WHITE PAPER

New Network Design for Transporting 5G Converged Traffic

5G is not just about upgrading the handsets, radios, and antennas that comprise the Radio Access Network (RAN). Offering 5G mobile services also requires substantial upgrades to packet-optical wireline networks that connect cell sites to each other and to data centers hosting accessed content, and everything in between. This means that for Mobile Network Operators (MNO) to achieve the 5G improvements over 4G LTE of 100x more devices, 100x faster data rates, 10x lower latency, and 1,000x higher data volumes, everything in the end-to-end mobile service path must be scaled and modernized eventually. This applies to connect, storage, and compute resources, resulting in a multi-year modernization journey that will start in the RAN and network edge and steadily move inward, a process that has already started in several countries.

Unlike previous introductions of mobile networking technology (2G, 3G, 4G), where the new generation was deployed to take precedence over the old generation, the 5G network approach is slightly different. 5G is intended to complement and coexist alongside 4G when initially rolled out, sharing as much connect, storage, and compute resources as possible to allow MNOs to support multiple generations of mobile services in a cost-effective manner. 4G continues to evolve from existing Long-Term Evolution (LTE) and LTE Advanced to LTE Advanced Pro and its next iteration in the form of ng-LTE (next-generation LTE), which are 4G enhancements that bring it closer to the expected 5G performance.

Holistically speaking, a mobile network includes a massive wireline network with radios hanging off its edges. This means the move to offering 5G mobile services is about far more than just a wireless upgrade.

Distributed Radio Access Network (D-RAN)

Traditional mobile networks were designed with multiple Radio Heads (RHs) and Baseband Units (BBUs) installed in the same location, called a macro cell site or cell site. RHs were installed atop a tower, with each serving a sector of 120 degrees in the common three-sector configuration. Early connections between RHs and BBUs were over electrical media (copper). The distance between RHs and the BBU installed at the base of a tower is typically around 200 to 400 feet or so in distance, which determines propagation latency.

Electrical connections between RHs and BBUs led to high electrical power consumption and associated energy costs. It also meant being susceptible to environmental conditions (lightning), Electromagnetic Interference (EMI), and Electromagnetic Conductance (EMC). These macro cell sites composed of RHs and BBUs were constructed in a distributed manner intended to serve subscribers within a typical radius of around 20 to 30 kilometers. This network topology, referred to as Distributed RAN (D-RAN), has been the primary method of deploying macro cell sites in most mobile networks around the world.

Backhaul Network

The network connection between D-RAN cell sites and the MNO Mobile Telephone Switching Office (MTSO) is called backhaul, since traffic from the former is hauled back to the latter. As newer generations of wireless technology offered faster speeds over the airwaves alongside an increased number of subscribers, backhaul traffic soared, and network operators realized that legacy copper-based backhaul technology simply could not maintain pace. This is precisely why packet-optical

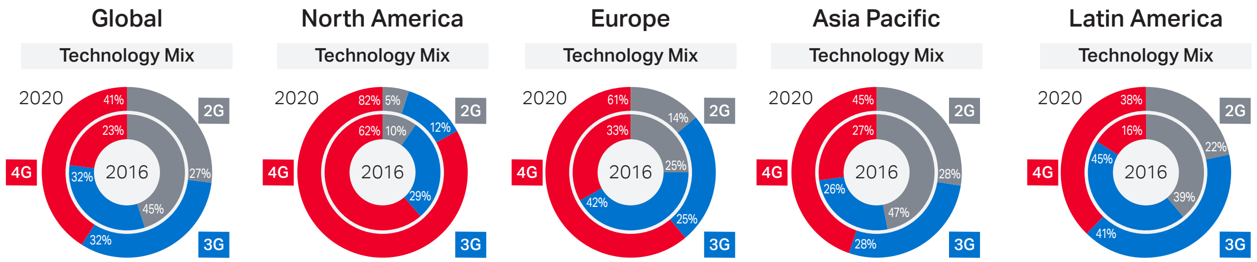

Figure 1. Multiple generations of mobile network technology deployed (source: GSMA)

technology became, and continues to be, the best option for high-capacity, low-latency, and major economies of scale for mobile backhaul networks. Routing and switching, transported over underlying optical technology, offers benefits associated with statistical multiplexing. The main benefit is optimized bandwidth utilization for reduced costs, which is why routing and switching technology is ubiquitous in most parts of the global network infrastructure, from edge to core.

Most mobile networks were constructed using D-RAN throughout the world. As new generations of mobile technology were developed, new radios and antennas were installed on existing towers alongside previous generations of radios and antennas. This is because MNOs were unwilling (or unable) to turn off previous generations of mobile services because new generations of mobile services required new radios and antennas at both cell sites and within handsets of subscribers. Figure 1 shows the mix of 2G, 3G, and 4G mobile network technology deployed around the world today, and into the next few years.

There is, and will continue to be, a mix of mobile network technologies; this is precisely why adding 5G must be seamless and cost-effective—a task easier said than done. In most developed countries, 2G mobile services have already been decommissioned, or soon will be. However, 2G will have a long life in many countries, as will 3G and 4G for the foreseeable future. 5G will use spectrum in the existing LTE frequency range (600MHz to 6GHz), and also in millimeter wave (mmWave) bands (24GHz to 86GHz). And since 5G operation in the sub-6 GHz bands is similar to 4G, MNOs will have to balance 5G infrastructure investments against the mobile services offered, network coverage, and availability of supported devices.

This is why MNOs demand that initial 5G roll out complement and coexist with existing mobile networks. It also means that a single, converged infrastructure, wherever and whenever possible, is an obvious primary goal.

Although multiple generations of wireless technology can and will coexist, multiple wireline overlay networks however are simply too costly and complex. This is why there is a pressing desire to converge different generations on a converged wireline network.

Centralized Radio Access Network (C-RAN)

As mentioned prior, initial D-RAN deployments connected multiple RHs atop a tower to BBUs at the foot of the tower using electrical technologies. Although this configuration served the industry very well for many years, optical networking technology has steadily advanced, with notable leaps in performance and cost-effectiveness compared to its copper-based brethren. Optical fiber-based media is also far less susceptible to environment conditions, which is another notable advantage. This has resulted in electrical connections between macro cell RHs and BBUs being steadily replaced by fiber optics over time.

Optical fiber-based communications enable much farther propagation distances than electrical copper-based communications, a fact that was not lost on MNOs and equipment vendors. Why not move and centralize multiple geographically dispersed macro cell BBUs into one location, and then connect to Remote RHs (RRHs) over distances afforded by fiber optics? This strategy led to fronthaul, which is the connection between centralized BBUs and geographically separated RRHs. BBU functions are increasingly being virtualized and are moving into data centers, leading to a cloud-based C-RAN. C-RAN was first applied to 4G for LTE HetNet densification and is also a prime candidate for 5G, given that the latter will leverage the higher-frequency mmWave spectrum. Propagation in this part of the spectrum yields shorter distances and more difficulties through obstacles, resulting in a reduced coverage area. This means that wide-scale 5G service coverage using mmWave spectrum requires significant densification of cell sites closer to subscribers, and more fiber to connect to these sites.

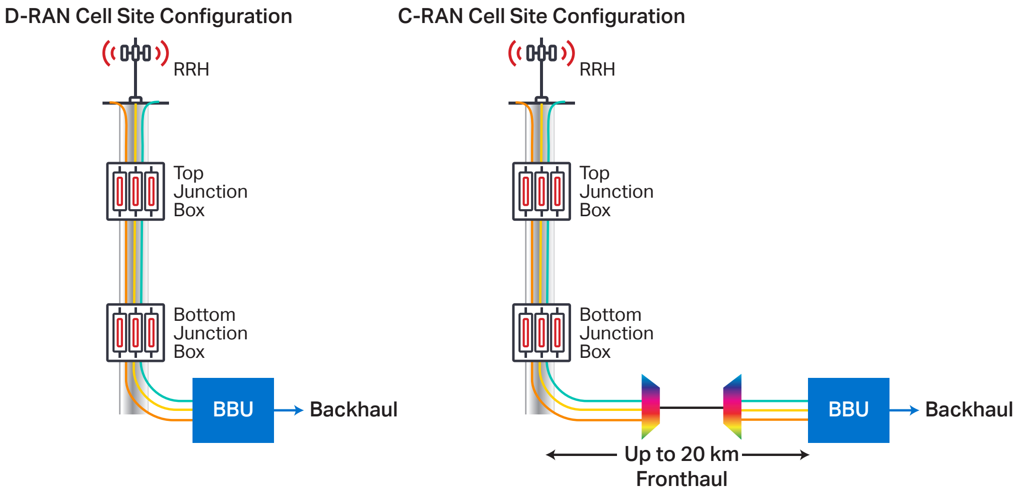

Figure 2. Backhaul and fronthaul networks

2G/3G/4G fronthaul network protocols

The two main 4G fronthaul protocols are Common Public Radio Interface (CPRI) and OBSAI (Open Base Station Architecture Initiative), although the former is far more widely deployed than the latter. CPRI is not a formal industry standard; rather, it is a public specification that has been implemented in such a way that interconnecting RRHs to centralized BBUs from different vendors is challenging at best, and in most cases, simply impossible. Although CPRI works and is deployed, MNOs are locked into a single vendor.

Opportunities

There are many advantages to C-RAN. This is why MNOs are increasingly investigating this relatively new configuration. For example, having multiple RRHs serving a broad geographic coverage area connected to centralized BBUs simplifies implementing Coordinated Multi-Point (CoMP), cooperative beamforming, and enhanced Inter-Cell Interference Coordination (eICIC), which are part of LTE Advanced. Moving once geographically dispersed BBUs into a centralized location allows for greater economies of scale, leading to a RAN that costs less to own and operate. C-RAN facilities can also host virtualized mobile core network functions (such as Serving Gateway User Plane part, Packet Network Gateway User Plane part) of the Evolved Packet Core (EPC) by leveraging data center technology advances related to both storage and compute.

Challenges

Network operations is a world of compromise, and the adoption of C-RAN is no different. Although there are several advantages to connecting remotely located RRHs to centralized BBUs, the assumption is that optical fiber is available. In many cases, optical fiber is already available between macro cell sites and the MTSO used for backhauling purposes, so adding RRHs to these existing cell sites and moving the BBUs into the MTSO is greatly facilitated. The challenge is related to maximizing the use of existing fiber, especially as some traffic carried on this fiber will be 2G/3G/4G D-RAN backhaul traffic and 4G/5G C-RAN fronthaul traffic, as multiple generations of mobile network technology are expected to coexist. New RRH cell sites will require new fiber-optic availability, which conjures up major challenges related to permits, rights of way, and the cost and time implications of trenching these fiber-optic connections.

Another key challenge associated with C-RAN is that the original electrical connection between an RRH and BBU was designed from inception for a propagation distance, which dictates latency, as high as 400 feet. The upper limit of CPRI-based fronthaul is around 250us round-trip latency, which includes the latency associated with the propagation of light and latency incurred as CPRI traffic traverses intermediate network elements. Although the maximum distance between RRHs and BBUs in 4G C-RAN is approximately 20 km, in practice it is typically less than 10 km. Stringent CPRI latency limits, coupled with the cost and right-of-way challenges associated with gaining access to optical fiber to connect to new RRHs in the quest for cell site densification, has significantly limited wide-scale 4G C-RAN deployments, at least for now.

5G mobile networks

5G promises 4G LTE improvements of 100x more devices, 100x faster user (man and machine) data rates, 10x lower latency, and 1,000x higher data volumes. To achieve these aspirational goals, fiber and cell site densification will be required, along with the adoption of many new and emerging technologies. 5G will leverage as much of the existing packet-wireline network infrastructure in the early stages, where possible, to simplify and reduce the costs of early 5G rollouts. This is evidenced by MNOs attaching 5G New Radios (NRs) to the existing 4G EPC, referred to as the Non-Standalone (NSA) mode configuration, and is an elegant way to introduce high-performance 5G radios for capacity and still use existing LTE radios for signaling, coverage, and voice of LTE delivery.

4G and 5G coexistence

From inception, 5G is planned to complement and coexist with 4G in initial rollouts. This has profound consequences on the wireline network that connects 4G and 5G cell sites to each other and to data centers where access content is hosted. These data centers offer storage and compute resources and can be located anywhere from the base of a cell site tower to thousands of kilometers way. Moving the storage and compute resources closer to the network edge has led to such industry initiatives as Multi-Access Edge Computing (MEC). The location of MEC resources will be dictated by the applications and use cases they are expected to support, leading to challenges for MNOs related to deciding where to place storage and compute resources. As virtualization continues to evolve, the ability to dynamically relocate resources is greatly facilitated by providing increased flexibility to dynamically orchestrate storage, compute, and connect resources.

5G fronthaul and midhaul

CPRI was designed for 4G and simply cannot scale to expected 5G rates in its current form. This has led to the development of newer 5G fronthaul protocols, including enhanced CPRI (eCPRI), IEEE 1914.3 Radio Encapsulation over Ethernet (RoE), and O-RAN fronthaul that is targeted at 5G C-RAN. Importantly, these new 5G fronthaul protocols leverage standards-based transport network protocols like Ethernet, thus allowing a wide range of standards-based, scalable, and cost-effective transport systems for carrying the 5G fronthaul traffic between the RRHs and centralized BBUs.

3GPP Rel-15 defined the 5G NR New Radio (NR) systems with a split Distributed Unit (DU) and Centralized Unit (CU) network architecture. The DU includes both real-time baseband processing system and radio elements. The CU is commonly known as the non-real-time baseband processing system.

Between the CU and DU, a new midhaul interface, F1, is defined by 3GPP, which has the same bandwidth characteristics of backhaul, but with tighter latency requirements.

It is also important to understand that the RU, DU, and CU could all be deployed in different network locations. This is predominantly dependent on use case scenarios, the type of ng-LTE or 5G NR radios used (mmWave or Sub-6 GHz), and available last-mile technologies.

With the introduction of 5G fronthaul and midhaul, Ethernet once again comes to the forefront as the protocol of choice for carrying all kinds of traffic, which has resulted in its near ubiquity. However, traditional best-effort Ethernet will not suffice given the latency-sensitive nature of 4G and 5G fronthaul/midhaul traffic, so enhancements are necessary.

Gain more 5G insights

IEEE 1914.3 Radio-over-Ethernet (RoE) encapsulation

The IEEE 1914.3 standard defines how radio information, both data and control, is mapped into Ethernet frames using standardized Radio-over-Ethernet (RoE) headers. The standard supports the encapsulation of time-domain IQ (4G CPRI or 5G eCPRI) into Ethernet frames using various mapping modes including Structure Agnostic Tunneling Mode and Structure Agnostic Line Coding Aware mode. Once radio information is framed, it needs deterministic transport network mechanisms to ensure bounded latency and zero packet loss since the data flows are still low-latency streams. To reduce the bandwidth in fronthaul, 1914.3 RoE also supports the mapping of time-domain IQ streams into frequency-domain data streams with Structure Aware mapping mode.

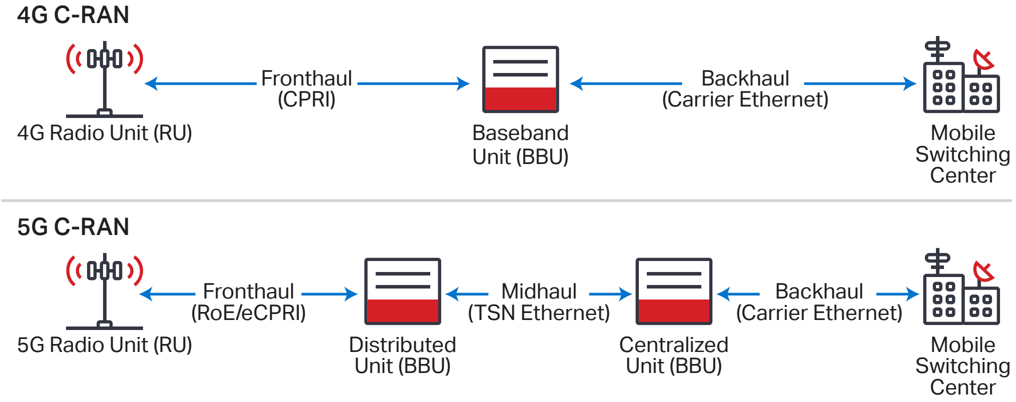

Figure 3. Existing 4G C-RAN vs. new 5G C-RAN configuration comparison

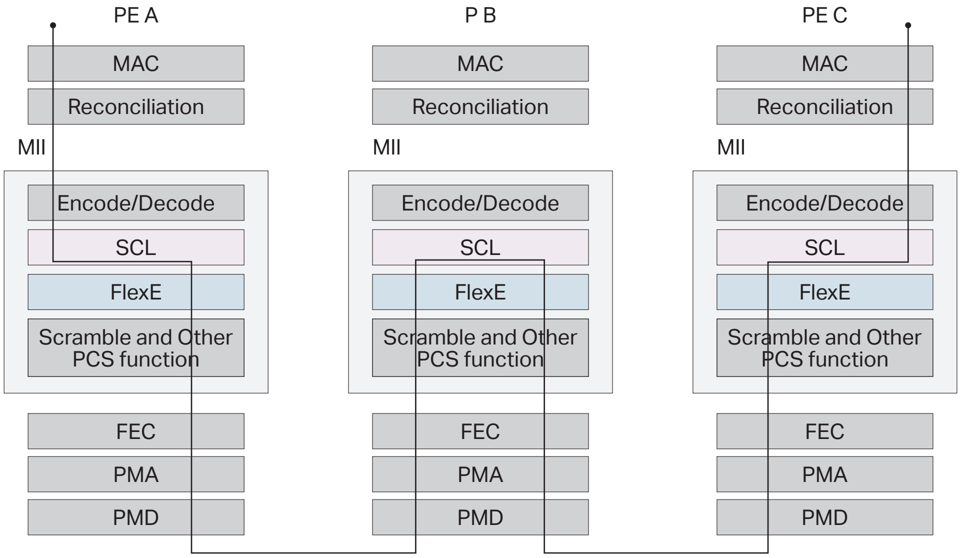

Figure 4. ITU-T G.mtn SCL with FlexEthernet

G.mtn (Metro Transport Networking) and FlexEthernet

There are three ways to transport traffic in use today. The first way is Constant Bit-Rate (CBR), which leverages legacy SONET/SDH or modern OTN to carry traffic. This method offers such connection-oriented advantages as constant low latency and zero packet loss, albeit at the expense of locking of capacity, whether it is being used or not. The second way is via traditional, highly cost-effective Ethernet leveraging statistical multiplexing for connectionless, best-effort transport, resulting in less predictable latency and non-zero packet loss. The third way combines these two via an enhancement to a deterministic forwarding mechanism—OIF Flex-E 2.0 Implementation Agreement, with ITU-T G.mtn specification. G.mtn offers the best of both worlds, such as fixed paths for tightly bounded latency and zero packet loss.

ITU-T G.mtn is a standards-based enhancement to FlexEthernet, ensuring data can travel from network ingress to network egress in a highly predictable amount of time, offering similar performance to Time-Division Multiplexing (TDM) options such as OTN, at a lower cost and complexity. The zero packet loss and tightly bound latency capabilities directly address the latency sensitivity associated with CPRI and eCPRI-based fronthaul traffic between RRHs and BBUs; as well as for the midhaul F1 traffic between the DU and CU.

Although low-latency traffic flows can be created using other transport technologies for MPLS, they do not offer the deterministic behavior required for 5G fronthaul and midhaul. G.mtn gets right down to how packets are scheduled within the switch based on a time-scheduled mechanism. G.mtn provides true hard-isolation (transport slicing) to mobile transport networks. The ITU-T G.mtn enhancements to Flex-E IA 2.0 includes defining a new path switching layer called Sliced Channel Layer (SCL), as well as adding additional OAM to Flex-E.

As the deterministic transport technology for MPLS or Segment Routing, G.mtn/FlexEthernet can properly support deterministic networking applications such as fronthaul, midhaul, and ultra-low-latency services backhaul. Figure 4 illustrates the new SCL layer enabling the path-based switching characteristics in FlexEthernet.

G.mtn enhancements to standards-based FlexEthernet make it a prime candidate for ng-LTE 5G fronthaul and midhaul transport. Additionally, since it is based on an open and field-proven standard in FlexEthernet, C-RAN fronthaul transport vendor lock-in is significantly reduced via a broader, open, and more secure vendor ecosystem.

Gain more routing and switching networking insights

Converged haul transport

Converged haul transport refers to a common physical network infrastructure carrying multiple generations of backhaul, fronthaul, and the newly defined midhaul interface traffic. The latter is specified as an upper-layer Radio Access Network (RAN) functional split specification for 5G by 3GPP. Midhaul, or High Layer Split (HLS) options, are less latency-sensitive, while Low Layer Split (LLS) options are characterized by tight latency requirements. In addition, different 5G NR gNB configurations are available; their selection for deployments largely depends on use case requirements, spectrum and spectrum bandwidth used, availability of last mile asset, and many other factors.

By converging all traffic types hauled to and from the RAN via a converged packet-optical wireline infrastructure, MNOs benefit from increased economies of scale by reducing costly overlay networks for a simpler network to design, deploy, and maintain. Overlay networks are unnecessary.

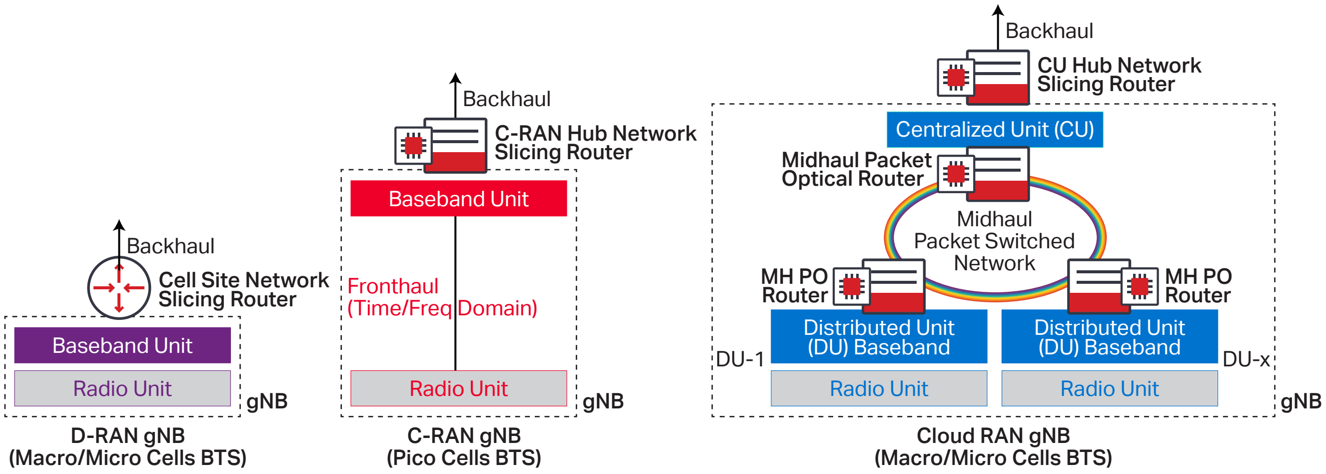

Figure 5. Different 5G NR gNB configurations and the relevancy of xHaul techniques

Migration is underway, with 5G NRs attached to existing 4G wireline infrastructure. But for 5G to reach its full promise, the wireline network must undergo significant modernization of standards-based fronthaul transport topologies, increased scalability, fiber and cell site densification, virtualization, and the guaranteed end-to-end service performance enabled by network slicing.

5G performance gains dictate that traditional network designs must be re-evaluated and changed if the full promise of 5G is to be delivered to the masses, man, and machine. For example, 5G network slicing will guarantee end-to-end performance across storage, compute, and connect (wireless and wireline domains), which is a monumental change from existing best-effort 4G networks. 5G also touts end-to-end latency of 10ms or less, which stands in stark contrast to existing 4G network latency of hundreds of milliseconds.

5G requires software platforms for a virtualized and distributed architecture that pushes intelligence and functionality to the network edge to serve new and unique 5G use cases, such as connected cars. A highly virtualized and distributed core network is managed end to end by leveraging orchestration and analytics, resulting in a network that can self-configure, self-optimize, and even self-heal in a far more autonomous manner, compared to existing 4G networks, to best address ever-changing network conditions.

Conclusion

Mobile network technology, designs, and mindsets used for decades must be challenged and changed if the full promise of 5G is to be delivered and successfully commercialized. MNOs already are actively developing and executing upon different strategies. The 5G NR NSA specifications were standardized, allowing MNOs to deploy 5G NR technology in conjunction with the expansion of existing 4G radio and core networks. As MNOs gain increased confidence in new 5G NR wireless technology, especially with new mmWave radio technologies, and as 5G handsets are rolled out, major upgrades will occur in the RAN and the end-to-end wireline network, starting with the fronthaul, backhaul, and the new midhaul network segments.

Each network segment can be supported by newly available technology toolkits (such as IEEE 1914.3 RoE, G.mtn/FlexEthernet, TSN and network slicing techniques), allowing MNOs to migrate away from closed, proprietary solutions to open, standards-based solutions. Ethernet transport is the frontrunner for fronthaul, especially when enhanced with G.mtn/FlexEthernet capabilities. Midhaul and backhaul could benefit from G.mtn/Flex-E and TSN for network slicing, as well as the brethren of Segment Routing and IP/MPLS features for network services delivery. A converged haul transport solution will allow MNOs to exploit the many benefits of this ubiquitous transport protocol that has permeated essentially all parts of the global network infrastructure. Why should things be done differently—and unnecessarily—in 5G for fronthaul and midhaul network segments?

5G is so much more than just a wireless upgrade. The entire end-to-end network, over both wireless and wireline network domains, must be considered. This is the industry's chance to embrace and deploy converged haul networks based on open, field-proven, and standards-based technology. The time to act is now.

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