators acknowledge not having fully proven whether the TCO of working with an integrated solution supplier in their virtualized RANs will be higher than working with best-of-breed suppliers on a mix-and-match basis. They agreed it is typically simpler to work in a large-scale deployment with a single supplier's offerings. In parallel there is a perceived advantage, at least in capital expense terms, in using an open RAN design. The theory is that open RANs, by being based on open specifications and architectures, will inspire a greater number of vendors to compete for supplying the components. This will need to be balanced against the possibility of increased integration costs either with providers taking on the integrator role in an open RAN deployment or contracting it to a third-party. Collecting evidence on these relative costs is an important goal on which many operators will be working in the coming one to two years in resolving which path they will choose.

[2] See, for example, O-RAN Architecture Description 2.0, July 2020, O-RAN Near-RT RIC Architecture 1.0, April 2020 and O-RAN A1 Interface General Aspects and Principles 2.0, July 2020 for perspective on the RICs intended operations.

Flexibility When Integrating into Operations

Operators also expressed an interest in harnessing the openness and programmability of their deployments to streamline their current procedures. Their expectation is that integration and operational tasks will be more efficient and flexible using software developed using openly published and maintained APIs versus using software based on proprietary interfaces. Given the scale and variety of locales into which they expect to deploy 5G RANs there is a belief that this ability to tune and customize their approach to operations will be to their advantage.

Spectral Efficiency

Several providers identified being able to maximize the use of the spectrum they have licensed as a motivation for using an open, virtualized RAN. In such an architecture, virtualized distributed unit (DU) elements in the RAN can be installed in a centralized server pool. When they are pooled in this way, radio control functions such as carrier aggregation, inter-cell interference co-ordination (ICIC), and coordinated multi-point transmission and (CoMP) reception can be implemented with greater efficiency (given the close proximity of the DU servers to each other in the pools). Given the size of their RANs and the spectrum investments they are making, being able to use an additional 10–20% (or more) of the capacity of those resources is a highly meaningful objective.

Where operators believe centralized open, virtual RANs will work best

Operators expect they will deploy disaggregated, centralized open RANs where their fronthaul transport has the bandwidth and functionality required to support open fronthaul communications[3] and where the uptake for their new 5G offerings will justify the investment. Generally, these are sites where enough fiber transport capacity has been deployed to carry fronthaul traffic between RUs at the radio sites and DUs located in centralized resource pools some kilometers away from the radio sites. These are mostly in more densely populated metropolitan areas, though the distribution is provider dependent. A second consideration is the fit or alignment of the DU capacity with the types of radio unit (RU) installed. In some cases, where dense millimeter wave or massive MIMO radios have been deployed, operators will choose to keep DU processing at the cell site, local to the RU. This choice, too, will be operator dependent and most often, dependent on the type of cell site location and RU deployment within the operator's network. If sufficient fronthaul capacity and control for the deployed RUs are available via pooled DUs, then that pooling can be pursued.

[3] See, for example, O-RAN Fronthaul Conformance Test Specification, O-RAN Alliance, July 2020. Note that the communications between RU and DU in open RAN designs is the highest capacity, most latency constrained component of open RAN control plane processing. Hence the requirement for high-capacity links between cell sites and DU pools in those deployments.

This overall profile can be broadly divided into two types of fiber infrastructure deployment circumstances: one in which an operator already has sufficient fiber capacity installed between radio sites and its nearby serving offices, based on previous investment into centralized RAN for 4G and a second in which the capacity is currently being installed or will be deployed in concert with the operator's 5G network installation. The first is true in many densely populated serving areas already (as in a number of cities in the Asia Pacific region), and the second generally applies to areas in which providers are installing upgrades specifically to support 5G (and in some cases also to support higher capacity broadband access for use in other services).

It is likely vRAN and O-RAN trials and deployments will move at a faster pace in the first scenario, as operators that have already built out centralized RAN configurations for 4G LTE and made investments into the fiber infrastructure supporting such sites tend to be in a better position to support more customized or specially configured trial configurations for 5G in a well-equipped central facility. By contrast, new site deployments for 5G without the prior investment in centralized RAN for 4G are likely to be in less dense areas and need more uniform profiles in the early going to sort out operating details. It is also true that fronthaul capacity requirements may be greater in denser areas, at least in part because of higher capacity, more feature-rich radios being deployed, in which case higher capacity fronthaul will be required.

Where centralized open, virtual RANs will not be preferred

Operators generally do not anticipate using centralized virtual RAN configurations where the fronthaul fiber infrastructure and capacity required to support DU pooling is not available or where the provider has decided not to make the fiber investment. One scenario in which this will be the case is where wireless backhaul is used, fiber optic transport is not available, and transmission bandwidth in the 10–100 Gbps (and higher) ranges needed to support DU pooling will not be available. In such cases a RAN configuration split locating RU, DU, and possibly centralized unit (CU) functions at the cell site and using lower backhaul capacities that will work in a microwave configuration are likely to be used. This is the case in a number of less dense and less developed coverage areas in Europe and North America, as well as in other geographies.

A diagram of this type of deployment is shown in Figure 1. This architecture could be used where wireless transport is installed between the DUs at the cell sites and the CUs at a centralized pool. Or it could be that the operator has chosen to place the DU at the cell site because of the performance requirements for the RUs that are deployed. In either case the midhaul or backhaul transport from the cell sites to the rest of the operator's infrastructure are working at a lower capacity than the case where the DU and CU controls have been centralized.

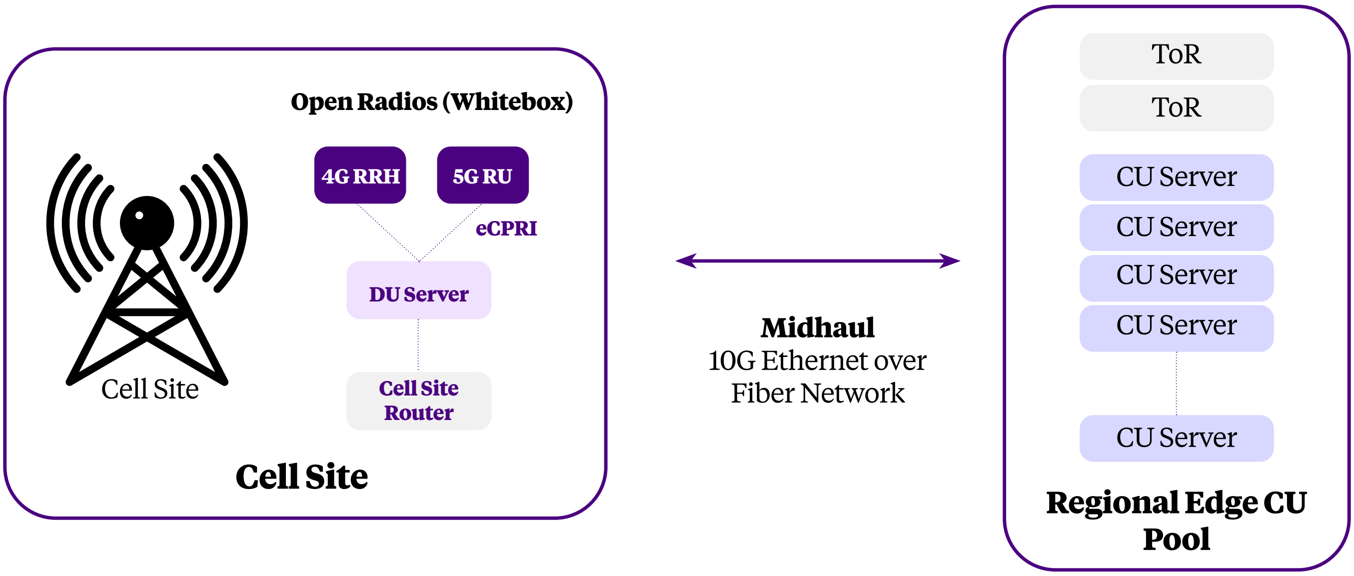

Figure 1. Example of DUs at the Cell Site, CUs in a Regional Pool

Timing of operators' initiatives

Each of the operators is engaged in the O-RAN Alliance toward developing specifications and the ecosystems related to implementing them. Some are deeply engaged as early and/or founding members, while others are involved at differing levels of specification contribution.[4] Each is deeply engaged in its own planning and developments toward its 5G RAN implementations.

Operators have generally begun their 5G deployments with some form of Non-Standalone 4G mobile core and 5G NR deployment. However, as standards such as 3GPP's Release 16 and (later in 2021) Release 17, and the O-RAN Alliance's specifications are completed, and products supporting them are brought to market, the stimulus for beginning to evaluate new scenarios for 5G network deployments is being created. In those cases, support for the more complete 5G Standalone end-to-end network and Service-Based Architecture starts to make sense. That can include starting to place 5G core network functions, such as user plane functions, in distributed sites adjacent to open RAN control software running in an open RAN CU pool. This may be done to start evaluating new RAN functions, such as those we mentioned previously, having to do with coordinated processing in both CU and DU pools in the open RAN design. It may be done to start testing functionality in new types of applications (such as URLLC or edge computing) or new radio capabilities using

[4] https://www.o-ran.org/membership

the newer specifications. All of these new 5G network functionalities are stimuli for beginning to evaluate the use of open RAN configurations in 5G RANs in greater depth and with more focus than has been possible previously.

Based on this progress in specifications and the arrival of products supporting them, operators indicated they expect 2021 and 2022 to be years in which open RAN designs will be evaluated in their labs, in collaboratively run community labs , and in trial sites they have identified. Evaluations in this period will focus intensively on the degree to which designs meet the functional objectives the operators have established for them. If implementations meet the objectives, operators expect the period from 2023 to 2025 to be years in which open RAN deployments will proceed faster and focus on a wider set of use cases.

Top challenges operators expect to face in open, virtual RAN adoption

Although there is pervasive commitment and enthusiasm for pursuing the use of open virtual RANs in their 5G networks, operators know that accomplishing those deployments will not happen without also addressing several significant challenges. In our discussions, five were identified as requiring the most attention:

- Element Interoperability
- Availability of Solutions
- Staff Skills
- Network Integration
- Deployment Scale

Element Interoperability

Operators know that open RAN designs are inherently modular and disaggregated (compared to the RAN designs they have used in the past). They know they will need to do extra work to ensure conformance with 5G and open RAN specifications from their open RAN suppliers, because of the greater number of suppliers they are likely to be considering. They also know there will be significant testing and validation to ensure the offerings function well in their operational environments. Addressing these points to ensure multi-vendor interoperability is one of the most important challenges they identified in considering use of open RANs in their deployments. It is one factor stimulating their investment in consortia, such as the O-RAN Alliance, and in collaborative testing centers, such as Open Testing and Integration Centers (OTICs), as means of containing their exposure.

[5] https://opennetworking.org/wp-content/uploads/2020/09/O-RAN-Embracing-Open-Ecosystem-09082020m.pdf, see Slide 19 regarding regional OTICs supported by members of the O-RAN Alliance as sites for evaluating O-RAN offerings in operator-specified test configurations.

Availability of Solutions

Although virtualization in the RAN has been an active area of R&D for multiple years, it is also true that work to create an open, disaggregated architecture and a set of specifications for open RANs has gained momentum and critical mass only in the past two to three years.[6] For example, many specifications in the O-RAN functional architecture have been approved in the O-RAN Alliance only in the past year. Although stakeholders' commitments are strong, operators know they are in the early stages of validating product implementations and need to work closely with suppliers until it is possible to use the solutions in production. Gauging this readiness is linked to the emphasis on interoperability (previously mentioned) and will have a strong effect on the timing of when trial and production phases will be implemented. As mentioned, most expectations are for 2021 and 2022 as the initial phase of test and evaluation to be the precursor for open RAN production deployments, materializing more broadly during 2023.

Staff Skills

Leading up to virtual and open RAN implementations for 5G it is safe to say operators have a strong and established track record in RF network engineering, site planning, radio deployment/operation, backhaul network design, and network operations. That said, with 5G and open RANs there are new capabilities whose operation needs to be mastered to make their new networks work. Technology evolutions in 5G RANs include new radio capabilities (new spectrum bands, new functionalities such as mmWave, massive MIMO, and beam forming), new component designs and new network architectures being deployed (baseband processing units disaggregated into modular RU-DU-CU implementations, RAN Intelligent Controllers being integrated into O-RANs). Transport networks are also evolving with new protocols and architectures being introduced that have not been used in preceding generations. For example, fronthaul transport between RUs at cell sites and DUs in centralized pools introduce new transport protocols such as eCRPI[7] , IEEE 1914.3 Radio over Ethernet, and Time Sensitive Networking[8] to support the new implementations. Similarly, running DUs and CUs as virtualized network functions in server pools using procedures historically handled by data center IT teams is a new collection of tasks to be mastered alongside running the new RF infrastructure designs. This introduces operations, support, and maintenance tasks into RAN operations that have not been a part of the required task set in the past, yet will be an integral part of the environment moving forward.

Some of the necessary familiarity with new implementations will be developed in hands-on work during operators' lab evaluations and trials, and more will come from various types of training and education. In some cases teams will need to be expanded by adding fiber transport and/or ICT infrastructure engineers to

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[6] See O-RAN Alliance specifications referenced in Footnotes 2 and 3 for details.

[7] http://www.cpri.info/downloads/eCPRI_v_2.0_2019_05_10c.pdf

teams already deep in radio engineering talent. Technical support will come from suppliers and integrators. Throughout the entire process a critical requirement for success is ensuring staff readiness to support the new implementations. Operators' teams are busy making sure they will have the necessary skills and core competencies to do that.

Network and Solution Integration

Assuming the interoperability and skill-level challenges have been addressed, there remain the tasks of bringing the new RAN infrastructures into operators' operations and business management systems as efficiently as possible. To some extent this is a normal task with the introduction of any new technology and platform. However, with open RANs and 5G the range of new designs being introduced is greater than in most prior deployments, and consequently the scope of the integration challenges is also greater.

To elaborate, there are multiple new radio capabilities to integrate and new control mechanisms to support them. Near-real-time and nonreal-time RICs will be introduced to support different portions of the control logic needed to run the RANs. New software modules, such as xAPPs running in Near-RT RICs, will need to be validated and deployed. Interoperability of the RIC based control and life-cycle management software with the CU-DU-RU infrastructures needs to be confirmed. Integration of the new architectures into the operator's overall OSS and BSS environment has to be accomplished (to ensure the RAN is aligned with service and network policies, that operations work smoothly with other areas of the operator's infrastructure, and integration with business support systems enabling the new 5G services is achieved).

Accomplishing this integration will involve contributions from both the operators' own teams and the suppliers and integrators with whom they have chosen to work. Although operators are clearly skilled at large-scale service and network deployments, they also recognize that integrating the range of innovations with which they are working in 5G is a significant challenge they must address. They are expending substantial energies putting resources and teams in place to ensure they can accomplish that.

Deployment Scale

The final challenge operators highlighted is the expanded scale of the networks they will be supporting in 5G over time. Increased density of radio deployment to increase the availability of services will be one source of expanded scale. This will occur in both macro and small-cell dimensions. The number of enterprise private networks operators support with 5G will be another source of expanded scale. Many of those cases will involve extending the operator's public infrastructure into an enterprise's facilities on a managed services basis.

[8] https://1.ieee802.org/tsn/

Growth on these dimensions means the operators will be supporting a larger footprint of operations. Although there is focus on introducing the tools and procedures that will allow this new scale of network to run successfully, operators consistently spoke about the need to plan for this expanded footprint as a key challenge in their 5G implementations. They will employ a range of approaches to supporting this expanded scale, including investing in new infrastructure, collaborating with wholesale and other providers that can augment their reach efficiently, and leveraging automation tools to increase their teams' productivity and reach. How effectively they can bring this blend of approaches to fruition in their own cases will have a significant effect on how well they can achieve their objectives in delivering new 5G services.

Result: Deep and Broad Commitment, Visions of O-RAN, Progress via Clearly-Scoped, Evidence-Based Phases and Steps

Operator leaders showed a deep and broad commitment to the strategic value of their 5G initiatives and an equally strong commitment to using open, virtual RANs in their deployments when their architectures align well with their service delivery requirements and when they are ready to deploy. Their motivations for prioritizing on the open RAN model are grounded first in a perception that they will provide the greatest overall efficiency in their deployments. This is coupled with a strong belief that open architectures will afford them a more robust platform for numerous types of innovation. There is strong and broad-based interest in the O-RAN architecture, as defined in the O-RAN Alliance, as offerings based on it are brought to market and validated.

Operators know that open RANs are an emerging model. Having invested substantially in their definition, they are prepared for calendar years 2021 and 2022 to be filled with testing, evaluation, and trials of the architectures in the types of use cases and coverage areas on which they are prioritizing. They expect 2023 to be the beginning of a more widespread use of the designs in both public and private wireless environments. They know that gains will only be achieved by overcoming the substantial challenges they face in preparing their teams for the introduction of the new designs, in validating the designs in their environments, and in scaling the introduction of the designs in their infrastructures in a reliable manner. Substantial planning, organizing, staffing, and engagement with suppliers and integrators is occurring pervasively in the community to address each of the challenges successfully.

By introducing open RANs in their 5G deployments, operators are focused on delivering new services, expanding their customer relationships, and growing their overall presence in their target market segments. However at the same time, because of the novelty of the architectures and the open questions about how efficiently and economically they can be deployed, they are evaluating the characteristics of the open RAN solutions as they are becoming available. They are looking closely at how open RAN architectures and offerings will align with the requirements they have in their various 5G deployment scenarios.

In support of those objectives, we developed an in-depth economic model of 5G RAN implementation approaches using ACG's Business Analytics Engine to help operators compare the TCO of alternative architectures in 5G RAN deployments. We expect the insights available from applying that model will be of material help to operators in defining their 5G RAN implementation plans. That model and a comparison of prominent 5G RAN deployment architectures are described in our companion paper to this report, The Economic Benefits of Open RAN Technology.

About the Author:

Paul Parker-Johnson is ACG's research lead in hybrid, multi-cloud infrastructures and their use in private, edge and public clouds. His current work is focused on use cases in industry 4.0 and vertical segments in which it is gaining uptake, including the use of machine learning and AI in distributed operations models. His long heritage of network design and analysis includes research on innovations in SDN, network functions virtualization, IP/MPLS and Segment Routing, open and disaggregated network architectures, and life cycle automation of ICT infrastructure deployments.

Addendum

A Backgrounder on Virtualized, Open RANs in 5G

Reference Information on Virtualized, Open RANs in 5G to Support Clear Understanding of the Analyses in the Two Papers Published About This Research

To set context for what we have investigated in this project and to the points we are highlighting in the papers written about it, we describe in this addendum (briefly) where virtualization happens in the 5G RAN and how open, virtualized RANs fit into 5G deployments.

First let's look at how RANs have been deployed before any of their processing has been virtualized. Figure 1 shows a RAN as typically implemented in mobile networks, primarily in generations before 5G. Note the integrated baseband processing unit at the cell site (the BBU). It provides radio control processing and user plane forwarding for the remote radio head (RRH) and radio units (RU) at the cell site. It is a physically integrated solution that interfaces the radios at the site with the rest of the operator's mobile network infrastructure over backhaul transport.

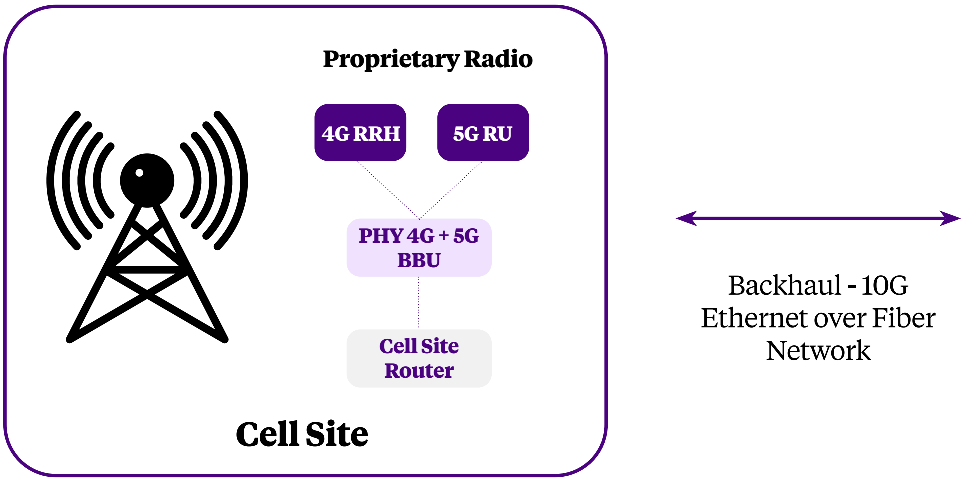

Figure 1. Physically Integrated Baseband Unit at Cell Site

Next, let's look at a proprietary virtualized RAN (vRAN), and after that, an open vRAN design. In a proprietary vRAN, some of the processing that controls the radios, along with forwarding of user data between the radios and the rest of the network, is separated out from the radios at the cell site and run separately in a general-purpose server. Processing for radios at one site can be co-located with processing for radios at other sites in a pool of servers at an aggregation point in the RAN and run as logically distinct, co-located functions.

In this way, baseband processing is virtualized, and a vRAN is created. Figure 2 shows such a design. The vRAN servers in the vRAN server pool are running software designed and implemented by one vendor and integrated into the network operations framework as a logical black-box by that vendor.

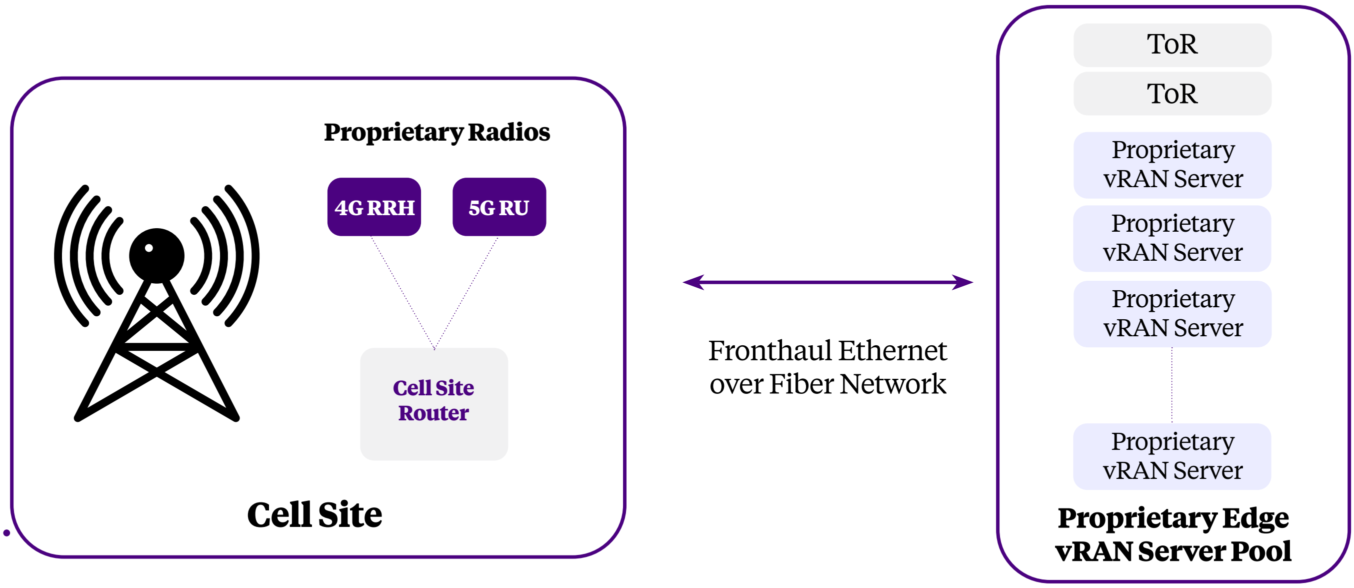

Figure 2: Proprietary vRAN Implementation

One benefit of this approach is gaining flexibility in how the radio controls of the network are deployed compared with how this has been done before. This can create more versatility and efficiency in the operation of the network than an operator has previously had. However, if such a design is implemented in a proprietary mode by a single supplier of the RAN solution, some of the theoretical flexibility one can obtain in a disaggregated implementation cannot be achieved. So a single supplier's proprietary vRAN, while presenting some advantages, still carries the constraint of being single-sourced.

An open RAN architecture, by contrast, supports participation by multiple vendors in a RAN using openly specified and documented interfaces between the elements of the RAN while also supporting the standardized functions of the broader network architecture that have been developed in other open forums, including 3GPP, ITU, IEEE, and IETF. In this manner an interoperable implementation of clearly defined functions can be chosen by an operator using any combination of suppliers they want at any of the points in the architecture that support the specification. In comparison to a proprietary implementation, an open RAN provides greater flexibility in supplier choice and in concept presents an opportunity for achieving various types of cost savings, for example, in lower prices for elements such as open radios or control software modules based on increased competition in the market for supplying them (more on this later). Figure 3 shows an open RAN architecture using one of the implementation options that has been defined for open RAN deployments by the O-RAN Alliance.

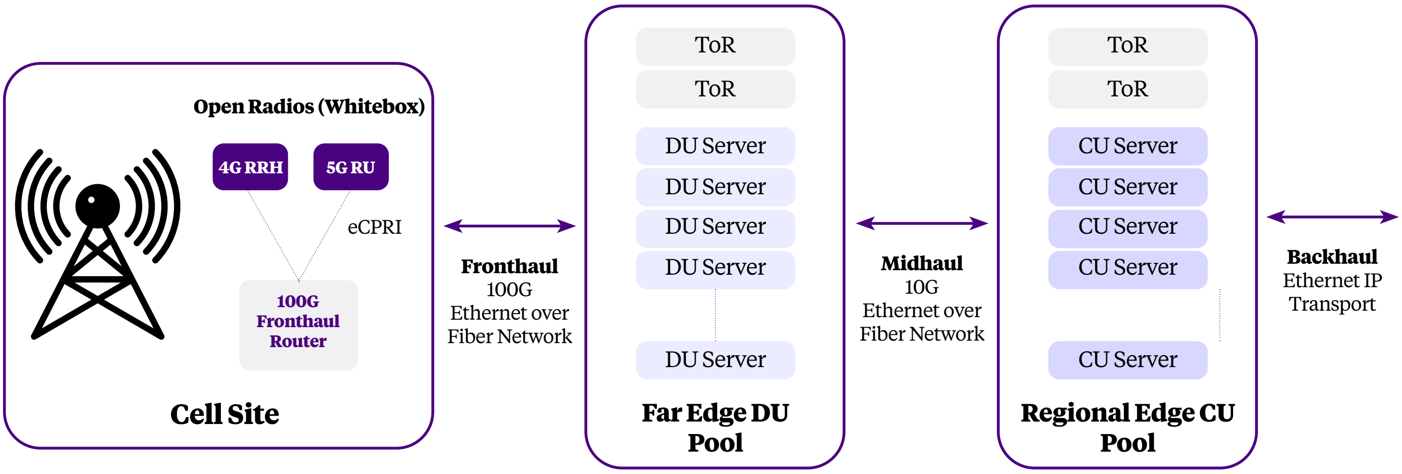

Figure 3. An O-RAN Deployment Using Disaggregated, Open, Modular Elements in a 5G RAN

The architecture for open RANs that standards development organizations and industry alliances[10] have developed defines a clear set of options among which vendors and operators can choose in deploying their 5G RANs. The options define how radio units, radio controls, user plane forwarding, and interfaces supporting the integration of the RAN into the rest of the operator's network can be deployed. By choosing between these options, operators can address distinct physical, technical, and operational characteristics that exist in different parts of their networks with designs that work well for each one (deploying into dense urban versus suburban or rural serving areas, for example).

The approach used in developing these options has been to define three types of infrastructure elements that can be used in an open RAN. Each can perform a subset of the functions required in the 5G radio protocol architecture. Those functions span from the lowest physical layer of operation (such as radio signal processing in a radio interface) through an intermediate set of processing and control layers, to the highest layer where the RAN hands off user data frames to other parts of the operator's network. The elements are:

- Radio Unit (RU)
- Distributed Unit (DU)
- Centralized Unit (CU)

RUs provide radio functionality at the cell site. DUs provide a number of functions supporting the operations of the radios, assembling and disassembling data units in their journey between the radios and higher level portions of the network. CUs provide the highest level interface between the RAN and other parts of the network, including the backhaul and the 5G core, and the management and orchestration functions associated with the RAN (via its higher level RAN Intelligent Controllers or RICs, and their management and control software applications).

[10] These include 3GPP, the ITU, and the O-RAN Alliance's working groups focused on defining the overall network and the RAN architecture and specifications that industry participants can use in developing their 5G deployments.

DU operations with respect to the radios need to be performed within extremely strict latency boundaries, whereas CU operations are less time constrained. Thus, there are limits as to how far away from radios DUs can be installed (typically 15–20 km), and there are bandwidth and capacity requirements that must be met for DU <-> RU links (significantly higher than for the DU <-> CU links). For this reason there are a number of trade-offs in how the options for deploying the RAN elements are chosen, because the requirements of the radios being used and the capabilities of the transport network available for connecting DUs and CUs with them must be considered.

Figure 4 illustrates this partitioning with more granularity and shows how it supports implementation options available to use in open RAN solutions; we include a diagram to show the function blocks in the architecture that are used to define the options. The diagram illustrates functions in both downlink and uplink directions. At the right end of the diagram is the RU, which interfaces to the RF domain. The blocks proceed to the left and upward in the protocol stack to the Packet Data Convergence Protocol (PDCP) and Radio Resource Control (RRC) functions, which provide the interface of the 5G RAN to the 5G core, the operator's backhaul transport, and its higher-level management applications.

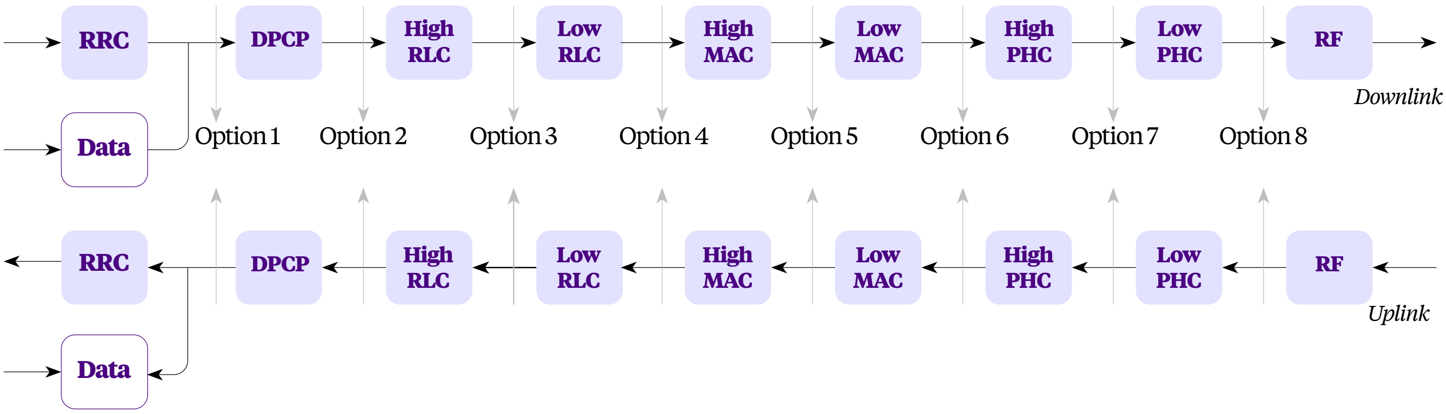

Figure 4. 5G Radio Protocol Function Blocks and Their Alignment with Open RAN Module Implementation Options[11]

The options that have been defined for how the functions can be combined into implementations are shown by the red arrows marking the point of interface between layers in the architecture that would exist in the implementation. Functions to the right of the demarcation are implemented in elements placed closer to the RU at the cell site. Functions to the left are disaggregated and placed at a site some distance from the cell site and its RUs. Those functions are combined in DU and CU modules that provide the capabilities required in each block.

[11] Source, A Flexible X-Haul Network for 5G and Beyond, Jorg-Peter Elbers and Jim Zou, Adva Optical, OECC/PSC Japan, 2019, Slide 8, also citing China Mobile Research Institute, Toward 5G C-RAN: Requirements, Architecture and Challenges, November 2016.

The options most frequently under consideration in both industry consortia and the operator community in planning their 5G RANs are options in the Option 7.x collection and Option 2. In the 7.x collection note that only the lower layer PHY and the RF functions are intended to remain at the cell site, while the rest of the functions (from higher layer PHY up to PDCP and RRC) are available to be implemented in DU and CU elements located centrally, away from the cell site. The connection between lower layer PHY and higher layer PHY occurs over fronthaul transport, requires adherence to strict latency bounds, as well as substantial transport capacity because of the volume of control traffic being supported. Option 2, by contrast, allows the majority of the radio protocols to be operated at the cell site and only a small subset of the higher layers in the stack to be run centrally.

Within the collection of options associated with Option 7, the O-RAN Alliance has aligned on Option 7.2 as the one its members have agreed will optimize deployments in most circumstances where centralized DUs are of interest.[12] In parallel, Option 2 has been identified by the Small Cell Forum as frequently preferred, as it allows a compact cell to be deployed, keeping many of the controls needed for network integration closely bundled into the small-cell implementation.

We have described the options that have been agreed upon for open RAN implementations in this way because the deployment scenarios we have explored with operators and which are included in the RAN economic modeling we have done are integrally related to this set of options for deploying open, virtualized RANs in 5G. When we refer to centralized versus distributed designs or when we mention placing DUs at cell sites versus deploying them in virtualized resource pools, we are referring to the manner in which the functions at the different layers of the 5G radio protocol stack are deployed to support a set of functional requirements in a particular 5G RAN scenario. By clarifying this terminology and the functions to which it is referring, it is more straightforward to consider the information in our reports about the operators' perspectives on their deployments and about the economic modeling we have done to compare deployment alternatives.

When we bring the considerations full circle to the analyses we have done in this research, we have reached an important juncture in the market's developments with respect to how RAN solutions will be deployed in 5G. Having agreed on what the architectures and the specifications are for how open RAN solutions can be developed, it is now time to assemble the evidence about their viability and appeal. Via lab testing, field trials, and early stages of deployment operators will determine where they can practically use open RAN designs, how soon, and for how much benefit.

Those questions are at the heart of this research. Its first part focused on discussions with prominent operators about their considerations in deciding where, when, and why they believe they will use open RAN designs in 5G. Those findings are summarized in the paper to which this vRAN Backgrounder is attached. In the second part we developed an in-depth economic model of the total cost of ownership of open RANs in 5G and used it to compare the economics of the most prominent options operators are considering in developing their 5G plans. The attributes of that model and the results of those comparisons are shared in The Economic Benefits of Open RAN Technology.