IP transport for 5G C-RAN architectures

Design considerations for mobile network operators

Application Note

Abstract

As mobile network operators (MNOs) plan how to increase the capacity and density of their RAN networks to support 5G applications, they are examining the merits of centralized RAN (C-RAN) architectures to reduce costs at cell sites and realize performance gains by pooling baseband resources at nearby hub sites.

At the same time, they are looking to a future that includes using virtualized RAN (vRAN) and eventually Open RAN to increase network scalability and reduce costs.

MNOs also need to support applications closer to end users to improve user experience and to reduce the amount of traffic being carried across their networks. They are evaluating how best to create their own data center environments and partner with public cloud providers for these applications.

This application note examines these changes and their implications for IP transport networks. It describes how the Nokia IP Anyhaul solution meets new mobile transport requirements with the flexibility needed to deliver on the promises of 5G—and beyond.

Contents

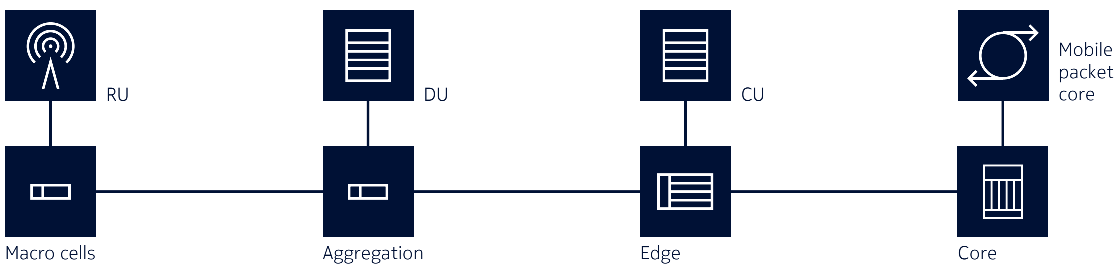
Mobile network transformation

As mobile network operators (MNOs) plan how to increase the capacity of their mobile networks in response to rising demand and in support of 5G applications, they are investing in new 5G spectrum and adding more cell sites. In doing so, they are considering the use of centralized RAN (C-RAN) architectures in some situations. Typically, these are where RAN cell sites are densely deployed within a geographic area.

C-RAN is used in 4G networks but with 5G, MNOs have more options for how they will deploy it. The 3GPP has defined new RAN functional splits, giving MNOs more flexibility to place RAN functions where needed to meet constraints such as performance, power, space, latency and cost.

One example of how RAN functions can be deployed is shown in Figure 1, which has a combination of radio units (RUs), distributed units (DUs) and centralized units (CUs).

Figure 1. C-RAN with new 5G RAN functional splits

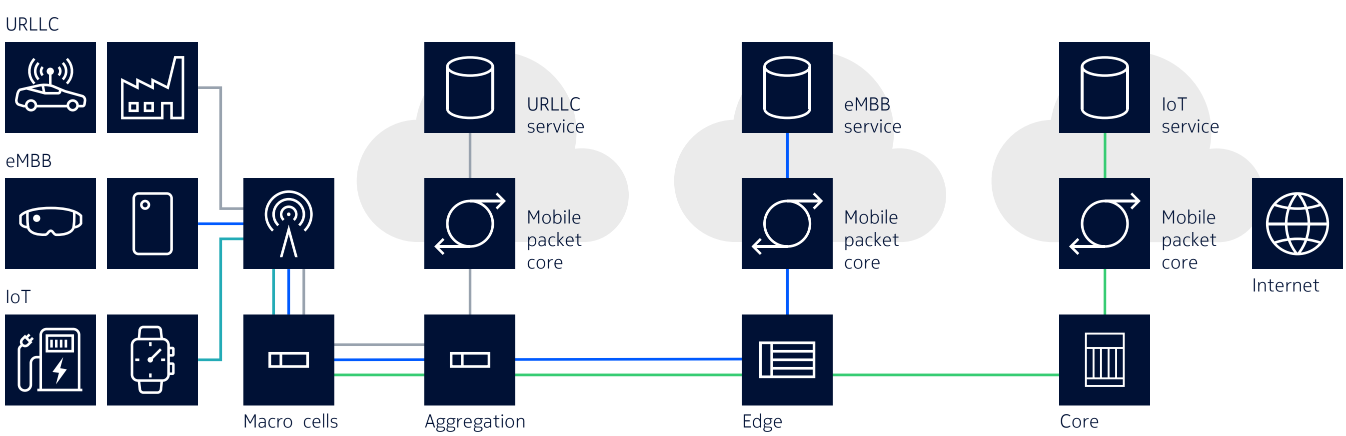


In addition to 5G RAN functional splits, 5G baseband functionality can be virtualized—running as virtualized network functions (VNFs) on data center servers.

MNOs also need to provide cloud services closer to end users for hosting latency-sensitive applications and to improve network utilization. This requires the disaggregation of some mobile core functions, placing them in edge cloud locations with applications rather than only at a centralized core location (see Figure 2).

Each application will have different needs for bandwidth, latency, timing and synchronization.

Figure 2. Edge cloud options



Mobile transport used to be a simple matter of setting up point-to-point services from cell sites to central mobile core locations. Now it is necessary to build transport connections between cell sites, disaggregated RAN and core network functions, and applications scattered at various nodes around the network. Moreover, these connections all require different levels of service.

It's a tall order.

Benefits of C-RAN architectures

C-RAN architectures save money and operational cost by having a pool of 5G baseband units (BBUs) at central locations that can be shared by the 5G radios in the cell sites. The benefit is greater when sites are denser because more resources are being shared.

Placing 5G BBUs centrally reduces costs at the cell site due to lower CAPEX, smaller space requirements, less power consumption and reduced truck rolls for troubleshooting and maintenance. Combined, these factors are the number one reason for centralization.

Centralizing baseband equipment facilitates communication and coordination between radios for functions such as coordinated multipoint transmission and carrier aggregation. Centralized processing can improve performance, resulting in improved user experience, better spectral utilization and less control plane traffic to carry between cell sites.

Having the 5G BBUs centralized also provides an evolutionary path to virtualized RAN (vRAN) and Open RAN architectures. The decomposition of the baseband functions into a virtualized CU (vCU) and a virtualized DU (vDU) enables the separation of the hardware and software. This separation allows the software to run on generalized hardware, saving money on hardware and introducing more flexibility and scalability.

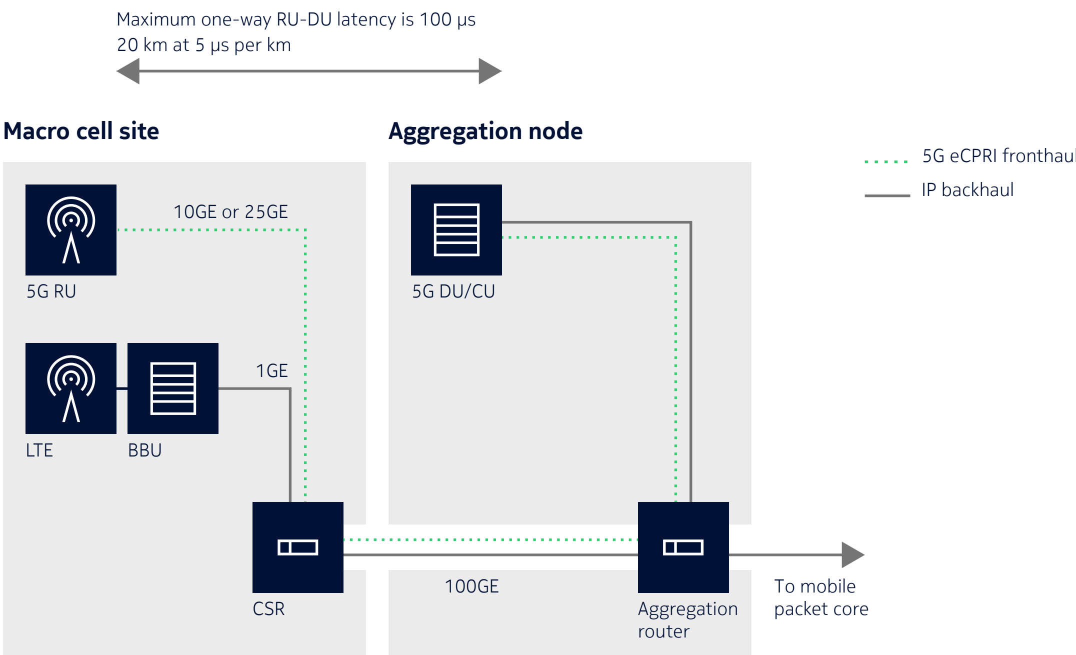
When coupled with open, standardized interfaces, the vCUs and vDUs also allow for multivendor solutions.

New 5G features make C-RAN implementation more feasible than it was in 4G. The functional splits in the enhanced Common Public Radio Interface (eCPRI) protocol result in more processing being done at the radio site than was possible with CPRI. Less data is transmitted to the centralized baseband, so less bandwidth is required—up to ten times less than with CPRI. Taking advantage of statistical multiplexing by using packet transport (Ethernet) provides even better gains.

4G D-RAN + 5G C-RAN hybrid network

Although 5G RAN may be centralized in some locations, it is likely that existing 4G decentralized RAN (D-RAN) systems will be left as they are to preserve existing investments. As a result, the first example network configuration to consider is a 4G D-RAN + 5G C-RAN hybrid network (see Figure 3).

Figure 3. Example of 4G D-RAN + 5G C-RAN hybrid network



In a typical 5G fronthaul application, the 5G RU is collocated at an LTE cell site. The 5G BBU, including both the DU and the CU in this example, is located at the aggregation node.

For good RAN performance, the maximum one-way latency between the RU and the DU is 100 µs. When fiber is used, latency of light over fiber is 5 µs per kilometer, resulting in a maximum distance of 20 km. For more latency considerations, see the ”Latency” section.

In this example, the 5G RU has 10GE or 25GE ports and is transmitting eCPRI fronthaul. Because eCPRI is Ethernet-based, it can be carried directly over time-sensitive Ethernet transport networks.

5G eCPRI fronthaul traffic from the 5G RU is forwarded by the cell-site router (CSR) to the aggregation router. From there, it is routed to the 5G DU/CU at the aggregation node. Upon completion of its DU/CU processing, what is now backhaul traffic transfers to the aggregation router, which then forwards it upstream to the mobile packet core.

While not shown in Figure 3, the CSR may also need to collect and aggregate other traffic streams. Macro cell sites typically support multiple generations of RAN equipment and may also support monitoring equipment and business services. These different traffic flows can be efficiently aggregated using a converged transport network to minimize cost.

In Figure 3, legacy 4G traffic leaves the BBU at the cell site in IP format and is routed as it has always been, through the CSR and the aggregation router and directly upstream to the mobile packet core.

Latency

As already mentioned, the maximum one-way latency budget between the RU and the DU RAN functions is specified as 100 µs. In practice, the actual latency budget depends on the RAN equipment itself, and there is some variability depending on the equipment used.

MNOs want to maximize the distance between the RU and DU so that their central RAN BBU site will have greater reach. This will allow each C-RAN site to serve more cell sites, reducing both CAPEX and OPEX.

In addition to the latency of light over fiber, another contributor to latency is the nodal delay time for packets to be received, processed and retransmitted by each router in the path. Nodal delay times for the current generation of routers are under 5 µs. Older generations of routers have nodal latency of 10 – 20 µs.

For fronthaul applications, MNOs need to consider the total nodal latency of all the transport platforms in the path between the RU and DU to ensure it will be within the latency budget. This is especially pertinent when cell sites are connected in ring rather than in point-to-point configurations.

MNOs can also use router quality of service features to ensure that fronthaul traffic is prioritized over backhaul or enterprise traffic and avoids queuing delays in the routers.

Synchronization

Synchronization is essential for the proper operation of the mobile network and for enabling functions such as handovers and cooperative processing to work properly.

In 2G, 3G and 4G frequency-division duplexing (FDD) mobile radio networks, frequency synchronization sufficed to provide accurate timing. 4G LTE-A (LTE – Advanced) features such as CoMP and eICIC, 4G time-division duplexing (4G TDD) and 5G radios all require both frequency and phase/time synchronization.

While Synchronous Ethernet (SyncE), the IEEE 1588v2 Precision Time Protocol (PTP) and Global Navigation Satellite System (GNSS) all provide frequency synchronization, PTP and GNSS are required for phase and time synchronization. SyncE and PTP are used together for better accuracy because having a stable frequency aids in accurate time and phase recovery using PTP.

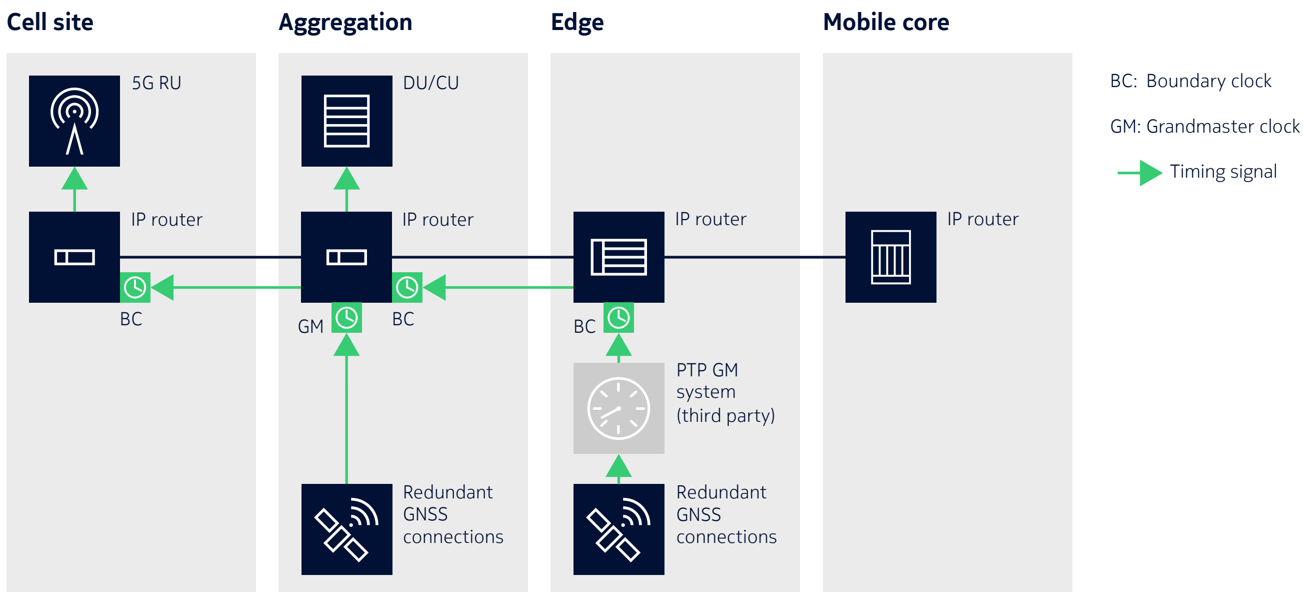
In 5G there will be many more radio locations, including small cells. Having a GNSS receiver at each cell site for timing would be cost prohibitive, so MNOs will need to have primary reference timing clocks distributed in their network, then use the network to distribute timing to all the RAN nodes. Also, with the danger of GNSS blocking, redundant timing sources will be required for network reliability.

Network timing

MNOs have many options for addressing timing in their networks.

In the example shown in Figure 4, which will be common in C-RAN scenarios, a GNSS connection provides the timing signal at the aggregation node using the integrated satellite receiver on the aggregation router. The router has PTP grandmaster clock capability and passes the signal to the DU/CU BBU at the aggregation site and to the RU at the cell site.

Figure 4. Network timing example



A backup timing signal comes from a timing source located at a different node in the network. The number of nodes in the path and the accuracy of their timing capability must be considered to ensure that the timing signal stays within the timing error specifications for fronthaul.

For communication between the RU and DU over fronthaul in 5G centralized topologies, there are very stringent specifications for time error.

New specifications

For phase and time synchronization, ITU-T G.8273.2 is the important new specification for timing accuracy applicable to fronthaul. In this specification, Class C is more stringent than Class A and Class B and is needed for 5G fronthaul. Class B is becoming a requirement for midhaul and backhaul applications.

For frequency, ITU-T G.8262.1 is a new enhanced Ethernet equipment clock specification that is about five times more stringent than the previous G.8262 specification. Compliance to G.8262.1 is necessary to achieve the required performance for G.8273.2 Class C and Class D for more accurate time/phase synchronization.

Several models of the Nokia 7250 Interconnect Router (IXR) product family, targeted at fronthaul, access and aggregation, are compliant with these new specifications, including G.8273.2 Class C. Other 7250 IXR and Nokia 7750 Service Router (SR) products are compliant with G.8273.2 Class B. In addition, Nokia routers use a proprietary Nokia Bell Labs algorithm for improved accuracy of the IEEE 1588v2 time protocol.

Routers in the 7250 IXR-e and 7250 IXR-R product lines, targeted at cell-site and C-RAN hub applications, are equipped with GNSS receivers and grandmaster clock capabilities. Various other Nokia platforms support GNSS SFPs. These SFPs provide both the GNSS receiver and PTP grandmaster capabilities. Using Nokia routers as grandmaster clocks saves having to buy and maintain additional external timing equipment.

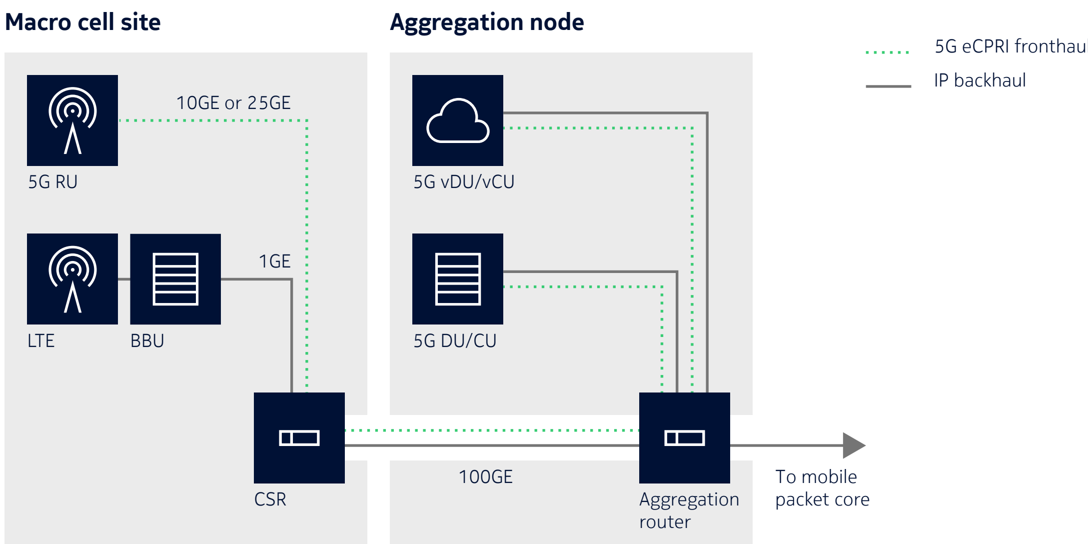
Evolution to vRAN and edge cloud architectures

Looking further ahead, MNOs may consider evolving to vRAN and edge cloud architectures.

vRAN

In time, MNOs may want to adopt a vRAN architecture, putting the CU/DU functions into a server architecture such as the Nokia AirFrame Data Center solution or a commercially available off-the-shelf server. Centralization of the RAN baseband functionality (see Figure 5) facilitates this virtualization.

Figure 5. Example of a vRAN architecture



MNOs may want to adopt vRAN incrementally, adding the virtualized architecture for new services while maintaining existing services on the physical RAN architecture.

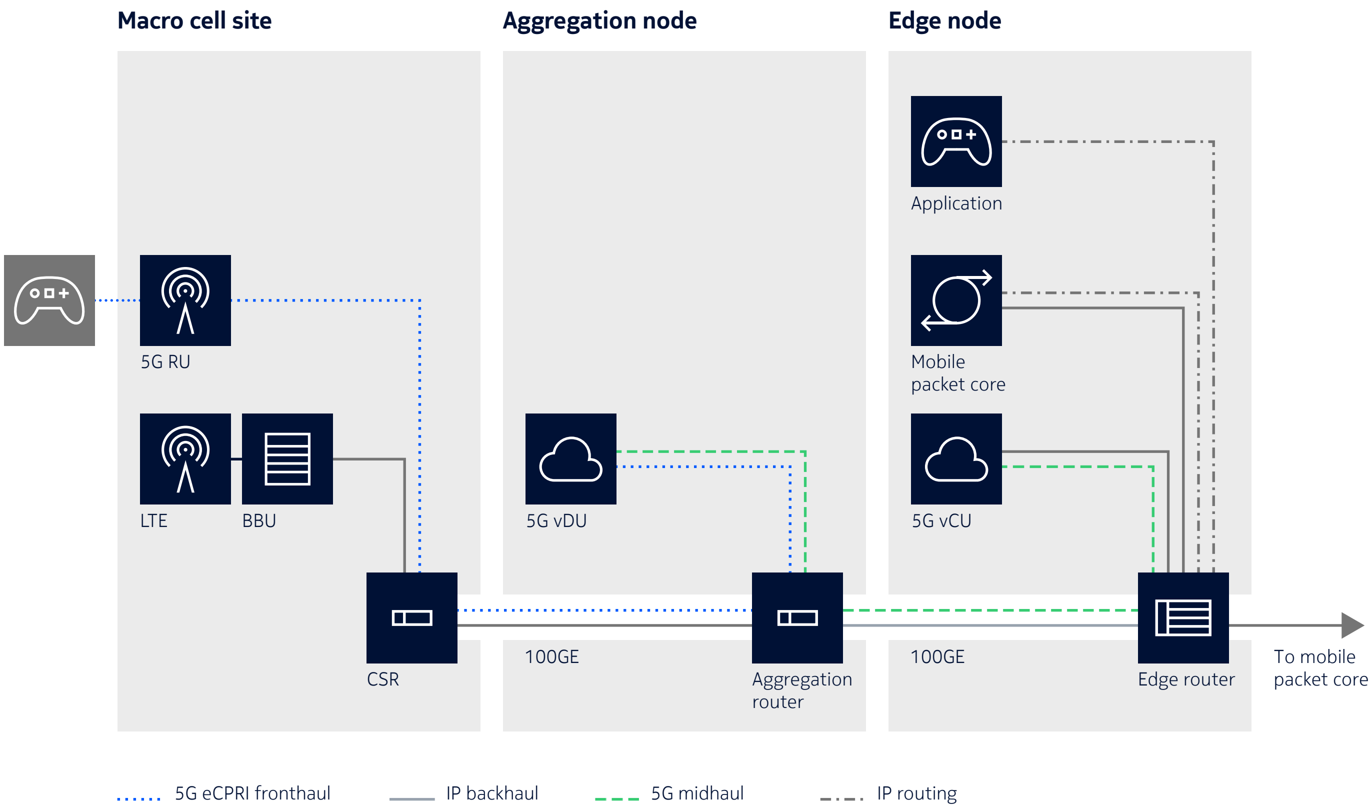
In a vRAN architecture, the transport network needs to provide connectivity to the virtualized functions running on servers with the same latency, timing and other fronthaul and midhaul performance requirements as it does with physical RAN components.

With 5G, another option is to have the vDU functionality at the aggregation node and vCU functionality at the edge node, connected by midhaul transport, as shown in Figure 6.

Edge cloud

In addition to vRAN, MNOs may want to host end-user applications close to end users to provide the quality of experience their customers expect. To do this, MNOs can set up an edge cloud architecture at their aggregation or edge sites, such as in the example shown in Figure 6.

Figure 6. Example of edge cloud architecture



To support applications at the edge node, MNOs would also need virtualized packet core functionality.

In this example, the transmission from a gaming application is received by the 5G RU at the cell site, then transmitted to the 5G vDU function on a server at the aggregation node. From there, the transmission moves to the edge node for processing at the vCU and the edge packet core functions before being delivered to the application's compute functionality.

Automation

The disaggregation of RAN and core network functions and the ability to place applications at aggregation and edge nodes provide agility to respond to user needs with new revenue-generating and cost-effective services. In these new network implementations, automation will be required for rapid, reliable provisioning and troubleshooting.

Segment routing adoption is accelerating because it simplifies the operational work required to set up routing tunnels between physical and virtualized network functions and applications. It facilitates workflows across functions located in various sites and servers. Adding traffic engineering to segment routing increases resiliency, aids in prioritizing low-latency traffic and improves network utilization.

Automation tools in network management platforms such as the Nokia Network Services Platform (NSP) provide end-to-end traffic engineering, including dynamic rerouting in the event of failures and load balancing according to preset policies.

For best performance, detailed telemetry data is required from the routers. Nokia Deepfield network analytics provide even greater insight for load balancing as well as threat detection and mitigation.

Zero-touch provisioning speeds deployment, reduces provisioning errors and leads to overall cost reduction.

These advanced IP routing and network management features are required for the eventual implementation of network slicing, where end-to-end connectivity is quickly and easily established across RAN, transport and core networks to support customized service offerings for new applications.

Security

Moving applications to the network edges opens up new security threats, particularly where third-party application and cloud providers and additional internet connections are involved. Enhanced security, as provided by Nokia FP-silicon-based router platforms, is required.

FP-based Nokia 7750 SR routers are designed to filter out attacks against their own operation and, when combined with Deepfield analytics, can screen out distributed denial of service (DDoS) attack traffic at the network edges.

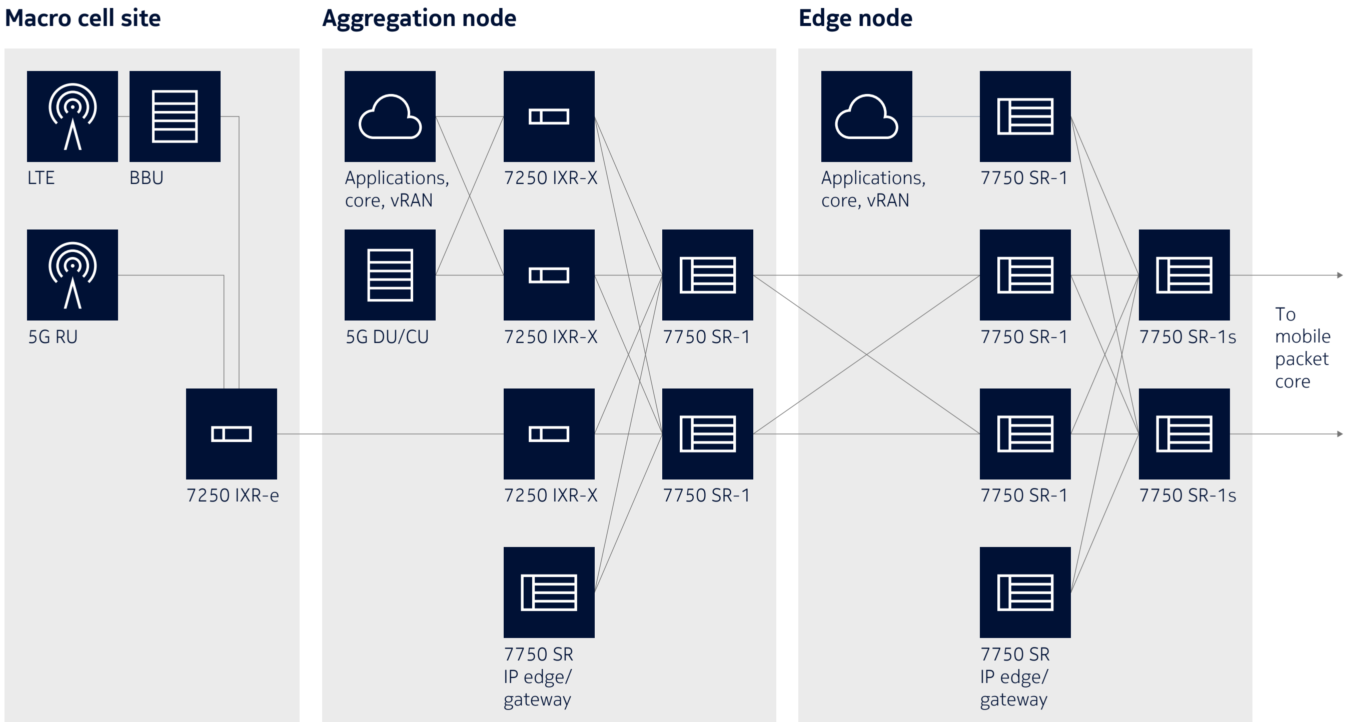
Nokia routers also protect user data with efficient firewall and IPsec capabilities that minimize the impact on data processing performance.

Nokia IP Anyhaul portfolio

The Nokia IP Anyhaul portfolio helps you get to 5G faster by meeting mobile network transformation requirements coming from centralized and virtualized RAN architectures as well as edge cloud implementations. It is widely deployed in networks around the world.

The portfolio provides choices for scaling both interfaces and bandwidth. In chassis-based architectures, operators can add cards or satellite port-extension routers as needed for growth. Alternatively, leaf-spine architectures at hub and edge nodes provide flexibility but still require the full capability set of carrier-class network routers (see Figure 7).

Figure 7. Example C-RAN and edge cloud implementation



Nokia 7250 IXR

The Nokia 7250 IXR routers provide highly scalable interconnectivity. They feature multi-rate port interfaces, including native 25GE, to allow cost-effective port speed upgrades over time. The 7250 IXR routers support fronthaul timing specifications, for highly accurate timing distribution.

The cost-effective 7250 IXR-e series is widely deployed as CSRs. The routers have 10GE and 25GE client interfaces for RAN connections and 100GE interfaces for their uplinks.

The Nokia 7250 IXR-R series provides redundant control and more scalability than the 7250 IXR-e series. The 7250 IXR-R routers are used in cell sites where more ports are needed and in aggregation applications.

Both the 7250 IXR-e series and the IXR-R series have integrated GNSS receivers along with grandmaster PTP timing capability. Compact and temperature hardened for cabinet installations, the routers can be flexibly deployed in diverse environments.

The Nokia 7250 IXR-X series allows cost-effective scaling in aggregation applications. These routers feature high densities of 10/25/40/50/100 and 400GE interfaces in space-saving 1RU platforms. The 7250 IXR-X series features exceptionally low power consumption (less than 0.1 w/Gb), which substantially lowers their operational cost compared to other solutions.

Nokia 7750 SR and Nokia 7750 SR-s

The Nokia 7750 SR and Nokia 7750 SR-s are built with Nokia FP silicon and have a range of models to fit various aggregation and edge roles in anyhaul implementations.

These routers provide higher scalability than the 7250 IXR routers along with the enhanced security plus IP edge and gateway services that are essential at edge cloud nodes.

Nokia SR OS

All routers in the IP Anyhaul portfolio use the same Nokia Service Router Operating System (SR OS) software to provide high-performance services consistently across the transport network. The Nokia SR OS is purpose-built to meet extreme reliability demands through real-time, modular and highly fault-tolerant operating system design.

With full IP routing and service capabilities, including support for Ethernet VPN (EVPN) and segment routing, the Nokia SR-OS has the intelligence to deliver the most stringent SLAs and end-user quality of experience. End-to-end network slicing is fully supported.

Nokia NSP

The Nokia NSP simplifies network management, orchestration and control. Its SDN controller capabilities allow network engineers to control the network and optimize traffic in real time.

Path computation, end-to-end traffic engineering and transport controller functions provide the automation critical to connect vRAN and core network functions and to facilitate network slicing. With automation you can deliver new services in hours rather than days or weeks.

Summary

To increase the capacity and density of RAN transport networks and to support 5G applications, MNOs are considering C-RAN and edge cloud architectures. The options are varied, and one size does not fit all.

To determine the best architecture to meet their needs, MNOs must consider many factors, including the types of RAN technology to be supported, ongoing RAN network transformation, plus potential applications and their bandwidth, latency, timing, and security needs. Based on their current network and future needs, MNOs can then decide on 5G RAN and transport network implementations that will work for them now and into the future.

The Nokia IP Anyhaul portfolio meets all the transport requirements of disaggregated RAN and core architectures as well as edge clouds, to help speed the journey to 5G.

Nokia - a trusted partner

The Nokia IP Anyhaul solution is a continuation of our decades-long commitment to excellence in mobile transport networks.

Nokia IP Anyhaul is deployed in hundreds of networks worldwide, including all major North American mobile networks. The portfolio supports agile and cost-effective evolution to 5G with maximum investment protection.

Nokia IP Anyhaul is the industry's most comprehensive portfolio of purpose-built IP/MPLS mobile transport platforms. Our commitment to continuous innovation makes us an ideal partner for evolving to 5G.

With Nokia, MNOs can rest assured that their investment will safely accommodate future growth.

We complement our product offering with a full set of services to help our customers plan, build, integrate and operate mobile anyhaul networks with a holistic view of the entire network. Our global reach, expertise, operational consistency and agility make us a trusted partner.

Learn more

To learn more about Nokia IP Anyhaul, visit the web page.

Abbreviations

BC	boundary clock
BBU	baseband unit
CAPEX	capital expenditures
CoMP	Coordinated Multipoint (transmission/reception)
CPRI	Common Public Radio Interface
C-RAN	centralized RAN
CU	centralized unit
D-RAN	distributed RAN
DU	distributed unit
eCPRI	enhanced CPRI
eICIC	enhanced Inter-Cell Interference Coordination
eMBB	enhanced Mobile Broadband
EVC	Ethernet virtual circuit
EVPN	Ethernet VPN
FDD	frequency-division duplexing
GE	Gigabit Ethernet
GM	grandmaster
GNSS	Global Navigation Satellite System
IoT	Internet of Things
IP	Internet Protocol
LTE	long term evolution
MNO	mobile network operator
OPEX	operating expenditures
RAN	radio access network
RoE	Radio over Ethernet
RU	radio unit
SLA	Service Level Agreement
URLLC	Ultra-Reliable Low-Latency Communications
vCU	virtualized centralized unit
vDU	virtualized distributed unit
VNF	virtualized network function
VPN	virtual private network
vRAN	virtualized RAN

About Nokia

At Nokia, we create technology that helps the world act together.

As a B2B technology innovation leader, we are pioneering the future where networks meet cloud to realize the full potential of digital in every industry.

Through networks that sense, think and act, we work with our customers and partners to create the digital services and applications of the future.

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