The future role of transport networks in 6G

Architectural requirements and innovative approaches

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White paper

Sustainable transport networks will play a crucial role in future mobile networks by offering a fast and reliable underlying communications infrastructure, even though their strategic importance is often overlooked or underestimated. Key challenges facing mobile operators are high data rates, massive connections, and sharply rising network complexities. This white paper discusses the technology drivers and architectural impacts.

Contents

Mobile network evolution

Current 3GPP Rel. 18 mobile standards and preliminary 6G work [1, 2, 3, 4] envision a re-vamp of today's rather rigid radio architectures for the Metaverse era. The renewals must prioritize cost-efficiency and flexibility to accommodate a myriad of new business models and service patterns. In response to these challenges, 3GPP and prominent industry interest groups, such as the O-RAN Open RAN Alliance, have proposed novel architectural concepts with enhanced split options and new interfaces.

Towards cloud-native architectures

The highly concentrated functions of a base transceiver station (BTS) in today's radio access networks (RAN) need to transition towards more flexible deployment schemes, along with an increased openness. This evolution involves processes like decomposition, disaggregation, virtualization and cloudification, commonly referred to as cloud RAN architectures.

Although mobile revenue growth is expected to remain stagnant in the next five years, there will be a significant surge in mobile subscribers and cellular traffic demand. Projections indicate around eight billion active 5G subscribers [5] and 3.7 Zettabytes of global cell traffic by 2028 [6]. Limited revenue growth will constrain the capital spending of mobile network operators (MNO), thus making scalable and energy-efficient transport solutions essential for future RAN expansion, densification or technology upgrades.

Importance of transport networks

To enable this architectural transformation, a high-performance transport infrastructure that connects all RAN instances is crucial. It needs to economically scale from very local intra-site to vast geographical areas, including non-terrestrial locations. 5G has already highlighted the significance of the transport layer in new cloud-ready RAN deployments, especially in the very cost-sensitive access and metro domains. New RAN interfaces require advanced transport solutions to cope with a significantly increased number of managed connection points and sharply rising network complexities. New, advanced RAN functions like distributed MIMO systems, or cell-free networks require the distribution of ultra-precise synchronization information from a primary reference timing clock (PRTC) over the entire network. Finally, as a main request of incumbent operators, future transport networks need to be ready not only to serve mobile premises, but data centers, enterprises and fixed broadband locations too in a well converged and unified manner.

Network architecture transformation

3GPP architecture directions

Recent 6G pre-studies propose novel IT-based network concepts and new paradigms by de-composing and re-architecting the RAN, mobile core and transport domains into programmable solution platforms managed under a common orchestration framework in a truly end-to-end (E2E) fashion. These renewed platforms aim to be open, programmable, dynamically scalable, highly secure, and ultra-reliable. Network functions and their resources can largely be moved or pooled where and when needed, for example, to encounter unforeseen traffic demands. The very efficient use of deployed network resources is key for operators to minimize their total cost of ownership (TCO) and improve their return on invests.

Re-architecting principles

Network re-architecting, a term adopted from the IT industry, means breaking down, virtualizing, and opening today's rather monolithic network architecture into smaller functional pieces and units. The network functions of such renewed architectures can be either physical (PNF), or virtual. Network function virtualization (NFV) refers to the move of network functions from hardware (HW) into virtualized network functions (VNF), or even containerized functions (CNF), run on cloud-native platforms.

Figure 1 shows the principle of the transformation on a simplified view: traditionally, LTE and 5G BTSs are deployed in a highly distributed manner (D-RAN) attached to mobile core facilities via an aggregating mobile backhaul network, with several packet switching and routing units (SRU) and transmission line units (TLU) in between. All network domains (RAN, transport and mobile core) have their own management systems (NMS), acting rather independently from each other.

The transition to a renewed architecture impacts all network domains. This shift will allow a vast variety of very cost-efficient implementation options to fulfil the MNOs' individual strategic directions, technology preferences, customizations, or adjustments to local conditions.

In the RAN domain the function of a BTS can be vertically decomposed into smaller entities, namely into radio (RU), distributed (DU) and centralized (CU) units, also referred to as a split RAN architecture. Where applicable, the units can be further horizontally separated and pulled apart into user and control/management plane instances, a process called CUPS. For example, in the case of CUs into several CU-UP user planes, and a CU-CP control plane instance. The instances can even be further virtualized, such as a vCU-CP residing in a telco cloud. The same principles can be applied to the core or transport network domains, which are also depicted as disaggregated S&R and TL layers in Figure 1.

Software-defined networking (SDN) concepts re-target the complex control plane parts by decomposing them into freely movable software functions to be processed centrally in the network control layers such as SDN controllers managing the transport domain. SDN controllers can serve and manage thousands of separated user plane (or forwarding) instances. In the very cost-sensitive access domains, all transport user plane functions are usually integrated into one compact network device (TL-SRU). These less complex and smaller transport domains are usually served by only one SDN controller. SDN-based approaches allow end-to-end (E2E) enabled and orchestrated service management across all domains.

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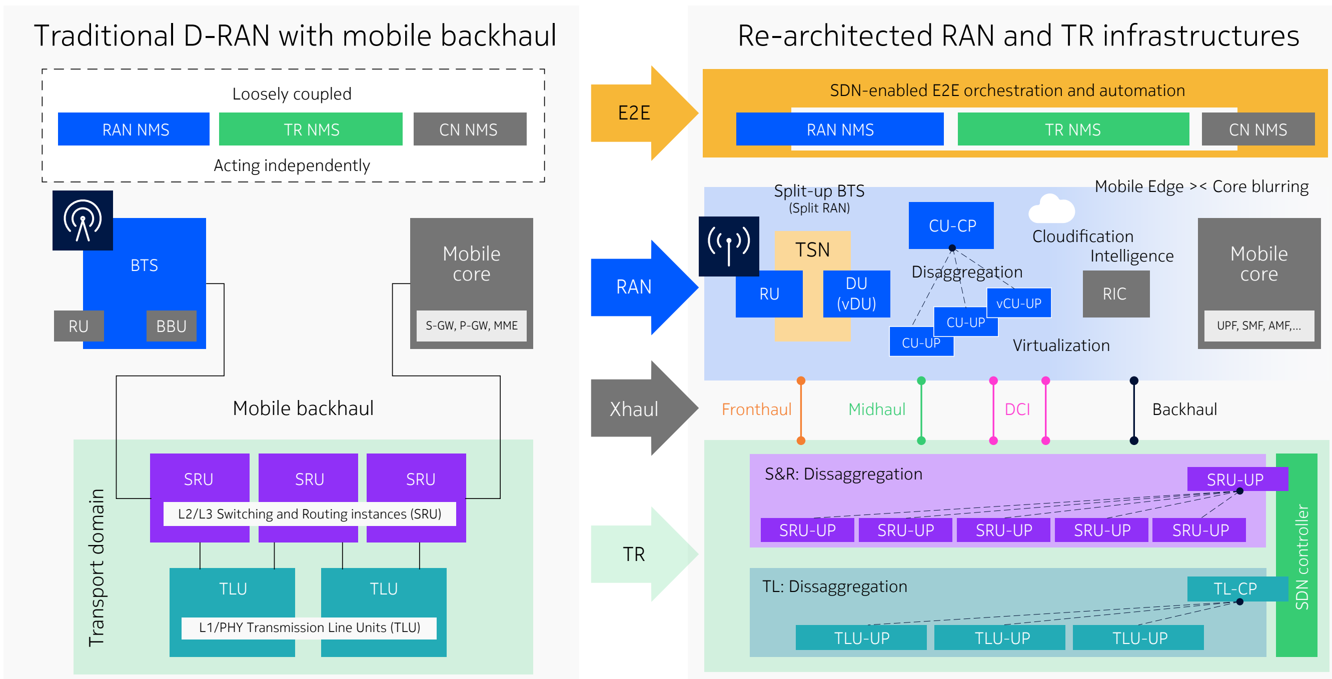
Figure 1: Re-architecting mobile and transport networks



Mobile xHauling

Split RAN architectures expose new interfaces to connect decomposed RAN units, whether locally or externally via a transport network. Thus, facing a much wider scope, the traditional mobile backhaul architectures need to be revised too. The transport requirements of the new interfaces, termed xHaul profiles, not only refer to the common mobile backhauling (BH), but now also encompass new midhaul (MH), and fronthaul (FH) network segments. Each segment must strictly fulfil its distinct xHaul profiles when interconnecting all RAN instances and core network sites.

Large-scale cloud RAN facilities that host DU or CU functions covering a large geographical area require high-capacity optical links into the Terabit/s (Tbps) range, called data center interconnects (DCI), which are part of the xHaul network too. XHaul networks predominantly use IP/ Ethernet technologies over optical (packet-optical) or microwave radio links.

Fronthauling between RUs and DUs requires time sensitive networks (TSN) as highlighted in Figure 1, which ensure strict determinism and low latencies. They must cope with high data rates and various cell traffic formats, including legacy types like common public radio interface (CPRI). Typically, legacy payloads are mapped to radio over Ethernet (RoE) frames or more efficiently converted into an evolved, Ethernet-based format such as enhanced CPRI (eCPRI), e.g., by means of FH gateways (FHG) or cell site gateways.

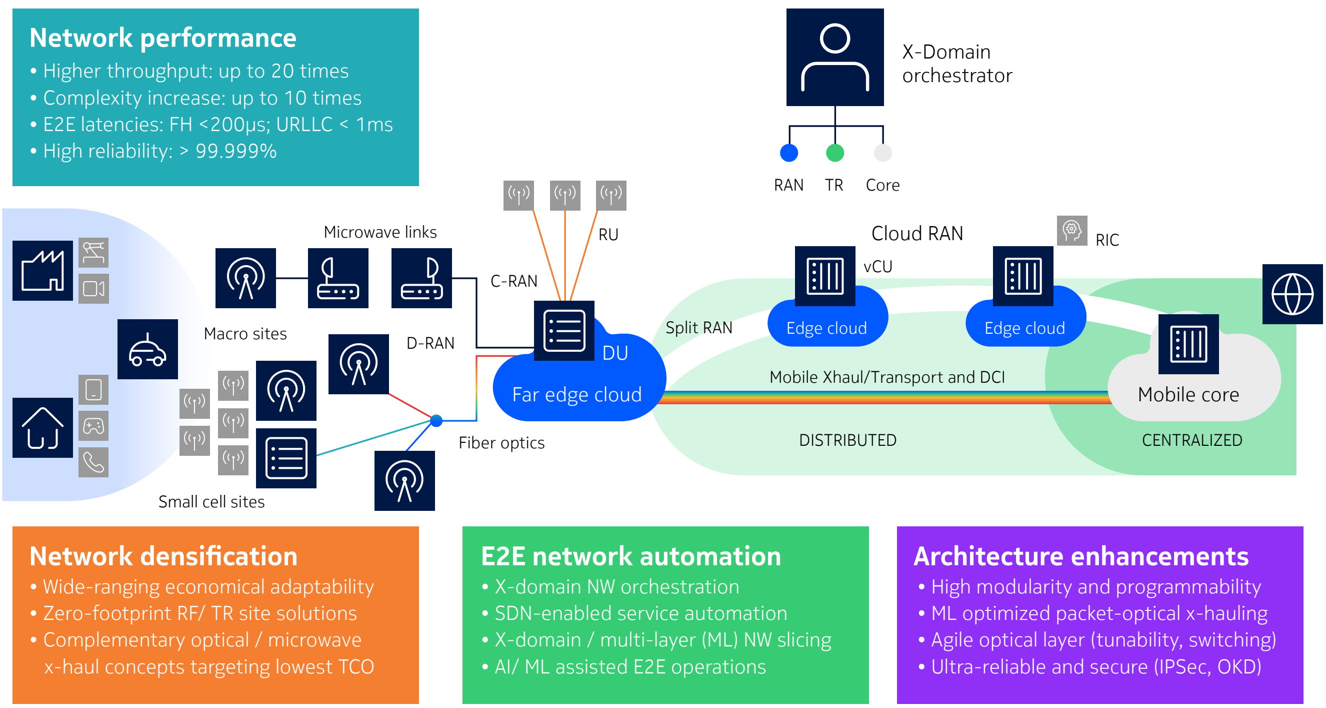
Cost-attractive semi-active or even purely passive optical xHaul solutions are the preferred options for MNOs to connect the cell and RAN premises via a fiber network over distances of up to 20 km. Where fiber is not economically applicable microwave links will be used instead.

Transport networks for mobile

6G requirement indications

6G-ready xHaul networks need to provide sustainable, wide-scaling and elastic concepts to support any kind of future network blueprints and types of cell site configurations in the most economical way, including in-building setups. The key drivers are performance, densification, end-to-end automation, and architecture enhancements, as shown in Figure 2.

Figure 2. Key drivers of future xHaul networks



The spectral bandwidth of the new 6G bands above 7GHz is expected to increase from 100MHz (current 5G) to 400MHz. With an assumed higher spectral efficiency, this adds up to even 20 times the cell capacity of 5G [7]. This demands BH/ MH link capacities beyond 10 Gbps, and real-time sensitive TSN networks for fronthauling when connecting RU sites with the DU premises. The L1 baseband processing split options (aka 3GPP split definition 7-X) define very low E2E latencies below 200µs and strict deterministic behavior, paired with very high data rates in the 100 Gbps ranges in the case of advanced massive MIMO radio configurations.

Further, the number of managed xHaul connection points will be boosted by urban network densification, a bunch of new split RAN interfaces, legacy LTE/ 5G interworking needs, and new O-RAN functions. This will raise the network complexity up to 10 times. Facing this challenge E2E automated xHaul solutions, aided by AI, will become essential, for instance, to support E2E network slicing at large scale. This will also imply the use of innovative transport technologies such as hard network slicing schemes or tunable optics to cope with highly aggregated, coarse granular traffic streams.

Latency-critical services, like ultra-reliable low latency communications (URLLC) require E2E latencies below 1ms between the application layers, blurring the lines between RAN, core, and xHaul domains. XHaul networks of the future are expected to be highly robust, resilient, self-healing and secure against any malfunctions or attacks.

Key technologies

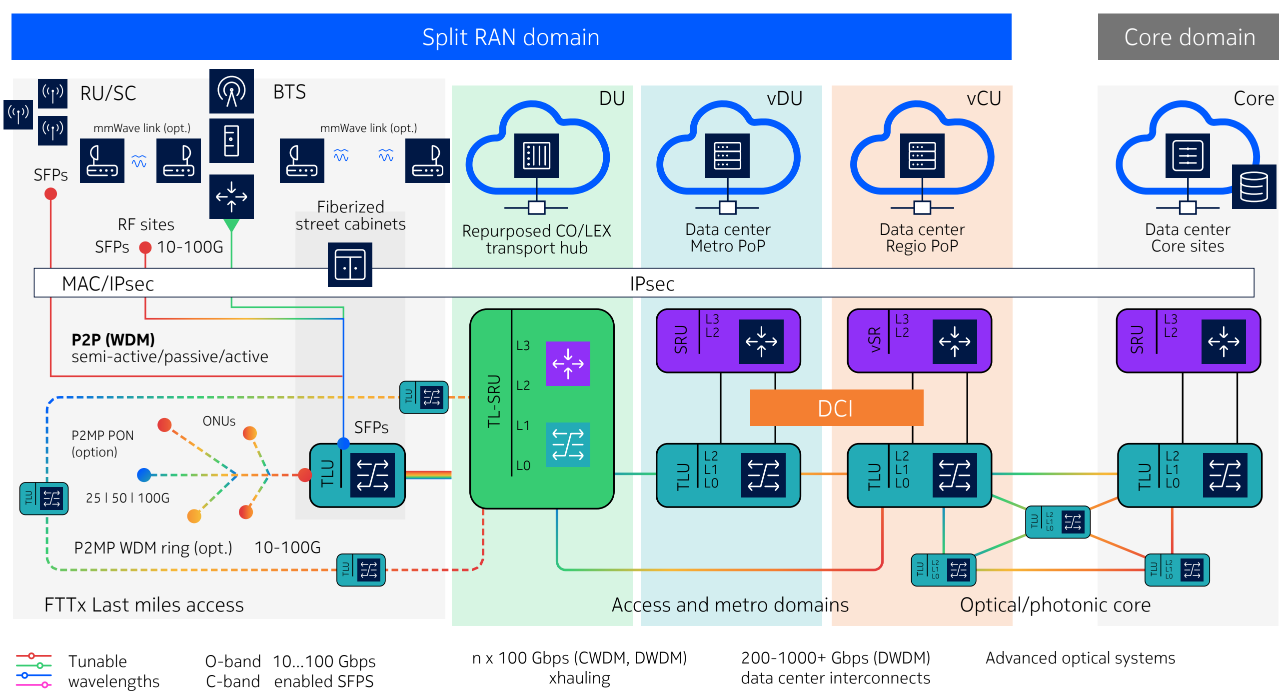
Fiber-optical infrastructures for xHaul networks will become the preferred 'last mile' choice of MNOs to connect cell towers or RAN instances, often called FTTx, where x indicates any fiber end-point location, including antennas (FTTA). In cases where fiber is not available or feasible, microwave or millimeter wave (mmWave) radio links will be used instead, even over non-terrestrial networks, e.g., via low earth orbit satellites (LEO) or high-altitude platform systems (HAPS).

The transport technologies encompass the physical and L1 functions, but also perform the L2/ L3 forwarding, multiplexing, switching, and routing of data. The IP/ Ethernet technologies allow compact multi-layer xHaul solutions even being integrated into native RAN equipment. In the future, virtualized transport functions are expected to gain traction in cloud RAN/telco setups.

IEEE, ITU-T and IETF are the most relevant standardization bodies to define important transport protocols, such as OTN, VPN, MPLS, GMPLS, or SRv6, to name just a few of them. IPv6 and SRv6 technologies are expected to gain momentum to efficiently manage future xHaul networks in a holistic E2E manner. IPSec (and optionally MACSec) will become mandatory to secure any xHaul traffic flows E2E, optionally hardened by quantum key distribution (QKD) methods.

Figure 3 shows a simplified xHaul infrastructure of a tier-1 operator with the possible locations of RAN and core network (CN) functions indicated atop a packet-optical transport layer. Split RAN functions don't only have to reside close to or at the cell premises (as for a vast majority of deployment cases) but can be placed all over the network — where and when needed. Also, DU and CU functions need to be carefully allocated to minimize external xHaul interfaces and reduce test and integration efforts. The depicted xHaul network (with some TLU and SRU variants and fiber deployment options indicated) ensures connection flexibility as well as economic feasibility and scalability from last miles access through the metro and optical core domains.

Figure 3. Simplified tier-1 packet-optical xHaul infrastructure



Unleashed optical systems

Photonic transmission, switching and routing technologies allow the most energy-efficient, lowest-cost-per-bit solutions to process and forward data streams of high capacity. The use of costly and energy-hungry electronic packet processing is minimized. As a result, MNOs will use optical systems by utilizing existing fiber assets as much as possible, or lease fiber services from third-party operators, such as neutral hosts. This strategic approach also entails a shift from capital to operational expenditures, which may be attractive for some operators. Investments in new infrastructures are done with caution and are likely to occur only when coupled with fiber-sharing models.

6G enabled packet-optical systems will predominantly optimize link capacities with wavelength-division multiplexing (WDM) techniques by placing multiple optical carrier signals onto a single fiber, each operating at distinct wavelengths of laser light. In addition, wavelength-tunable components, such as lasers or filters will allow very flexible, agile, and energy-efficient solutions for coarse-granular traffic patterns, e.g., 100 Gbps pipes.

In practical economic terms, there exists a throughput limitation of around 1 Tbps per fiber, particularly for xHaul applications in the cost-sensitive access domain. This limitation is influenced by factors such as the number of wavelengths employed, carrier data rates, link lengths, modulation schemes, and other relevant parameters.

Advanced research to further scale optical network capacities in accordance with Shannon's Law have demonstrated a transformative leap beyond 1 Petabit/s. This is mainly achieved via three pivotal pathways: (1) transmission speed increase, (2) spectrum utilization by WDM, and (3) spatial division multiplexing (SDM). Transmission speed scaling has seen a remarkable evolution driven by innovations in coherent optics, skyrocketing to an impressive 1.2 Tbps mark. This substantial increase has also significantly extended the range of optical links, spanning from hundreds of kilometers to tens of thousands. Higher spectrum utilization is achieved by advanced WDM techniques operating across the optical C- and L-bands, e.g., denser wavelength placements, or even by exploiting the U-bands. SDM techniques can further boost capacities by simultaneously transmitting multiple, spatially separated rays of light over fiber, either by multi-core or multi-mode means. However, SDM concepts which will use new types of optical fiber are still a matter of research, and commercial solutions are not expected within this decade.

The Innovative Optical and Wireless Global Forum (IOWN GF) has recently published a technology evolution roadmap [8] for the mutually influential networking and computing domains, by driving related collaborative advanced research work, such as in the optical transport fields.

Empowered microwave systems

Wireless transport systems offer cost-effective solutions in complementing the fiber, particularly for tail and first aggregation levels over xHaul networks but also widely for enterprises and mission-critical markets. Wireless point-to-point links in the traditional bands (6–40 GHz) will remain a strategic asset of MNOs for 5G+ and 6G expansion. The technological evolution to support different deployment scenarios is promising, with projected link capacities to reach 100 Gbps in the future. Besides implementing L2/L3 networking and packet processing capabilities, these systems will introduce new advanced, highly integrated radio components, like systems integrated on a chip (SoC) or in a package (SiP), aiming to further boost link capacities or longer link distances.

Emerging solutions in the millimeter wave bands, namely E-band (71–76 and 81–86 GHz) systems have evolved from initial 1 Gbps capable devices to now 10 and 25 Gbps over a few kilometers. Moreover, the industry is even expanding towards the higher W-band (92–114.25 GHz) and D-band (130–174.8 GHz).

While the W-band is a likely extension of the E-band (similar propagation behaviour), D-band systems and their sub-THz technologies are considered as disruptive. They combine ultra-high capacity (up to 100 Gbps) and ultra-low latencies (< 10 μs) capabilities, by offering small form factors with antenna sizes down to a few square centimeters.

Such solutions primarily target urban network densifications with street-to-street or rooftop connectivity over less than 1 km, exploiting poles and street furniture. In such scenarios the next fiber point of presence might be a few hundred meters away from the radio location. TCO calculations often tend to favor mm-wave options to avoid costly fiber trenching work and long approval processes.

To maximize performance in all dimensions, investments in fundamental sub-THz technology research and development is needed as off-the-shelf components are often not available. These up-front investments are important to anticipate future market needs, creating the basis for innovative 6G products. Figure 4 depicts some future sub-THz applications and breakthroughs such as single chip integration of RF signal processing, new glass substrate materials for system and circuit integration, or flat phase-array antennas, capable of automatic beam steering and self-alignment.

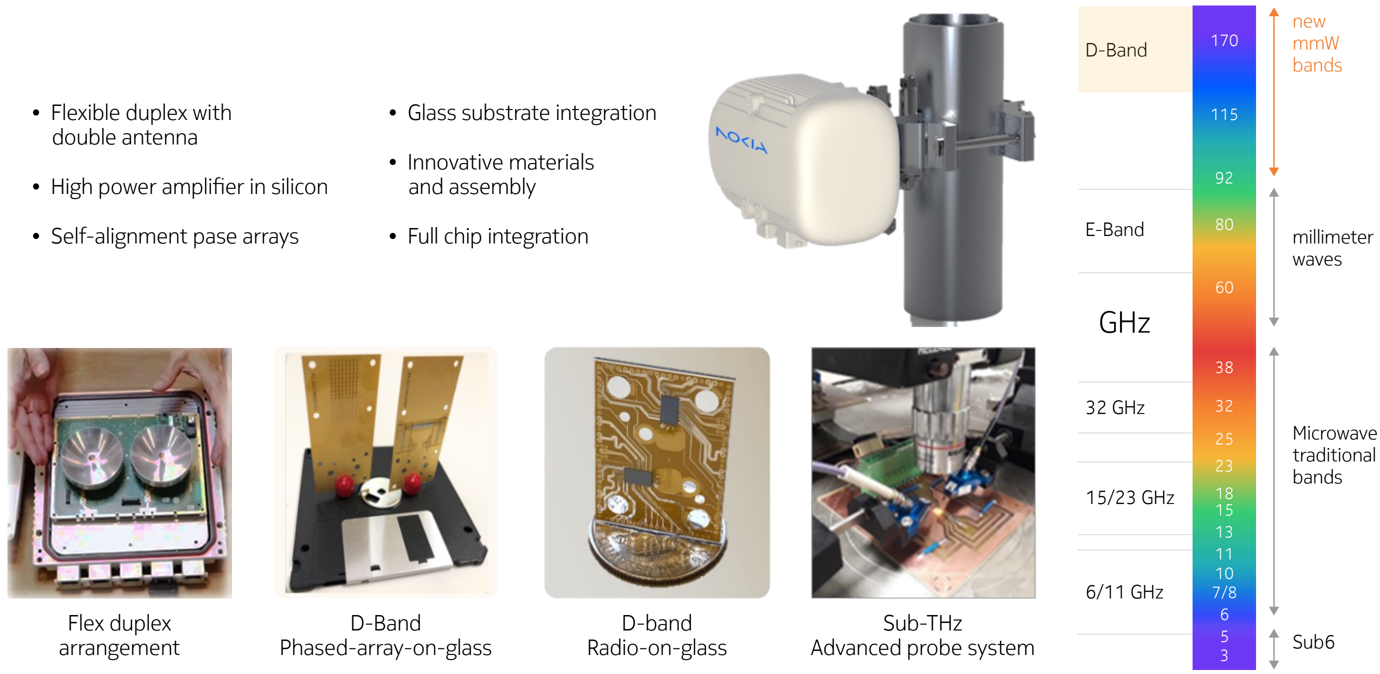
RAN and transport equipment provide interface slots for optical small form factor pluggables (SFP) to connect onto the fiber network. Commercially attractive SFPs will use certain favorable optical transmission bands, namely the O-band (small dispersion) and C-band (low attenuation). Likely O-band solutions will gain momentum as they allow cost-attractive SFPs of up to 100 Gbps that take advantage of the high-volume DCI market, as well as by adopting optical high-end technologies, such as coherent signal processing, photonic integration, wavelength tuning, and temperature hardening to minus 40 degree Celsius for harsh outdoor environments at cell towers.

To ensure wide commercial availability, leading telco and component vendors have founded the Mobile Optical Pluggables Alliance (MOPA), which has defined high-level requirements and technical blueprints for the use of SFPs in xHaul applications, recently including 112 Gbps SFPs [9].

With the advent of residential fiber rollouts, passive optical network (PON) systems will complement packet-optical solutions mainly in the MH and BH space. For time-sensitive fronthauling O-RAN has defined a cooperative transport interface (CTI) to allow a pro-active cooperative dynamic bandwidth assignment (CO-DBA) over passive optical networks (PON).

25G PON systems are introduced as of now, 50G PON deployments will start from 2025 onwards, and the first 100G PON products are expected by 6G time frames. The PON evolution follows, slightly delayed, the same technological progress curves as active optical systems, like O-Band wavelength multiplexing, or coherent modulation and detection.

Figure 4. Sub-THz technology research



Spectrum is also one of the main assets of the satellite industry, which is developing microwave connectivity solutions for the 5G and 6G ecosystem by complementing terrestrial networks for backhaul, fixed wireless access or primary mobile access in remote areas, natural disasters or emergency situations. The so-called non-terrestrial networks (NTN) will mainly use LEO satellites or HAPS, which host selected RAN functions onboard. NTNs offer a novel approach to directly access mobile user devices. Advanced low-latency concepts anticipate the co-location of BTS and RAN units to the satellite feeder facilities at the ground stations via xHaul networks [10].

E2E orchestration and operation

SDN-based service automation

Future mobile networks need highly automated solutions for E2E service provisioning, especially for transport services coping with the complexities required to dynamically manage 5G and 6G networks.

SDN concepts separate the user and control/ management plane functions of a network element into three layers: (1) the network applications, (2) the intelligent SDN controller, and (3) the network infrastructure with the physical devices. A transport SDN controller as depicted in Figure 5, centrally hosts and coordinates the network control functions of a given (or all) transport sub domains. It informs via its northbound interface (NBI) the network applications in the network management system (NMS) about the status of all xHaul network resources. In turn, the applications communicate which transport services are currently needed, and the controller dynamically updates and optimizes the traffic routes and flows accordingly. It accomplishes this by configuring the impacted devices in the network infrastructure through its southbound interface (SBI). The state-of-the-art protocol for the SBI communication is OpenFlow, as defined by the Open Network Foundation (ONF). However, it is expected that in future protocol-independent concepts, like open source P4 programming (p4.org), will largely replace OpenFlow, by offering better flexibility and faster adaptability in supporting new features.

Large multi-domain networks can have flat or hierarchical SDN controller topologies under an E2E orchestrator as shown in figure 5. SDN principles also apply to the RAN and core network domains but with different conceptual approaches in the control and domain-specific service management and orchestration layers (SMO).

Artificial intelligence

Artificial intelligence (AI) and machine learning (ML) will play a significant role in future xHaul networks. Information exchange and data collection between the transport and mobile domains, e.g., regarding key performance indicators (KPIs), are important inputs and prerequisites, either for the model training as well as in the operations. MNOs will use AI to analyze vast amounts of data from networks, services, devices, customers and more. It will help to extract valuable insights for operational improvement, increased revenue, and enhanced customer experiences. Transport-specific AI/ ML benefits include smart trouble-shooting, parameter optimization, traffic prediction and optimization. These advancements are expected to boost operational efficiency and performance by up to 30%.

Xhaul management and orchestration

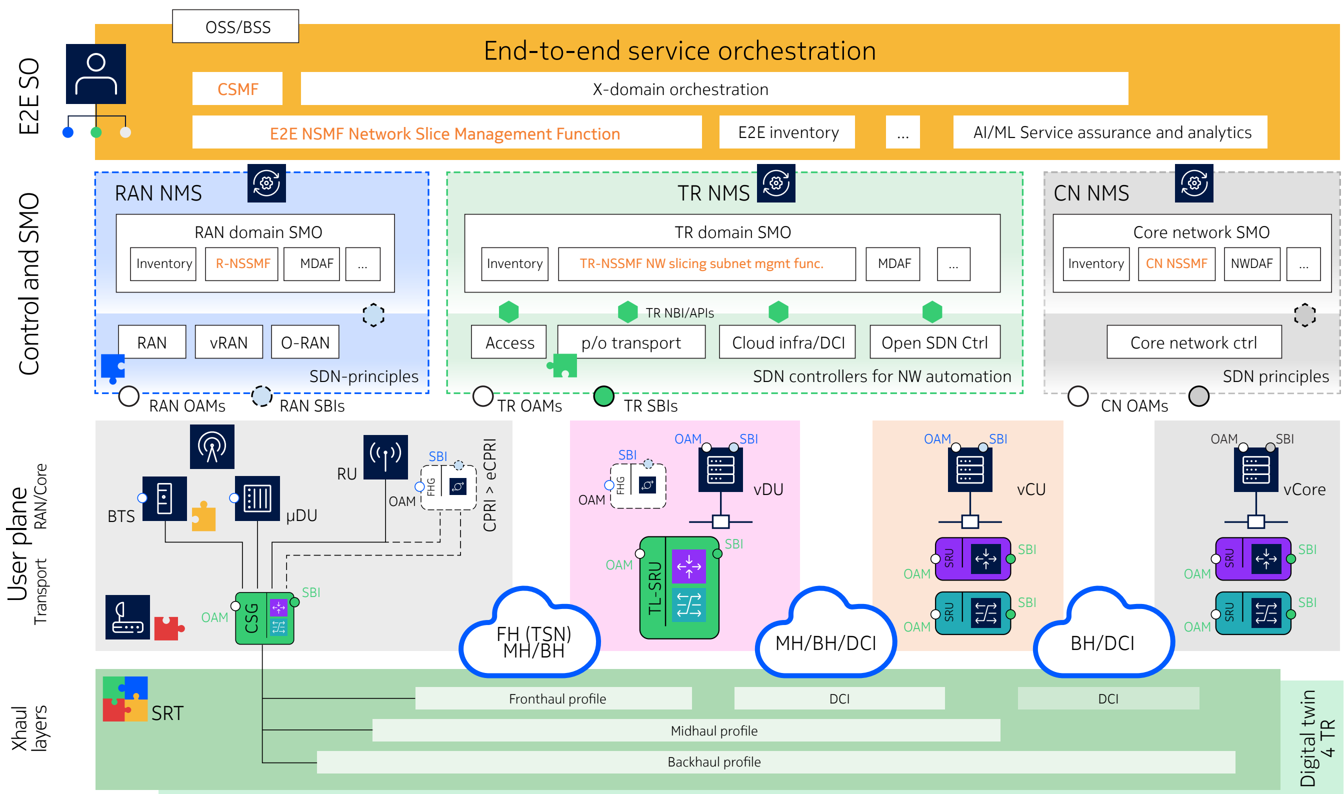
The high complexity of future xHaul networks and the tight and dynamic interactions with the RAN and CN domains necessitates full SDN automation and E2E orchestrated management for transport services. To simplify and automate network management, model-driven management and interfaces such as YANG (yet another next generation) will be needed in combination with protocols like network configuration protocol (NETCONF). Having a centralized view of the entire xHaul network optimizes the use of costly network resources, valuable site assets, and the know-how of operational personnel.

Future transport control and SMO layers will utilize SDN controllers to automate the configuration, stitching and management of xHaul connections over different transport sub domains. These include access, packet-optical metro, core, and cloud/ DCI network domains, as depicted in figure 3. Open SMO concepts and components such as open SDN controllers will also be used more widely.

Figure 5 shows a simplified setup of an E2E service orchestration framework (E2E SO) highlighting some relevant functions for E2E network slicing. Each SMO domain manages its own network slicing subnet management functions (NSSMF), which are synchronized by a centralized network slicing management function (NSMF) residing in the upper x-domain E2E SO layer, which owns the full E2E view. A communication service management function (CSMF) takes the business requirements from the operations and business support systems (OSS/BSS) and translates them into network slice requirements to be processed by the NSMF and sub-domain NSSMFs.

The RAN and CN domains have similarly structured control and SMO layers, with corresponding functions, e.g., for the inventory, management data analytics service (MDAS), NSSMF, and others. The RAN NMS comprises the traditional RAN, vRAN and complementary O-RAN control and management instances. The latter includes the RAN intelligent controller (RIC), as previously shown in Figure 1, which is split into a 'smart' near-real-time (RT)-RIC and non-RT-RIC instance (not depicted). The CN's service-based architecture (not depicted) provides a modular framework for the functions that are interconnected via an interface message bus, i.e., an internal transport network.

Figure 5. SDN-based E2E SMO for network slicing (simplified)



It is worth mentioning that local, intra-site, or system-internal RAN and CN connections are managed within their own domains. However, new concepts may envision embedded SDN controller functions (or interfaces) such as transport SDN agents integrated into innovative BTS solutions.

Recent innovations allow novel integrated RAN and microwave xHaul solutions, like simplified radio transport concepts (SRT) as indicated in Figure 5. These ideas smartly complement the RAN management architecture and BTS resources with additional capabilities, to deliver a true E2E service management, automating the operations from RAN to CN through the whole xHaul network.

Unlocking the power of digital twins

The adoption of digital twins in transport networks has surged due to the increasing complexity and demands in network management and maintenance. These digital replicas of real-world entities offer network operators a valuable tool to enhance their understanding and management of network service architecture. Leveraging digital twins in transport networks yields numerous advantages, including cost savings, time efficiency, and enhanced creativity.

This transformative technology has revolutionized the traditional testing and evaluation processes of operators. Previously reliant on costly lab setups with limited resources, operators can now harness digital twins to test and evaluate changes in seconds to any size or kind of network configuration within a virtual environment. This shift significantly reduces operational and capital costs while unlocking new possibilities for network administration and innovation. Beyond their conventional applications, digital twins for transport networks (DT4TN) are useful in other areas such as sales enablement, security testing, employee training, and energy management. The technology facilitates real-time synchronization between virtual and physical entities, offering closed-loop network control throughout the network's lifecycle. Case studies of successful DT4TN implementations within tier-1 infrastructures demonstrate impressive benefits and advantages.

The digital twins taskforce within IOWM GF is adding significant value to the TR NMS by enriching the SMO layer with the power of digital twins concepts. The work is perfectly aligned with the overall goals of the IOWN GF in streamlining future network management and stimulating innovation.

Conclusion

The Metaverse era, with its immersive fusion of physical and digital realms through extended reality (ER), holds great promise. It offers bright prospects to mobile operators to connect the world, but also implies challenges in upgrading and managing future networks with a smart mix of established, groundbreaking, and eco-friendly solutions. Transport technologies will become ubiquitous in the mobile 6G landscape — from system-internal to end-to-end connections via xHaul networks. It demands operators and vendors proactively make strategic decisions on both operational and technical fronts. These should be made well in advance of new field deployments to fully unlock the potential of innovative transport technologies and networks.

Abbreviations

3GPP	3rd Generation Partnership Project
BH	Backhaul
BTS	Base transceiver station
CN	Core network
CNF	Containerized network function
CO-DBA	Cooperative dynamic bandwidth assignment
CPRI	Common public radio interface
CSMF	Communication service management function
CTI	Cooperative transport interface
CU	Centralized unit
CU-CP	Centralized control plane units
CU-UP	Centralized user plane units
CUPS	Control and user plane separation
D-RAN	Distributed RAN
DCI	Data center interconnect
DT4TN	Digital twins for transport networks
DU	Distributed unit
E2E	End to end
eCPRI	Enhanced CPRI
ER	Extended reality
FH	Fronthaul
FHG	Fronthaul gateway
FTTA	Fiber to the antenna
FTTx	Fiber to the premises, node, building, distribution point, home, etc.
GMPLS	Generalized MPLS
HAPS	High-altitude platform systems
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IOWN GF	Innovative Optical and Wireless Network, Global Forum
IPsec	Internet protocol security

IPv6	Internet protocol version 6
IT	Information technology
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
KPI	Key performance indicator
L1, L2, L3	Layer 1, layer 2, layer 3
LEO	Low earth orbit
MACsec	Media access control security
MDAS	Management data analytics service
MH	Midhaul
MIMO	Multiple input, multiple output
ML	Machine learning
mmWave	Millimeter wave
MNO	Mobile network operator
MOPA	Mobile Optical Pluggables Alliance
MPLS	Multiprotocol label switching
NBI	Northbound interface
NETCONF	Network configuration protocol
NFV	Network function virtualization
NMS	Network management system
NSMF	Network slicing management function
NSSMF	Network slicing subnet management function
NTN	Non-terrestrial network
O-RAN	Open RAN
ONF	Open Network Foundation
OSS/BSS	Operations/business support services
OTN	Optical transport network
PNF	Physical network function
PON	Passive optical network
PRTC	Primary reference timing clock
QKD	Quantum key distribution
RAN	Radio access networks
RIC	RAN intelligent controller
RoE	Radio over Ethernet

RT-RIC	Real-time RAN intelligent controller
RU	Radio unit
S&R	Switching and routing
SBI	Southbound interface
SDM	Spatial division multiplexing
SDN	Software-defined network
SFP	Small form factor pluggables
SiP	System in a package
SMO	Service management and orchestration.
SO	Service orchestration
SoC	System on a chip
SRT	Simplified radio transport
SRU	Switching and routing unit
SRv6	Segment routing IPv6
TCO	Total cost of ownership
TL	Transmission line
TLU	Transmission line unit
TL-SRU	Combined transmission and switching and routing unit
TSN	Time-sensitive network
URLLC	Ultra-reliable low latency communications
vCU-UP	Virtual CU-CP
VNF	Virtualized network function
VPN	Virtual private network
vRAN	Virtual RAN
WDM	Wavelength-division multiplexing
XHaul	Includes backhaul, midhaul and fronthaul
YANG	Yet another next generation

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About Nokia

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

As a B2B technology innovation leader, we are pioneering networks that sense, think and act by leveraging our work across mobile, fixed and cloud networks. In addition, we create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

Service providers, enterprises and partners worldwide trust Nokia to deliver secure, reliable and sustainable networks today – and work with us to create the digital services and applications of the future.

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