New Packet Network Design for Transporting 5G Fronthaul Traffic

A Technical Paper prepared for SCTE•ISBE by

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In memoriam to my esteemed colleague, Jim Kleinsmith.

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Introduction

5G is not just about upgrading the handsets, radios, and antennas that together 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 1000x higher data volumes, everything in the end-to-end mobile service path must eventually be scaled and modernized. This applies to connect, storage, and compute resources resulting in multi-year modernization journey that will start in the RAN and network edge and steadily move inwards, which has already started in several countries.

Unlike previous introductions of mobile networking technology (2G, 3G, 4G) where the new generation of was intended to replace the old generation – but never did – 5G is not intended to replace 4G. 5G is intended to complement and coexist alongside 4G (and 2G and 3G mobile services in many cases) meaning they must coexist by sharing as much connect, storage, and compute resources as possible if MNOs are to support multiple generations of mobile services in a cost-effective manner. 4G will also continue to evolve over time from existing Long-Term Evolution (LTE) deployed today, to future LTE Advanced and LTE Advanced Pro, which are enhancements to 4G that bring it closer to expected 5G performance.

Holistically speaking, a mobile network is a massive wireline network with radios hanging off its edges. In most cases, the only wireless part of the end-to-end journey of data flowing between users and accessed content is between from User Equipment (UE) and cell site antennae. The rest of the end-to-end journey is predominantly over packet-optical wireline networks, although wireless backhaul does exist.

In short, this means the move to offering 5G mobile services is about far more than just a wireless upgrade.

Content

1. Distributed Radio Access Network (D-RAN)

Traditional mobile networks were designed with multiple Radio Heads (RH) and Baseband Units (BBU) 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 3-sector configuration. Early connections between RHs and BBUs was 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 comprised of RHs and BBUs were constructed in a distributed manner intended to serve subscribers within a typical radius of around 20km to 30km. This network topology is referred to as Distributed RAN (D-RAN) and has been the primary method of deploying macro cell sites in most mobile networks around the world.

1.1. 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 it was realized that legacy, copper-based backhaul technology simply could not maintain pace. This is precisely why packet-optical technology became, and continues to be, the best option for high-capacity, low-latency, and major economies of scale for mobile backhaul networks. Packet switching, transported over underlying optical technology, offers benefits associated with statistical multiplexing. The main benefit yielded is optimized bandwidth utilization for reduced costs and is why packet 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. This is illustrated below showing the mix of 2G, 3G, and 4G mobile network technology deployed around the world today, and into the future.

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

There is, and will continue to be, a mix mobile network technology, and is precisely why adding 5G needs must be seamless and cost-effective; easier said than done, no doubt. In most developed countries, 2G mobile services have already been, or will soon be, decommissioned. However, 2G will have a long life in many countries, as will 3G and 4G for the foreseeable future. This is why MNOs understand and demand that 5G not be intended to outright replace previous generations of mobile network technology. It also means that a single, converged infrastructure, wherever and whenever possible, is an obvious primary goal.

Not all use cases require 5G performance and is one of the reasons why sub-generations of 4G LTE technology (LTE Advanced, LTE Advanced Pro) are actively being deployed with vendors continuing to invest in associated product roadmaps for many years to come. Although multiple generations of wireless technology can and will coexist, multiple wireline overlay networks are simply too costly and complex. This is why there is a pressing desire to converge different generations on a converged wireline network.

2. Centralized Radio Access Network (C-RAN)

As mentioned above, 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 when 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 to be steadily replaced by fiber optics over time.

Optical fiber-based communications enable much farther propagation distances than electrical copper-based communications, and this was not lost on MNOs and equipment vendors alike. Why not move and centralize multiple geographically dispersed macro cell BBUs into one location and then connect to Remote RHs (RRH) over distances afforded by fiber optics? This 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 a cloud-based C-RAN. Although C-RAN was first applied to 4G, it is a prime candidate for 5G as well, given that the latter will leverage the higher frequency millimeter wave spectrum. Propagation in this part of the spectrum yields shorter distances and more difficulties through obstacles resulting in a reduced coverage area. This means wide-scale 5G service coverage requires a significant densification of cell sites closer to subscribers, and more fiber to connect to these sites.

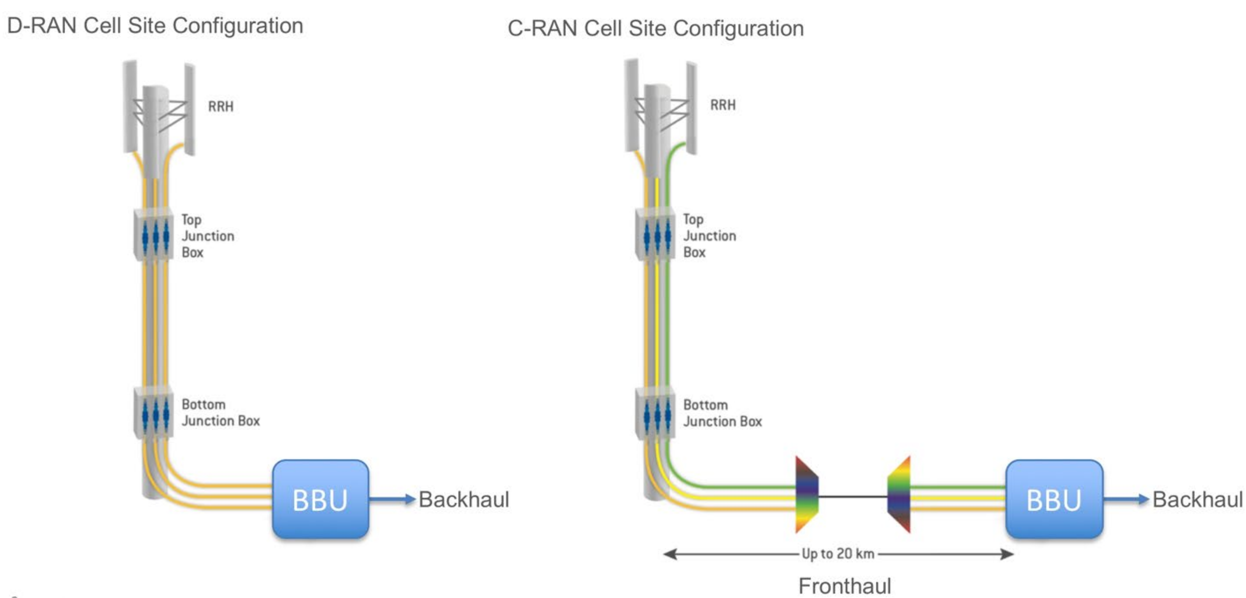

Figure 2 – Backhaul and Fronthaul Networks (ref: EXFO)

2.1. Fronthaul Network

The two main 4G fronthaul protocols are Common Public Radio Interface (CPRI) or 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's a *public specification* that's 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.

2.2. 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 lower cost RAN to own and operate. C-RAN facilities hosting of virtualized mobile network functions (Serving Gateway, Packet Gateway, Home Subscriber Server…) of the Evolved Packet Core (EPC) by leveraging ongoing data center technology advances related to both storage and compute.

2.3. Challenges

We live in a world of compromise, and the adoption of C-RAN is no different. Although there are several advantages to connecting RRHs to 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 backhaul 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 for many years to come. 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 a 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 200us, 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 20km, it is deployed over just a few kilometers, in most cases. 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 to cell site densification has significantly limited wide-scale 4G C-RAN deployments, at least for now.

3. 5G Mobile Networks

5G promises 4G LTE improvements of 100x more devices, 100x faster user (man and machine) data rates, 10x lower latency, and 1000x 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, where possible, in the early stages to simplify and cost-reduce early 5G rollouts. This is evidenced by MNOs attaching 5G New Radios (NR) to the existing 4G EPC, referred to as the Non-Standalone (NSA) configuration, and is an elegant way to test and prove the performance of the 5G NR products, before wide-scale deployments can commence.

3.1. 4G and 5G Coexistence

From inception, 5G is not intended to outright replace 4G. This has profound consequences on the wireline network that connects 4G an 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, and anywhere in between. Moving the storage and compute resources closer to the network edge has led to such industry initiatives as Multi-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, <u>and</u> connect resources.

3.2. 5G Fronthaul

CPRI was designed for 4G and simply cannot scale to expected 5G rates in its current form. This has led to the development of enhanced CPRI (eCPRI) targeted at 5G C-RAN. Standards-based transport of eCPRI traffic between RRHs and centralized BBUs is required, and must be open, scalable, and cost-effective. Although there are different ways of transporting this new type of traffic, such as Passive Optical Networks (PON) technology, Ethernet has once again come 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 traffic, so enhancements are necessary.

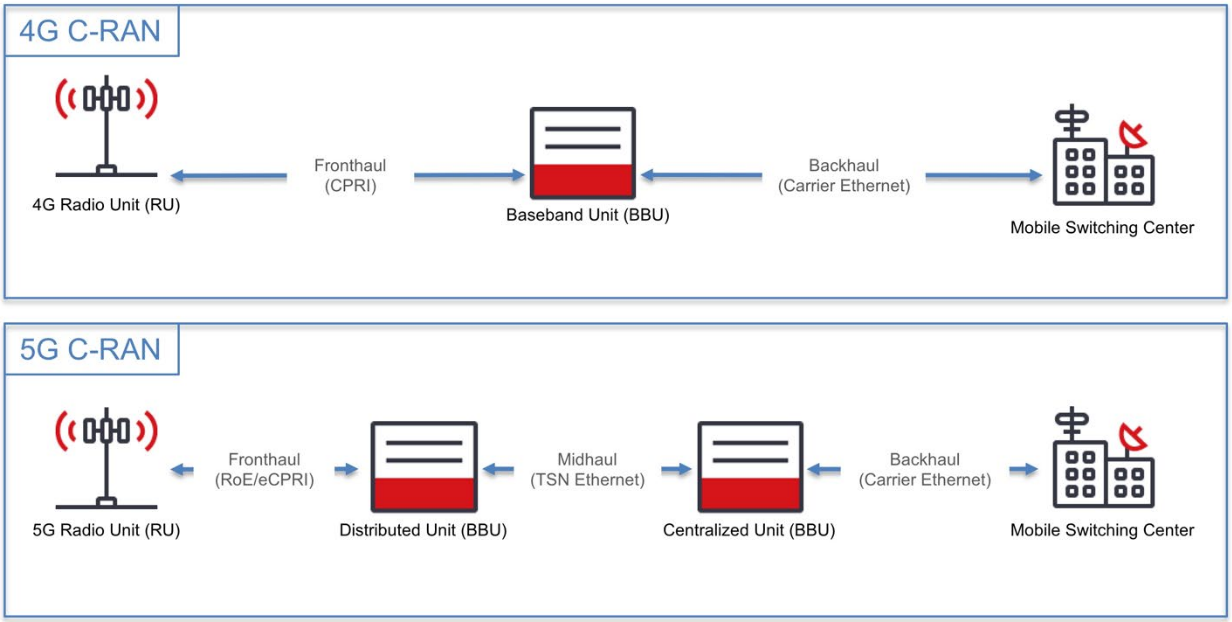

Figure 3 – Existing 4G C-RAN vs. New 5G C-RAN Configuration Comparison

3.3. IEEE 194.3 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) and frequency domain IQ (5G eCPRI). Once radio information is packetized, is needs deterministic transport network mechanisms to ensure bounded latency and zero packet loss.

3.4. IEEE Time-Sensitive Networking (TSN)

There are three ways in use today to transport packet traffic. The first way is Constant Bit-Rate (CBR) that leverages legacy SONET/SDH or modern OTN to carry packet traffic offering 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 deterministic Time-Sensitive Networking (TSN) that offers the best of both worlds, such as fixed paths for tightly bounded latency and zero packet loss.

TSN is not a new protocol; rather, it is a standards-based enhancement to traditional, IEEE standards-based Ethernet that ensures 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, albeit 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.

Although deterministic traffic flows can be created using other technologies, such as MPLS, they don’t offer the low latencies required 5G fronthaul. TSN gets right down to how packets are queued within the switch and how they’re allowed to block or not block each other. While MPLS can carve a path through the network, traffic is still queued and buffered along the way and thus doesn’t provide as tight controls as the Link Layer 2 techniques available with TSN, which is one level of tighter control, at the bit level.

The IEEE TSN Working Group has created standards to enhance existing, best-effort Ethernet such that it can properly support deterministic networking applications, such as fronthaul. These standards fall into four main categories of functionality; (1) Synchronization, (2) Reliability, (3) Resource Management, and (4) Latency, as illustrated in Figure 3.

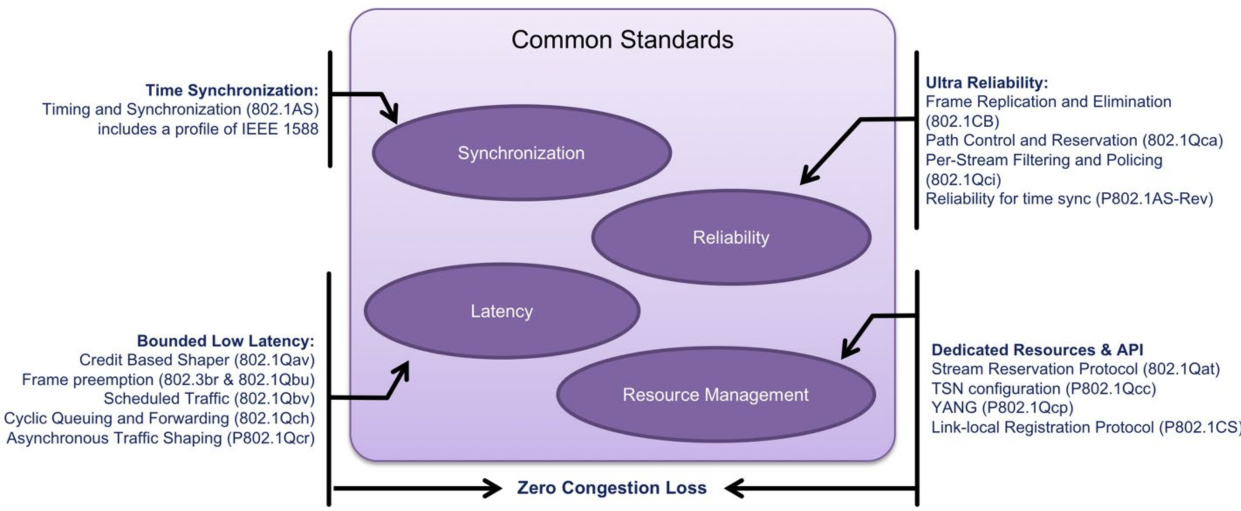

Figure 4 – Time-Sensitive Networking (TSN) Standards (ref: IEEE)

TSN has been used for decades in such applications as industrial Ethernet, audio-visual, and power grid automation. TSN-based Ethernet achieves deterministic transport of 4G CPRI and 5G eCPRI by controlling timing synchronization, traffic scheduling (forwarding, queuing), and system configuration of all nodes in the end-to-end traffic path. There are multiple IEEE standards associated with the TSN Working Group related to synchronized network elements, controlled/accountable latency, prioritization of different traffic classes (deterministic and non-deterministic), guaranteed bandwidth reservation, and enhanced redundancy and resiliency. These enhancements to standards-based Ethernet make it a prime candidate for 5G fronthaul transport, and since it is based on open, well-understood, and field-proven standards, 4G C-RAN fronthaul vendor lock-in is significantly reduced via a broader, open, and more secure vendor ecosystem.

4. Converged Haul Transport

Converged Haul transport refers to a common physical network infrastructure carrying multiple generations of backhaul traffic, fronthaul traffic, and what is being called *midhaul* traffic, which is related to a variety of *functional split* proposals of 5G fronthaul traffic. Fronthaul *High Layer Split (HLS)* options are best served by either IP routers or Ethernet switches, while *Low Layer Split (LLS)* options are best served by the better performance of Ethernet. 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.

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 in terms 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.

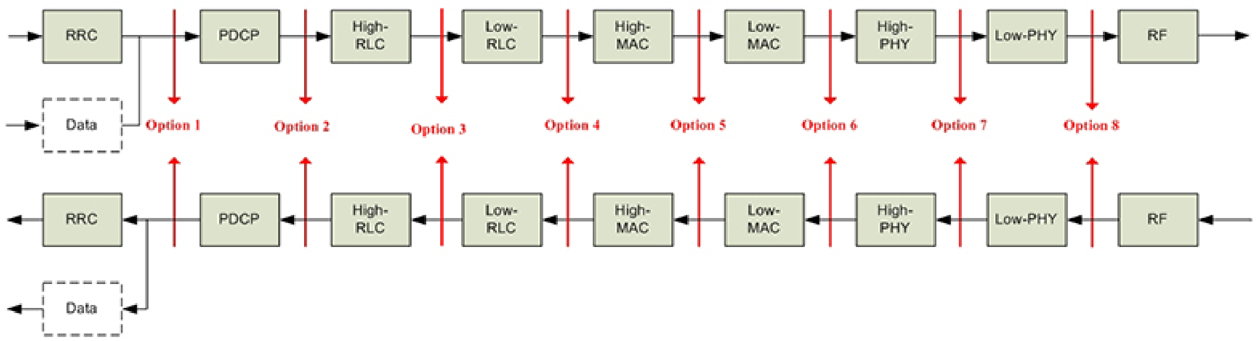

Figure 5 – Proposed Functional Splits (ref: 3GPP)

5G performance gains dictate that traditional network designs must be reevaluated 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 is 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 self-driving cars. A highly virtualized and distributed core network is managed end-to-end by leveraging orchestration and analytics resulting in a more *adaptive 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 know this and are actively developing and executing upon different strategies today. The 5G NR NSA specifications were recently standardized allowing MNOs to test the 5G NR technology in field trials and proofs-of-concept by connecting them to the existing 4G core wireline network. As MNOs gain increased confidence in new 5G NR wireless technology, 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 new midhaul network segments.

Fronthaul is a new battleground with a variety of proposed functional splits being debated in the industry because MNOs want to migrate away from closed, proprietary solutions to open, standards-based solutions. Ethernet transport is the frontrunner, especially when enhanced with TSN capabilities, and 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 the fronthaul and midhaul be any different?*

As 4G and 5G are expected to coexist, fronthaul working groups and associated standards will facilitate carrying 4G CPRI and 5G eCPRI over a common Ethernet-based wireline architecture that can also be used to carry backhaul, and the new midhaul traffic as well. This is the industry's chance to develop and deploy fronthaul networks based on open, field-proven, and standards-based technology – *the time to act is now!*

5G is so much more than just a wireless upgrade – the entire end-to-end network must be considered.

Abbreviations

2G	2nd Generation Mobile Networks
3G	3rd Generation Mobile Networks
4G	4th Generation Mobile Networks
5G	5th Generation Mobile Networks
BBU	Baseband Unit
CAPEX	Capital Expenditures
CBR	Constant Bit-Rate
CoMP	Coordinated Multi-Point (CoMP)
CPRI	Common Pubic Radio Interface
C-RAN	Centralized/Cloud Radio Access Network
D-RAN	Distributed Radio Access Network
eICIC	enhanced Inter-Cell Interference Coordination
eCPRI	Enhanced Common Public Radio Interface
EPC	Evolved Packet Core
IEEE	Institute of Electrical and Electronics Engineers
MNO	Mobile Network Operator
ms	milliseconds
NR	New Radio
NSA	Non-Standalone
OBSAI	Open Base Station Architecture Initiative
OPEX	Operational Expenditures
OTN	Optica Transport Network
PON	Passive Optical Network
RAN	Radio Access Network
RH	Radio Head
RoE	Radio-over-Ethernet
RRH	Remote Radio Head
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
TDM	Time-Division Multiplexing
TSN	Time-Sensitive Networking
us	microseconds

Bibliography & References

The Mobile Economy, 2017, GSMA
Radio Access Architecture and Interfaces, TR 38.801 v0.2.0, 3GPP
Mobile Fronthaul Testing Reference Guide, 2016, EXFO

