NACHHALTIGKEIT ALS HERAUSFORDERUNG FÜR 6G

The future Role of Transport Networks towards 6G

Architectural Requirements and Innovative Approaches

Abstract

Sustainable transport networks are crucial for future mobile networks by offering fast and reliable communication, though their importance is often overlooked. Key challenges are high data rates, massive connections, and network complexity. The article discusses the technology drivers, and architectural impacts.

Mobile Networks Evolution

Towards cloud-ready Architectures

Current 3GPP Rel. 18 mobile standards and early 6G work [1, 2] envision a revamp of present, rather rigid radio architectures for the Metaverse era. The renewals must prioritize cost-efficiency and flexibility to accommodate diverse business models and services. Organizations like 3GPP and O-RAN drive modern architectural concepts with enhanced split options and new interfaces. The highly concentrated basestation functions (BTS) in today's radio access networks (RAN) need to transition towards an increased openness, involving processes like decomposition, disaggregation, virtualization, and cloudification, known as Cloud RAN.

Despite expected stagnant mobile revenue growth in the next five years, there will be a significant surge in mobile subscribers and cellular traffic demand. Projections indicate around 8 billion active 5G subscribers and 3.7 Zettabytes of global cell traffic by 2028 [3]. Limited revenue growth will constrain the capital spendings of mobile network operators (MNO), thus making scalable and energy-efficient transport solutions essential for future RAN expansions, densifications, or technology upgrades.

Importance of Transport Networks

To enable this architectural transformation, a high-performance transport infrastructure to connect all RAN instances is crucial. It needs to economically scale from very local to vast geographical areas, even including non-terrestrial locations. 5G has already highlighted the significance of the transport layer in new cloud-ready RAN deployments, especially in the highly cost-sensitive access and metro domains. New RAN interfaces require advanced transport solutions coping with a significantly increased number of managed connection points, and thus network complexity. Advanced RAN functions like distributed MIMO systems, or cell free networks require the distribution of ultra-precise synchronization information over the entire network. Finally, future transport networks are expected to

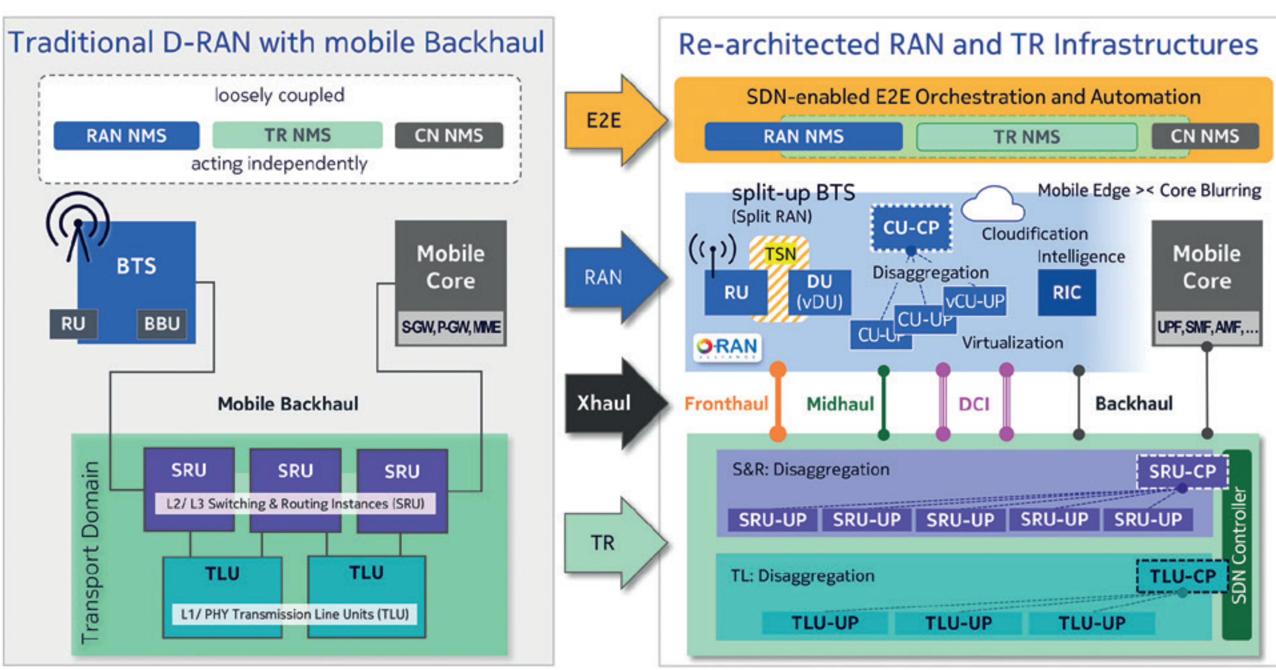

Figure 1: Re-architecting Mobile and Transport Networks

serve not only mobile premises, but datacenters, Enterprises, or fixed broadband locations in a unified manner too.

Network Architecture Transformation

3GPP Architecture Directions

Recent 6G pre-studies propose novel, IT-based network concepts by decomposing and re-architecting the RAN, mobile core, and transport domains into programmable solution platforms managed by an orchestration framework in an end-to-end (E2E) fashion. These renewed platforms aim to be open, flexible, scalable, secure, and reliable. Network functions can largely be moved or pooled where and when they are needed, for example to encounter unforeseen traffic demands.

Re-architecting Principles

Network re-architecting means breaking down, virtualizing, and opening of today's rather monolithic network architecture into smaller functional pieces and units.

Fig. 1 shows the principle of the transformation on a simplified view: traditionally, LTE and 5G BTSs are deployed in a distributed manner (D-RAN), attached to mobile core facilities via an aggregating mobile backhaul network, with several packet switching & routing (SRU) and transmission line (TLU) units in between.

All network domains (RAN, transport, and mobile core) have their own management systems (NMS), acting rather independent from each other. The transition to a renewed architecture impacts all domains: the BTS functions are split into radio (RU), distributed (DU), and centralized (CU) units, referred to as Split RAN architecture. These units can be further separated and pulled apart into user and control/management plane instances, some of them even virtualized, running in a Telco cloud. The same principles can be applied to the transport domain with its separately depicted SR and TL layers. Software-defined networking concepts (SDN) retarget the complex control plane parts into freely movable software functions to be processed centrally in the network control layers, like SDN controllers managing the transport domain. This SDN-based approach allows a truly E2E enabled and orchestrated service management across all domains.

Mobile Xhauling

Split RAN architectures expose new interfaces to connect decomposed RAN units, whether locally or externally via a transport network. The interfaces' transport requirements, commonly termed xhaul profiles, refer to the corresponding mobile backhaul (BH), midhaul (MH), and fronthaul (FH) networks. Xhaul networks predominantly use IP/Ethernet technologies over optical or microwave radio links. Large-scaling cloud RAN facilities hosting DU or CU functions over a large geographical area require high-capacity optical links into the Terabit/s (Tbps) range, called Data Center Interconnects (DCI).

FH networks require extreme time sensitivity (TSN), strict determinism, and low latencies. They must handle high data rates and various cell traffic types, including legacy formats like CPRI. Typically, legacy payloads are mapped to Ethernet frames (RoE), or more efficiently converted into an evolved, Ethernet-based format (eCPRI), e.g., by FH gateways (FHG). Semi-active or even purely passive optical xhaul solutions are the preferred options of the MNOs to connect the cell and RAN premises via a fiber network over distances of up to typ. 20 km. Where fiber is not eco-

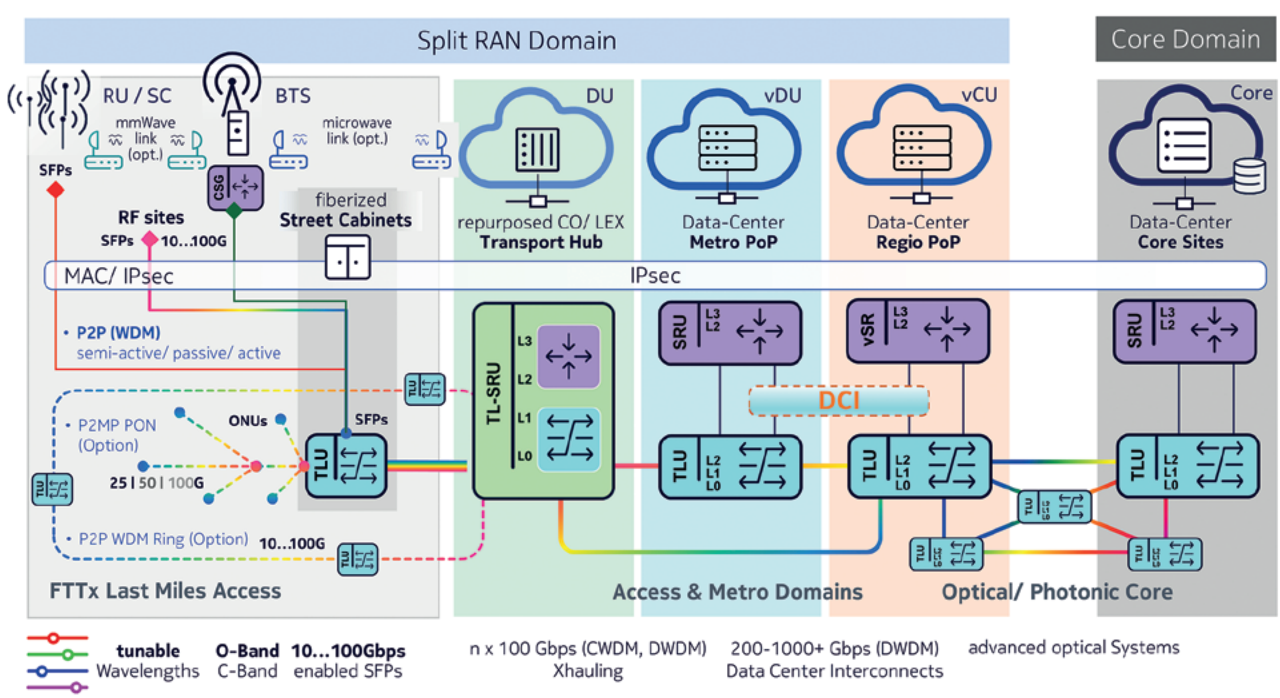

Figure 2: Simplified Tier-1 packet-optical Xhaul Infrastructure

nomically 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 types of future cell site configurations in a most economical way, including in-building setups. The key drivers are performance, densification end-to-end automation, and architecture enhancements.

The 6G bands (7 GHz) are expected to carry 20 times the capacity of 5G [4]. This demands BH/MH link capacities beyond 10 Gbps, and extremely high data rates for real-time sensitive FH traffic into the 100 Gbps ranges. Even more, the urban network densification, a bunch of new split RAN interfaces, legacy LTE/5G interworking needs, and new O-RAN functions will boost the number of managed xhaul connection points, and thus raise the network complexity up to 10 times. Facing this challenge E2E automated xhaul solutions, aided by artificial intelligence (AI) will become essential, e.g., to support E2E network slicing at large scale. Latency-critical services, like ultra-reliable low latency communications (URLLC) require E2E latencies below 1 ms between the application layers, blurring the lines between RAN, core, and xhaul domains. Future xhaul networks are expected to be highly robust, resilient, self-healing and secure against any malfunctions or attacks.

Key Technologies

Transport networks encompass physical and L1 functions, but also perform layer L2/ L3 forwarding, multiplexing, switching, and routing of data. The IP/Ethernet technologies allow very 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 important standardization bodies to define the relevant protocols, like OTN, VPN, MPLS, GMPLS, or SRv6, just to name a few of them. IPSec (and optionally MACSec) will become mandatory to secure any xhaul traffic flows E2E, optionally hardened by Quantum Key Distribution (QKD) methods.

Fig. 2 shows a simplified xhaul infrastructure of a Tier-1 operator with indicated, possible locations of RAN and core networks (CN) functions atop of a packet-optical transport layer: split RAN functions may not only be placed close to or at cell premises (as for a vast majority of deployment cases) but also all over the entire network - where and when needed. The xhaul network and transport equipment ensures the connection flexibility as well as economic feasibility and scalability from the last miles access, through the metro, and optical core domains.

Unleashing Optical Systems

Photonic transmission, switching, and routing technologies will prevail. They allow most energy-efficient, lowest-cost-per-bit solutions to carry data streams of high capacity by minimizing costly and energy-hungry electronic packet processing. For the physical transmission MNOs will exploit existing fiber assets, or lease fiber services from third-party operators. New investments in fiber will be approached with caution.

6G enabled packet-optical systems will optimize link capacities with wavelength-division multiplexing (WDM) techniques. In combination with wavelength tunable components and lasers they offer a high flexibility in managing coarse-granular traffic streams of up 100 Gbps. In practical economic terms, there exists a throughput limitation of around 1 Tbps per fiber,

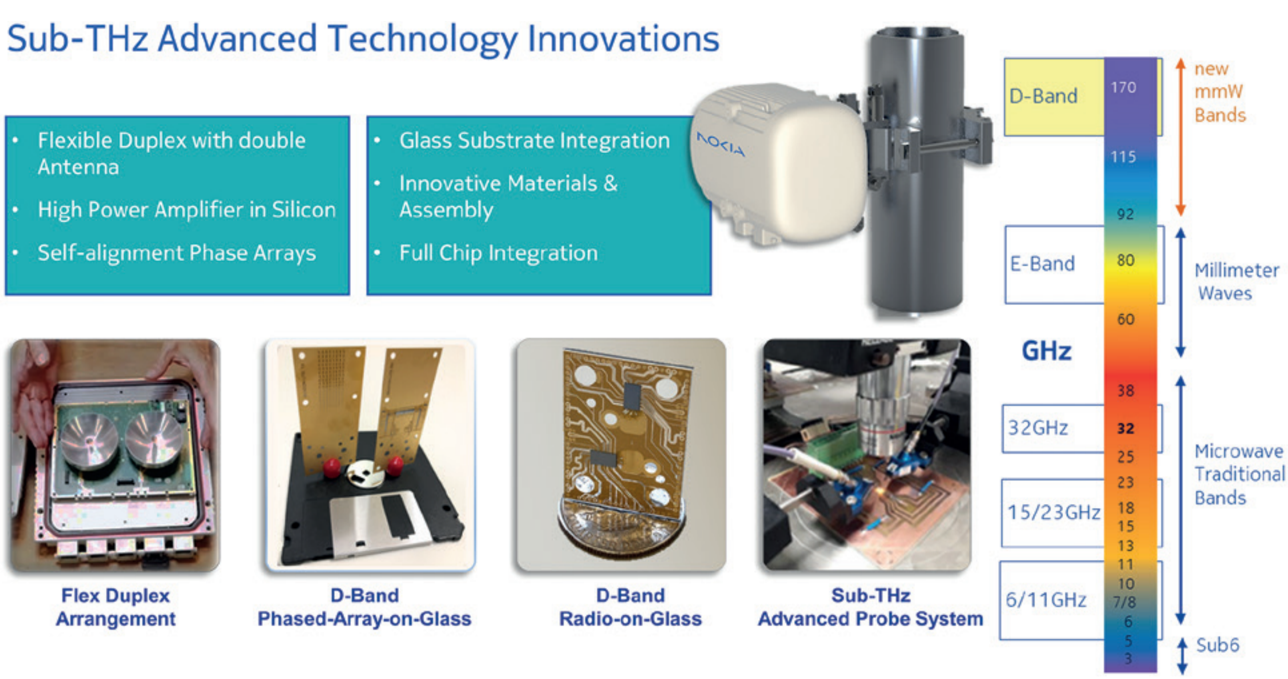

Figure 3: Sub-THz Technology Research for D-Band Solutions

particularly for applications in the cost-sensitive access domain. Advanced research to further scale optical networks in accordance with Shannon's Law have demonstrated a transformative leap beyond 1 Petabit/s. However, commercial solutions are not expected within this decade.

RAN and transport equipment provide interface slots for optical small formfactor pluggables (SFP) to connect onto the fiber network. Commercial attractive SFPs will use certain favorable optical transmission bands, namely the O- (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 gaining from the high-volume DCI market. To ensure a wide commercial availability leading Telco and component vendors have founded the Mobile Optical Pluggables Alliance (MOPA) by defining high-level requirements for SFPs in mobile networks [5].

With the advent of residential fiber rollouts passive optical point-to-multipoint network (PON) systems will complement packet-optical solutions mainly in the MH/BH, and in future FH space. 25G PON systems are introduced as of now, 50G PON (and beyond) solutions will start from 2025 onwards.

Empowering Microwave Systems

Wireless transport systems offer cost-effective solutions, particularly for tail and first aggregation levels of xhaul networks. Wireless links in the traditional bands (6–40 GHz) will remain a strategic asset of MNOs for 5G+/6G expansion, with future microwave systems reaching 100 Gbps.

Emerging solutions in the millimeter wave bands (71–175 GHz), namely the E-, W- and D-bands offer ultra-high capacity and low latency. They primary target urban network densification with link lengths of typically less than 1 km. Up-front invests in the research of innovative sub-THz technologies are crucial for the success of 6G ready systems. **Fig.** 3 depicts some future sub-THz applications and breakthroughs.

Complementing the wireless terrestrial networks, the satellite industry has developed non-terrestrial solutions (NTN) using low earth orbit (LEO) satellites. At ground stations low latency xhaul networks connect the BTS/RAN units with the satellite feeder facilities. NTN enables direct access to user devices, particularly in remote areas, or mission critical communications [6].

E2E Orchestration and Operations

SDN-based Service Automation

Future mobile networks need highly automated solutions for E2E service provisioning, especially for the underneath transport services coping with the high network complexities.

SDN concepts separate the user and control/management plane functions of a network element into three layers: the network applications, the intelligent SDN controller, and the (physical) network infrastructure as shown in Fig. 4. The SDN controller centrally hosts and coordinates the network control functions of a given (or all) transport domains. It informs via its northbound interface (NBI) the network applications in the NMS about the status of all xhaul network resources. In turn, the applications tell what transport services are currently needed, and the controller dynamically

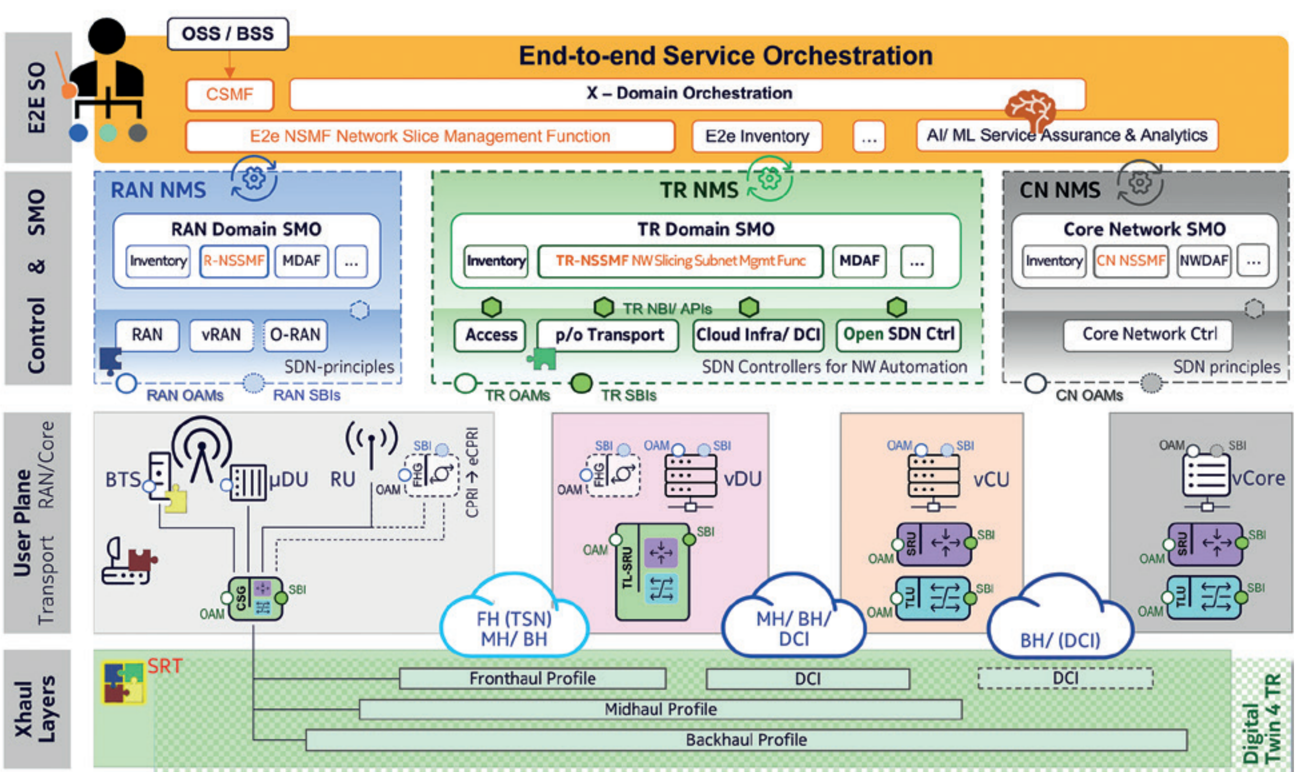

Figure 4: SDN-based E2E SMO for Network Slicing (simplified)

updates and optimizes the traffic routes and flows accordingly, by configuring the impacted network devices in the network infrastructure through its southbound interface (SBI).

Multi-domain networks can have flat or hierarchical SDN controllers under an E2E orchestrator. SDN principles also apply to the RAN and core domains but with different approaches in the control and service management orchestration layers (SMO).

Artificial Intelligence

AI and machine learning (ML) will play a significant role in future xhaul networks. MNOs will utilize AI to analyze the vast amounts of data from customers, devices, networks, and more, aiming to extract valuable insights for operational improvement, increased revenue, and enhanced customer experiences. The transport benefits include smart troubleshooting, parameter optimization, traffic prediction and optimization. These advancements are expected to boost operational efficiency and performance by up to 30 %.

Xhaul Management & Orchestration

The high complexity of future xhaul networks, and the tight and dynamic interactions with the RAN and CN domains require a fully SDN automated and E2E orchestrated management approach for the transport services. Having a centralized view over the entire xhaul network will allow a highly efficient use of costly network resources, valuable site assets, or the operational staff. **Fig. 4** 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 E2E Network Slice Management Function (NSMF). A Communication Service Management Function (CSMF) translates the OSS/BSS business requests into network slice requirements for the NSMF, and subsequent NSSMFs.

Recent innovations allow smartly integrated RAN and microwave xhaul solutions, like Simplified Radio Transport (SRT) concepts. The idea behind complements the RAN and TR NMS architectures, together with additional BTS resource capabilities to deliver a truly E2E service management, automating the operations from RAN to CN through the entire xhaul network.

Unlocking Digital Twins

Digital twins enhance transport network management framework, in responding to rising complexity. They create virtual replicas, benefiting operators with cost savings, time efficiency, and innovation. Operators can shift from costly labs testing to rapid digital twin testing by evaluating changes in a virtual environment quickly. Beyond traditional use, digital twins aid in sales, security, training, and energy management. They offer real-time synchronization, ensuring closed-loop control throughout the network lifecycle. First case studies of successful digital twin implementations into Tier-1 infrastructures have impressively highlighted the benefits and advantages.

Conclusion

The Metaverse era, with its immersive fusion of physical and digital realms through extended reality, 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. This demands operators and vendors to 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.

References

[1] 6G: Aufbruch zur Vernetzung neuer Welten (Ed. 04/ 2020), Techn. Paper, ITG/VDE

[2] The 6G Architecture Landscape (R.1.0, 08-12-2022), Techn. Paper, 5G PPP Architecture WG

[3] Cellular Data Traffic Forecast Report–2Q23 (23-08-2023), Market Forecast, OMDIA

[4] Envisioning a 6G future (2023), Techn. Paper, Nokia Bell Labs

[5] MOPA Technical Paper (v2.2, 01-10-2023), Techn. Paper, Mobile Pluggable Alliance

[6] AST Space Mobile (19-09-2023), Web Info, AST Space Mobile

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