# Mobile Backhaul

by Brian Lavallée

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# EXECUTIVE SUMMARY

Mobile backhaul (MBH) networking technologies are in a constant state of change as Mobile Network Operators (MNOs) struggle to maintain pace with voracious bandwidth demand growth rates that show no signs of abating. MBH networks must improve in terms of capacity, reliability, and availability as access to user content is increasing via mobile devices such as smartphones, tablets, laptops, and even cars. The perfect storm of more users increasingly adopting more powerful smartphones that support higher upload/download speeds to access content means that MBH networks that interconnect users to their content have become critical network infrastructure. As a result of this perfect storm, MNOs are constantly seeking new and innovative means to maintain pace with mobile user bandwidth demands. Concurrently, they are simplifying their overall network infrastucture to reduce ongoing operating costs to combat constant price erosion due to a hyper-competitive mobile network market, coupled with evolving and diminishing brand loyalty.

Ongoing demand for increased bandwidth has resulted in constant innovation in MBH networks. The advent of Carrier Ethernet and Mobile Backhaul as a Service (MBHaaS) offers the potential for decreasing MBH network costs while simultaneously improving bandwidth, reliability, availability, monitoring, and end-to-end management capabilities. Improving Radio Access Network (RAN) capacity with improved coverage also opens up new business opportunities with new and highly coveted revenue streams. Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) will create a more open mobile network development environment that will facilitate the introduction of innovative new services and product offerings, many of which have not been dreamed of yet.

This book looks at the early days of MBH technology, where we are today, and where we expect this part of the mobile network infrastructure to be headed in the future. We also review some of the emerging opportunities for industry players that either consume or wholesale MBH services. This is an exciting time for the mobile communications industry, and the changes coming represent an important modernization in the world of MBH networking.

## INTRODUCTION TO MOBILE NETWORKING

The increasing popularity of mobile networks and associated services shows no signs of abating in the coming years; rather, it's quite the opposite! MNOs are constantly expanding the capacity, reach, and reliability of their wireless networks, which creates ongoing opportunities to adopt new technologies. As MNOs update their Long Term Evolution (LTE) networks and expand their LTE Advanced (LTE-A) networks to address the growing demand for mobile data services, a simultaneous upgrade of the MBH part of their network infrastructure is also required to ensure it does not become the bottleneck for mobile users trying to access their content, which is increasingly residing in distant web-scale data centers. The proliferation of mobile apps among smartphone users—including email, streaming video, Internet access, gaming, and social media—means the ever-increasing demand for more bandwidth will undoubtedly continue for the foreseeable future. MNOs not properly prepared and positioned to address these significant infrastructure challenges are at serious risk of falling behind their competitors in this hyper-competitive environment—which no MNO desires.

Legacy 2G wireless technologies were originally created for voice traffic and are not applicable to modern data-centric applications and services. This means MNOs are compelled to upgrade their mobile network infrastructure to address the new data-centric requirements related to improved resiliency, capacity, scalability, latency, synchronization, and Quality-of-Service (QoS). These network requirements are associated with the primary challenges related to upgrading MBH networks to seamlessly converge voice and data services between the RAN and the MNO's Mobile Telephone Switching Office (MTSO), located toward the network core. MNOs are constantly evaluating new MBH network solutions that offer economical yet technically advanced capabilities that are far simpler to design, own, and operate.

Considering the substantial initial and ongoing investments associated with implementing any new technology, a careful consideration of Carrier Ethernet as the next-generation MBH network technology of choice is warranted. Carrier Ethernet offers MNOs cost-effective MBH connectivity that enables operational efficiencies, management capabilities, and extreme scalability that are absent in traditional 'old-school' MBH networks in operation today. Carrier Ethernet allows MNOs to provide packet-based MBH connectivity from the RAN cell sites to the wireline-based core network in a seamless manner, resulting in a far simpler data-centric network that is entirely packet-based from user to content.

## TRADITIONAL MOBILE NETWORK ARCHITECTURE

In a traditional mobile network infrastructure, point-to-point connectivity between a NodeB and a Radio Network Controller (RNC) resulted in a fairly simple network design. This simple network design changed substantially with the advent of packet-based LTE because LTE eNodeBs require communication with other eNodeBs, Serving Gateways (SGWs), and Mobile Management Entities (MMEs). In comparison, non-LTE networks do not require or even support the direct communications between geographically separated base stations. The increased complexity of LTE-based networks requires substantial thought and attention to the design and deployment of MBH connectivity before choosing and deploying an updated MBH network solution. See Figure 1 for an illustrated view of a modern mobile network.
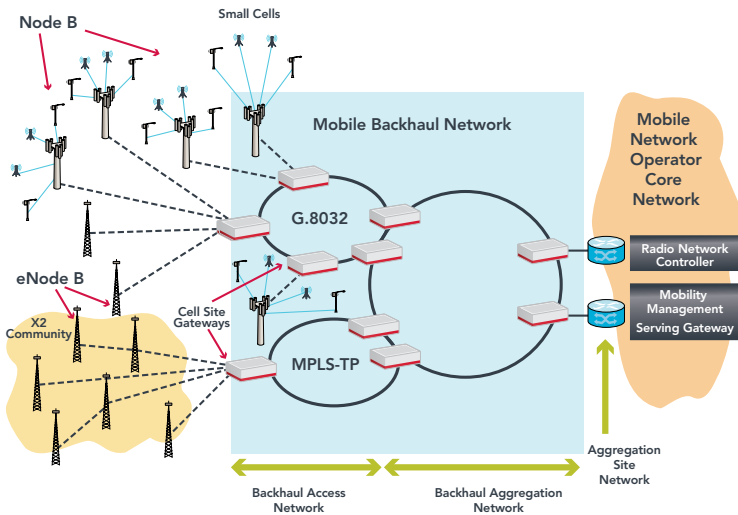


Figure 1: Typical modern mobile network architecture

## GENERATIONS OF MOBILE NETWORK TECHNOLOGIES (2G/3G/4G/5G)

The generational improvements of mobile technologies from 2G to 3G to 4G and beyond represent the evolution of mobile technologies since the inception of mobile data services more than 15 years ago. As data rates have increased, so have network complexity and the cost of mobile telecom equipment. The latest cellular standards were developed with an eye toward increasing data rates, resiliency, and management capabilities while supporting cutting-edge technologies that will decrease deployment and operational costs for MNOs. See Table 1 for a comparison of mobile network technology data rates.

| Wireless Standard | | Upload Rate | Download Rate |
|---|---|---|---|
| 2.5G | GPRS | 20 kb/s | 114 kb/s |
| 2.75G | EDGE | 60 kb/s | 384 kb/s |
| 3G | UMTS | 64 kb/s | 384 kb/s |
| | W-CDMA | 153 kb/s | 2 Mb/s |
| | HSPA-3.6 | 384 kb/s | 3.6 Mb/s |
| | HSPA-7.2 | 2 Mb/s | 7.2 Mb/s |
| Pre 4G | HSPA14 | 5.7 Mb/s | 14 Mb/s |
| | HSPA+ | 22 Mb/s | 56 Mb/s |
| | LTE | 50 Mb/s | 100 Mb/s |
| 4G | WiMAX 2 | 500 Mb/s | 1 Gb/s |
| | LTE Advanced | 500 Mb/s | 1 Gb/s |

Table 1: Mobile network technologies comparison

## Global System for Mobile Communications (GSM)

GSM is a mobile telephony standard developed by the European Telecommunications Standards Institute for 2G mobile networks and was intended to replace the first generation (1G) of analog mobile networks with a digital, switched, full-duplex mobile telephony solution. GSM is currently deployed and in use in more than 90% of mobile networks the world over and is thus the default global standard for mobile telephony today. GSM networks are currently active in more than 200 countries worldwide and, over time, have been expanded to encompass data communications via General Packet Radio Services (GPRS) and Enhanced Data rates for GSM Evolution (EDGE).  Yet these data rates pale in comparison with modern 4G networks.

## Code Division Multiple Access (CDMA)

CDMA is an example of a channel access method that supports multiple access, allowing multiple transmitters to access a single communication channel simultaneously. CDMA is used by various radio communication technologies, and variants of CDMA form the basis for 3G data services, both for CDMA- and GSM-based MNOs. CDMA supports frequency sharing between multiple transmitters while preventing interference between transmitters by using spread-spectrum techniques that assign a unique identification code to each transmitter sharing that channel. This capability to share frequency bandwidth among multiple transmitters without congestion or contention is a key benefit of CDMA technology. Unfortunately, CDMA does not support the higher-bandwidth channels required to address modern bandwidth demands.

### High-Speed Packet Access (HSPA)

HSPA, a combination of the High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) mobile networking protocols, extends and improves the performance and utility of existing 3G mobile data networks by using Wideband CDMA (WCDMA) protocols. Enhancements to the HSPA standard, known as HSPA+ or Evolved HSPA, were released in 2008.

### Long-Term Evolution (LTE)

LTE is a standard developed by the 3rd Generation Partnership Project (3GPP), a consortium of telecommunications standards organizations from around the world that collaborate to develop a series of cellular telecommunications standards. LTE has been in use for high-speed mobile data by MNOs since 2010, and continues to grow worldwide. Although LTE is based on EDGE and HSPA technologies, it offers increased capacity via core network advances and an alternative radio interface. LTE provides an upgrade path for MNOs using both GSM and CDMA networks. LTE is often referred to as 4G, although it technically does not fully conform to the 3GPP standards. The International Telecommunication Union (ITU) has since ruled that LTE can be referred to as 4G, along with WiMAX and HSPA+.

### LTE-Advanced (LTE-A)

LTE-A provides improved performance and functionality over basic LTE while remaining compatible with existing LTE equipment. This backward compatibility enables phased migrations to an LTE-A infrastructure while allowing MNOs to continue using existing LTE assets. LTE-A is an evolutionary LTE development offering many new and significant features:

- Uses additional spectrum and multiplexing to support higher data access speeds

- Built on a native IP-based, packet switched network

- Fully supports IPv6-based data services

- Supports theoretical peak data rates of 1 Gb/s download and 500 Mb/s upload

- Has Coordinated Multipoint Transmission (CoMP) to achieve higher, aggregated data rates

Many MNOs are modernizing their mobile networks with LTE-A technologies and associated services. Others are actively evaluating the technology in anticipation of implementing LTE-A technology and services in the coming years

based on market demands in various regions, as some smartphone markets are more advanced than others.

## Technologies for Evolving Mobile Networks

In addition to the underlying wireless technologies previously discussed, MNOs are actively addressing the problems of surging bandwidth demands by using a variety of other technologies as well. In general, these strategies improve coverage and/or increase overall mobile network capacity by shunting traffic off of existing macro cell-based networks.

## Macro Cells

Macro cells are what most people think of when discussing mobile networks and are represented by high-power cellular sites hosting several radios and antennas installed atop high towers or rooftops. Macro cells can have a range of more than 30 kilometers and serve hundreds to thousands of mobile users, so the underlying infrastructure must be robust. Macro cells are quite expensive to build, own, and operate on an ongoing basis. They are typically installed above most obstacles situated between mobile users and mounted radios to ensure optimal coverage, but signals are still often degraded when mobile users are inside buildings or behind structures. Adding more macro cells in an effort to improve coverage and capacity is an option in some cases, although this strategy is often not feasible from environmental, economic, regulatory, and time-to-market perspectives, leading to other new and viable alternatives, such as small cells.

## Distributed Antenna Systems (DAS)

DAS is based on the premise that multiple low-power antennas can provide improved coverage and increased network resiliency than one high-power antenna can provide within a targeted geographic area. By distributing available radio power over multiple smaller antennas, coverage is improved because more mobile users will be in direct Line-of-Sight (LOS) to an antenna in the distributed array. Distributed antennas can be aggregated using passive splitter technology and/or active technologies, including repeaters and amplifiers. DAS is popular in confined spaces that experience local high-volume traffic, such as sports arenas, public transportation stations, shopping malls, and convention centers.

## Small Cells

Small cells address both coverage and capacity issues associated with existing macro cell limitations by using low-power radios installed closer to mobile users, thus improving services delivered in poorly served areas, indoors, and

outdoors. Small cells reuse the existing wireless spectrum in conjunction with existing macro cells, thus negating the requirement to acquire new spectrum that, if available, is extremely expensive. Small cells are cheaper, easier, and quicker to deploy than adding additional macro cell sites and thus can be strategically placed to address poor coverage in not-spots around metropolitan areas, both indoors and outdoors. It is expected that indoor small cells will initially be adopted more often than outdoor small cells because mobile users usually access content while indoors. As well, outdoor small cells commonly experience more installation issues related to regulations, rights of way, and access to MBH connectivity, often making them far harder to deploy than indoor small cells. That said, with the growing demand for higher capacity RAN connectivity, issues related to installing small cells outdoors will undoubtedly be resolved.

Small cells implement power control technology to limit their effective range to approximately 200 meters and can be deployed on a permanent basis or to handle temporary demands, such as those related to a sporting event that attracts a large number of mobile users within a concentrated area over a certain period of time. It is expected that as many as half of all operator-owned small cells will use fiber-based MBH networks, with the remainder served by wireless and copper-based networks. Fiber-based networks offer the required benefits related to capacity, latency, and cost. In some cases, however, such as within a busy city center, access to fiber-based MBH will be a challenge to overcome, (if possible at all).

### Cloud RAN or Centralized RAN (C-RAN)

C-RAN is a relatively new technology developed to support the large-scale consolidation of numerous geographically dispersed Remote Radio Heads (RRHs) back to a single centralized Baseband Unit (BBU) in which the traffic is routed across a switched packet network to the Mobile Telephone Switching Office (MTSO). Since the advent of 3G, most cell sites separate the analog and digital signals to achieve greater efficiency and reduce Radio Frequency (RF) loss due to long cable runs between the BBU and the RRH mounted atop the tower. With 3G, radio signals between the BBU located in the site hut and the RRH mounted atop the tower, as close as possible to the antenna air interface, now traverse a fiber link using the Common Public Radio Interface (CPRI), which is a very high-speed interface requiring low latency, thus requiring fiber-based connectivity. It should also be noted that CPRI is not actually an industry standard, so implementation differences do exist.

C-RAN takes the abstraction of BBU and RRH to its logical extreme. Instead of using fiber between the RRH on the tower and the BBU housed in the collocated hut, C-RAN connects the RRHs via fiber to a central BBU that can aggregate tens to hundreds of RRHs located kilometers to tens of kilometers away. See Figure 2 for more detail on the C-RAN architecture.
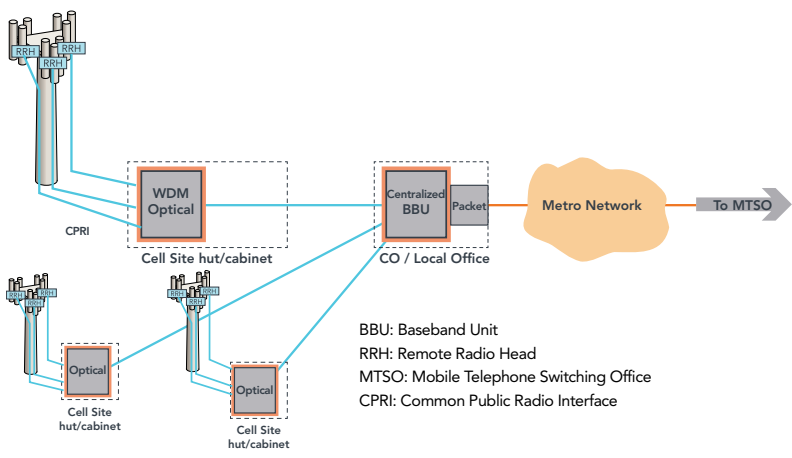


Figure 2: General C-RAN reference architecture

By centralizing and pooling the processing power in a single BBU attached to many RRHs, MNOs can leverage NFV and cloud concepts to dynamically allo-cate resources where they are most needed at any particular time. Traditional cell site design configures the RRH and BBU for the maximum potential traf-fic load, even though those resources might be significantly underused most of the time. C-RAN allows the central BBU to adjust for demand variations by shifting resources away from lightly loaded sites to heavily loaded sites. This architecture allows for a less-expensive, centralized infrastructure com-pared with the distributed architecture of traditional cell sites. MNOs can also conceivably share the centralized BBU, thus further reducing overall network operational costs by sharing network costs.

## MODERN MOBILE NETWORK CHALLENGES

Upgrading MBH networks is an ongoing challenge for MNOs striving to maintain and grow market share while struggling to keep deployment and operational costs to an absolute minimum to remain competitive in the short term and financially viable in the long term. MBH networks today serve 1 Gb/s to a macro cell, but this will soon be insufficient due to surging band-

width demands related to the exponential proliferation of Over-the-Top (OTT) mobile applications, more mobile users accessing content more often and for longer periods of time, and increasingly powerful smartphone adoption. As shown in Figure 3, MBH bandwidth will soon surpass 1 Gb/s to the macro tower due to these mobile market trends, and thus represents significant new technology challenges, as well as new business opportunities.

**Mobile Backhaul Traffic Growth (per Access Cluster)**
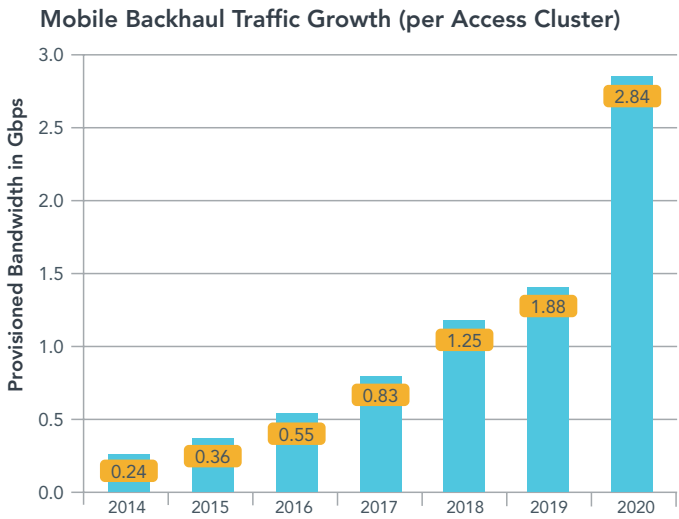


Figure 3: Projected MBH traffic growth from 2014 to 2020[1]

## MOBILE USER GROWTH

Smartphone use is expected to increase from just over 50% in 2014 to almost 70% by 2018. Bandwidth consumption by mobile users commonly increases as they transition to smartphones, precisely because OTT applications support high-bandwidth content, such as video streaming. The majority of bandwidth consumption of tablets and phablets (large-format phone or small-format tablet) has traditionally been over WiFi networks, but that trend is starting to shift increasingly toward mobile data network access, which will further contribute to MBH network bandwidth growth in the coming years. Figure 4 illustrates a breakdown of mobile broadband penetration by device type.

Although smartphones will continue their steady climb in market share, tablets and phablets are more aggressively gaining market penetration. This situ-

[1] Forecast of Mobile Backhaul Requirements, 2014 (ACG Research)

ation creates a perfect storm with the growing number of devices demanding ever more bandwidth.  As bandwidth consumption continues to increase on the RAN side of the network, the demands placed upon MBH networks that connect mobile users to content also increase. The mobile traffic reaches the air interfaces of cell sites, carried over MBH networks, which are mostly fiber-based.

**Penetration of Mobile Broadband Devices**
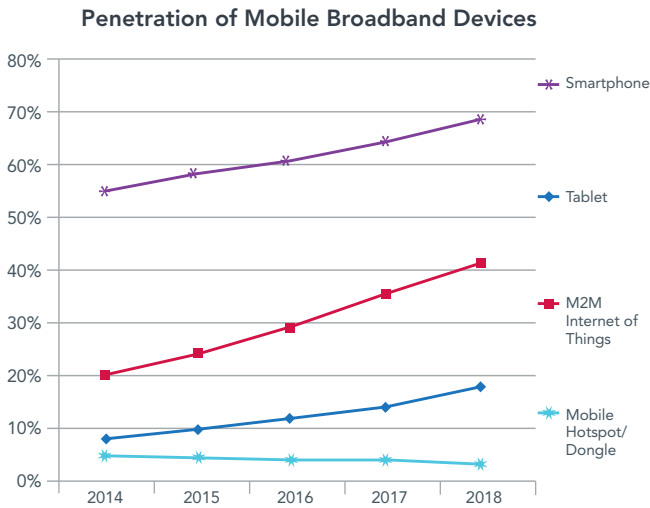


Figure 4: Mobile device market penetration[2]

## BANDWIDTH AND APPLICATION GROWTH DRIVERS

Many software vendors and service companies are releasing OTT smartphone apps that create a rich media experience for mobile users. Web pages that were once static now offer streaming video content that is automatically played, rich media-based advertisements to gain and maintain a user's attention, and high-fidelity music. Unlimited bandwidth data plans increasingly offered by MNOs will also have a substantial effect on bandwidth usage, as users who once had data caps, which encouraged them to use WiFi access whenever possible, continue to migrate to mobile broadband data networks. As a result, peak period bandwidth requirements are projected to increase five-fold between 2014 and 2018. See Figure 5 for a breakdown of current and projected bandwidth usage for the most popular OTT application types.

Entertainment and social networking OTT apps will continue to be the predominant growth factors related to increased bandwidth consumption, al-

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2 Forecast of Mobile Backhaul Requirements, 2014 (ACG Research)

though almost all categories of OTT apps will follow an upward trend over time. The growth in bandwidth usage for video and other entertainment is rather intuitive, but it should be noted that most social media apps are now

based on sharing video clips, pictures, and music. Thus, social networking is the second biggest bandwidth consumer behind video streaming services and is also projected to keep trending upward over time.

**Weighted Application Bandwidth Usage on Smartphones**
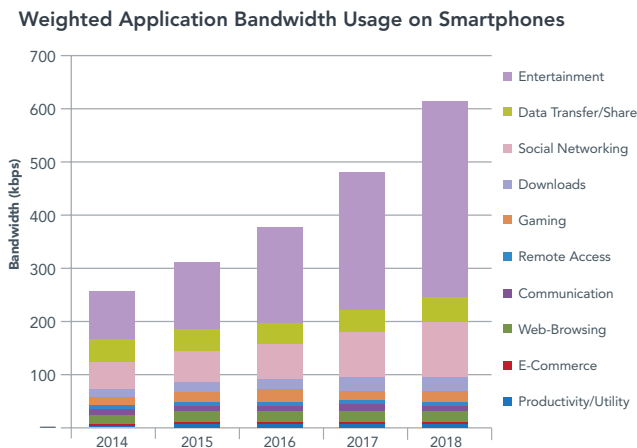


Figure 5: Smartphone bandwidth usage by application type[3]

## PHYSICAL PLANT COST CONTROL

In addition to addressing the ever-increasing demand for bandwidth, there are also strong financial and operational benefits related to modernizing MBH networks to packet-based technologies, such as Carrier Ethernet, which is rapidly gaining in popularity among most MNOs as they upgrade their legacy TDM-based MBH network assets. Although macro cells were originally designed to support just one radio technology, most macro cells today now host 2G, 3G, and 4G equipment both atop the tower and within the collocated hut at the tower base, resulting in complex and expensive installations. Carrier Ethernet-based MBH networks, can yield 40% or more in savings over router-based MBH networks. Figure 6 shows the potential cost savings of the Present Mode of Operations (PMO) based on router-based MBH networks compared with the Future Mode of Operations (FMO) based on Carrier Ethernet-based MBH networks, and is one of the primary reasons for the rapid and increased adoption of the latter, especially in North American MBH networks.

[3] Forecast of Mobile Backhaul Requirements, 2014 (ACG Research)

**Cost Breakdown (2018)**

- Replacing expensive routers with purpose-built economical Carrier Ethernet switches
- Additional CAPEX savings at Edge Layer because of better wave-fill due to ring technology

Legend: ■ Access  ■ Edge  ■ Core

Values shown: 1.00 (Present Mode of Operation), 0.59 (FutureMode of Operation)
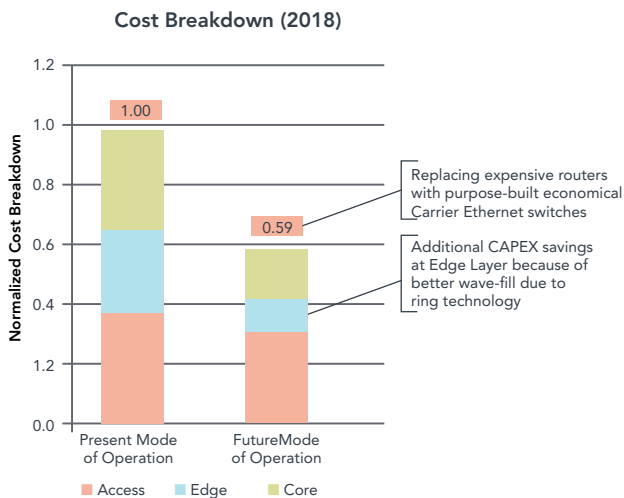
Figure 6: Cost savings of PMO vs. FMO for access, edge, and core networks

## Power Considerations

As aging MBH networks based on router-based technology are upgraded to Carrier Ethernet-based networks, the result is a simpler, more compact, more reliable, lower cost, and environmentally friendlier MBH network solution. Two of the most constrained physical plant resources are electrical power and physical space, limitations that are alleviated by more compact and energy-efficient networking equipment at macro sites. Carrier Ethernet equipment that consumes less power also generates less heat, thus reducing the need for expensive and complex cooling at remote macro sites. Reduced energy consumption and associated dissipated heat also increases the reliability of electrical and optical components.

## Security Enhancements

MBH network solutions based on Carrier Ethernet technology support a wide variety of embedded security features that ensure the protection of both the transported mobile user traffic and the mobile network itself. The following network functions must be protected to ensure the overall integrity of the mobile network:

- Session setup and tear-down information
- Administrative data used by network operators

- Management capabilities for network applications

- QoS information

- Services information

- Privacy information

- Intrusion detection systems

For MNOs and network equipment vendors alike, security is a primary concern as it pertains to all parts of the mobile network because our reliance of this critical piece of infrastructure is only increasing from social and business perspectives.

### Network Resilience and Availability

Another key consideration when upgrading MBH networks is the resilience of the network offered by Carrier Ethernet equipment that connects macro cells to the MNO's core network and beyond. Using modern Carrier Ethernet-based solutions that support a ring topology between access and aggregation devices offers significant fault tolerance that can rapidly reroute traffic around network faults within 50 milliseconds to handle inevitable network faults such as fiber cuts and failed equipment. See Figure 7 for a typical example of a modern ring topology for MBH networks.
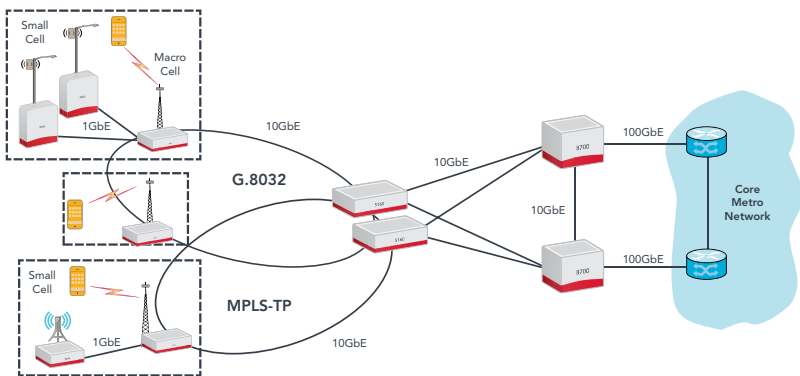


Figure 7: Typical MBH implementing ring-based topology resilience

This intrinsic architectural resilience allows network designers to spend more time addressing capacity factors instead of having to over-engineer each installation to provide physical fault tolerance. Ethernet rings based on G.8032

standards offer resilience that is simple to deploy yet provides carrier-grade availability to mobile users accessing their content.

## Mobile Backhaul Architecture Options

MBH networks include a diverse collection of architectures, topologies, technologies, and equipment options. Even within individual architectures, there are a variety of technological approaches from which to choose. MBH networks also support specific features that together ensure an acceptable quality of experience, such as:

- Sophisticated network timing and synchronization features
- Operations, Administration, Maintenance, and Provisioning (OAM&P) features
- QoS prioritization capabilities
- Protection capabilities

MBH networks offer three main topologies based on the specific equipment chosen and the operating environment in which deployment will take place: ring, hub and spoke, and daisy chain. Each topology has its own benefits and limitations, so a thorough understanding of each option is critical to selecting the correct topology, although sometimes the equipment and/or the available fiber plant assets will ultimately dictate the topology decision.

## RING TOPOLOGY

The venerable ring topology offers many advantages to MBH network design, including simplicity of deployment, rapid sub-50ms service restoration in the event of faults, and a fully standards-based solution, enabling reduced costs and a faster return on investment. Another advantage of the ring topology is its capability to easily scale to a large number of interconnected nodes (macro cells) accessed via high-bandwidth Ethernet over fiber. Ring topologies offer multiple logical connectivity options such as point-to-point, point-to-multipoint, and multicast, which increases network efficiency by optimizing the amount of traffic traversing the mobile network. Ethernet ring-based topologies are based on widely accepted industry standards, such as ITU-T G.8032, thus facilitating the interoperability of different vendor equipment. See Figure 8 for examples of some popular Ethernet ring-based topologies.
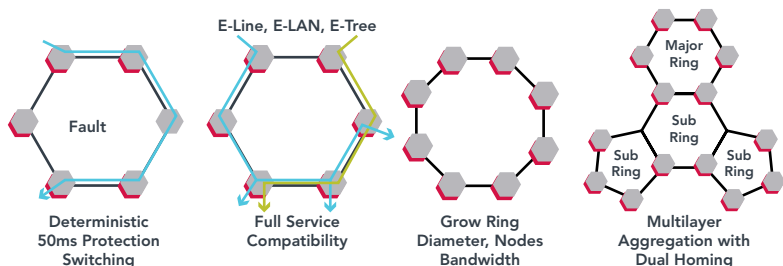
Figure 8: Typical Ethernet ring-based topologies interconnecting cell sites

## HUB AND SPOKE

The hub and spoke architecture, another common network topology used in MBH networks, relies on one or more aggregation points that connect two or more remote sites. One typical approach of hub and spoke in MBH networks is to aggregate multiple small cells at a convenient macro cell site where a larger link can then be used to connect to the MTSO. This is also why existing macro cell backhaul network links of 1 Gb/s commonly deployed today will soon be insufficient and will have to be upgraded as bandwidth consumption grows. See an example of hub and spoke topology in Figure 9.
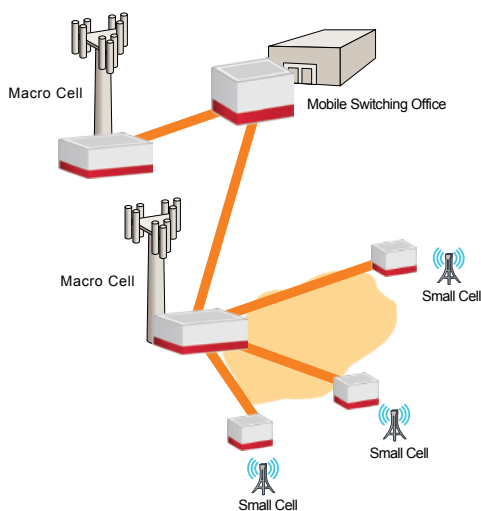


Figure 9: Typical hub and spoke MBH network

## DAISY CHAIN

The less-common daisy chain network topology is an option for connecting sites located along a highway or road, or along other geographical features such as a mountain ridge. In this scenario, running individual backhaul circuits from each site back to an aggregation point may be cost-prohibitive, or even impossible due to geographical constraints. Note that a MBH network daisy chain topology may require additional engineering to provide the desired fault tolerance, given its effectively point-to-point physical network architecture. See an example of a daisy chain topology in Figure 10.
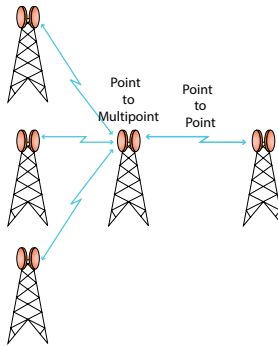


Figure 10: Daisy chain MBH network architecture

## PHYSICAL MEDIA OPTIONS

In addition to a variety of topology options, there are also many options available for MBH network links running over wired or wireless media. Within each media type, multiple media options can be deployed based on application needs.

### Wireline (Wired) Media

The two primary wireline media options for MBH network installations are fiber and Hybrid Fiber-Coax (HFC), which are discussed in the following two sections.

### Fiber Backhaul

Although fiber-based backhaul links are considered the gold standard of MBH networking, smaller bandwidth needs, geographical limitations, fiber availability and deployment costs, and architectural constraints can limit the situations in which fiber can be cost-effectively deployed, if at all. Fiber boasts the highest potential bandwidth capacity among all available media options

and can be deployed as point-to-point, ring, hub and spoke, and daisy chain topologies.

## Hybrid Fiber-Coax (HFC)

HFC-based networks have been the network media of choice for cable operators since the early 1990s. Considering the high cost of laying and suspending cable TV wiring, cable MSOs "future-proof" their cable plants by installing a cable product that bundles copper-based coax media along with optical fiber media within the same casing, enabling the option of using either copper-based or fiber-based data transmission along a link, based on whichever media best matches the network link requirements. Cable MSOs can use their HFC plants to carry MBH traffic of their own if they are selling mobile services, or they can sell wholesale MBH network services to third-party MNOs to increase their revenue streams.

## Wireless

Various wireless technologies are also available for use to backhaul mobile network traffic, including microwave and millimeter wave in point-to-point, multipoint, LOS, and Non-Line-of-Sight (NLOS) configurations, as discussed in the following three sections. This MBH method is typically used when fiber-based connectivity is either too expensive or simply not an option, such as the case in downtown cores where fiber installation is not a viable option.

## Microwave and Millimeter Wave Wireless

Microwave MBH links are historically the connection mechanism of choice for remote site locations in which wireline connectivity is not a viable option. Microwave links typically offer data speeds of 1 Gb/s, with ongoing refinements of the microwave MBH standards to eventually support data speeds up to 10 Gb/s over a transmission range of 50 kilometers, or more. Although improving in each new generation of technology, microwave links still suffer from signal degradation related to meteorological conditions, such as rain, and often require special equipment and personnel to install, deploy, and maintain. Although millimeter wave links are well-suited for backhaul of small sites in urban settings, they offer a more limited reach. However, for certain "thin" applications requiring low to moderate bandwidth and associated range, millimeter technology can still be a viable option whose cost-effectiveness has resulted in its increased adoption. In either case, regulatory licensing is a major hurdle that must be taken into account when choosing wireless MBH.

## Point-to-Point and Multipoint Topologies

In certain scenarios, wireless point-to-point network designs can replace or complement traditional wireline-based backhaul networks because they can sometimes be deployed faster and at lower cost than wireline-based networks, especially in locations in which wireline access is either too expensive or simply unavailable. Multipoint links connect a single aggregation site to multiple remote sites to smooth out data traffic fluctuations that can create network inefficiencies in point-to-point links. Considering that mobile user data usage is bursty in nature, multipoint strategies combine the traffic to and from multiple sites to smooth out these seemingly erratic data traffic fluctuations.

## Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) Links

A LOS wireless link is the traditional method of using wireless technology for MBH networks. Under LOS, wireless transmitters located on a site tower are directed toward one or more wireless receivers located up to 50 kilometers away. Precise alignment of the transmitter and receiver LOS is crucial for proper operation. NLOS links are frequently used for small site backhaul connections in dense urban environments in which direct LOS links are not possible due to structures and geographical limitations. NLOS MBH links use passive or active reflectors to "bounce" the signal around and/or over obstacles. NLOS links are usually of lower bandwidth than LOS or wired backhaul links.

## SYNCHRONIZATION

Synchronizing mobile networks is crucial to prevent service interruptions or dropped calls as mobile users traverse the mobile network. Poor synchronization can lead to a variety of issues from dropped calls, poor video streaming, reduced access speeds, and an overall poorer Quality of Experience (QoE). Common network synchronization technologies and options in service today include external timing reference sources, synchronous Ethernet (SyncE), 1588v2 Packet Timing Protocol (PTP), Global Positioning System (GPS), or hybrid combinations of these options for improved redundancy. See Figure 11 for common synchronization and timing requirements of the various mobile technologies deployed today.

| Application | | Frequency | Phase/Time |
|---|---|---|---|
| CDMA2000 | | 50 ppb | <3 usec to <10 usec |
| GSM | | 50 ppb | N/A |
| WCDMA | | 50 ppb | N/A |
| TD-SCDMA | | 50 ppb | 3 usec inter-cell |
| LTE-FDD | | 50 ppb | N/A |
| LTE-TDD | | 50 ppb | 1-5 usec inter-cell |
| WiMAX (TDD) | | 50 ppb w BTS's | 1-1.5 usec |
| PBX Trunk | | 32-50 ppm | N/A |
| SmartGrid synchrophasers | | N/A | <1 usec to 1 nsec |
| Mobil Backhaul | | 16 ppb | 1-1.5 usec |
| Small Cell | FDD Local | 100 ppb | N/A |
| | FDD Home | 250 ppb | N/A |
| | TDD Local | 100 ppb | 3 usec |
| | TDD Home | 250 ppb | 3 usec |

Figure 11: Mobile network technology synchronization requirements

## OPERATIONS, ADMINISTRATION, MANAGEMENT, AND PROVISIONING (OAM&P) OPTIONS

Mobile backhaul options require OAM&P capabilities to help MNOs proactively and reactively maintain the health of their mobile networks in a cost-effective manner. Rich OAM&P tools help accelerate the deployment and maintenance of MBH network deployments by facilitating troubleshooting operations to rapidly isolate and fix faults, thus ensuring Service Level Agreements (SLAs) by improving overall network availability. Deployed OAM&P should support Layer 2 and Layer 3 SLA assurance performance measurement, testing, and reporting capabilities to address differentiated services running in the network. Figure 12 summarizes various OAM&P capabilities deployed in MBH networks today

| | |
|---|---|
| SLA Portal | SLA Reporting<br>End Customer Visibility |
| Zero Touch Provisioning | Fast Install; Reduced<br>Configuration Errors |
| Turn-up Acceptance & SLA Conformance Testing | IETF RFC 2544 Generator/Reflector<br>ITU-T Y.1564 Generator/Reflector |
| Layer 3 SLA Monitoring & Metrics: Delay, Jitter | IETF RFC 5357 TWAMP<br>Two-Way Active Measurement Protocol |
| Layer 2 SLA Monitoring & Metrics: Delay, Jitter, Loss | ITU-T Y.1731 Ethernet OAM |
| Service Heartbeats, E-to-E & per-Hop fault detection | IEEE 802.1ag CFM<br>Connectivity Fault Management |
| OAM for MPLS-TP Infrastructure (via GAL/G-Ach) | RFC 6428 BFD AIS, RDI, LDI, CC, CV<br>RFC 4379 LSP Ping, Traceroute |
| Enhanced troubleshooting, rapid network discovery | IEEE 802.3ah EFM<br>Physical Link |

Figure 12: Comprehensive OAM&P tools available in today's MBH networks

## CLASS oF SERVICE (CoS)

Modern MBH networks support CoS options that enable MNOs to prioritize network traffic according to the criticality of the traffic being delivered in a smooth and uninterrupted manner. For instance, if there is a one-second delay in the retrieval of web page data from the Internet, the end-user probably does not notice that anything is amiss. However, a one-second delay within a stream of data that includes a video with audio is indeed noticeable and can become rather annoying. Similarly, a delay in the delivery of packets that comprise a voice call can produce a noticeable gap to the end-user, resulting in an unacceptable QoE. CoS options allow MNOs to treat time-sensitive traffic, such as voice and real-time streaming video, as a higher priority for uninterrupted delivery, compared with web- or file-based data traffic. See Figure 13 for more details  on how CoS helps keep time-critical data flowing, as expected in MBH networks, where different services share a common mobile network infrastructure yet have different SLA performance attributes applied as they traverse the mobile network.
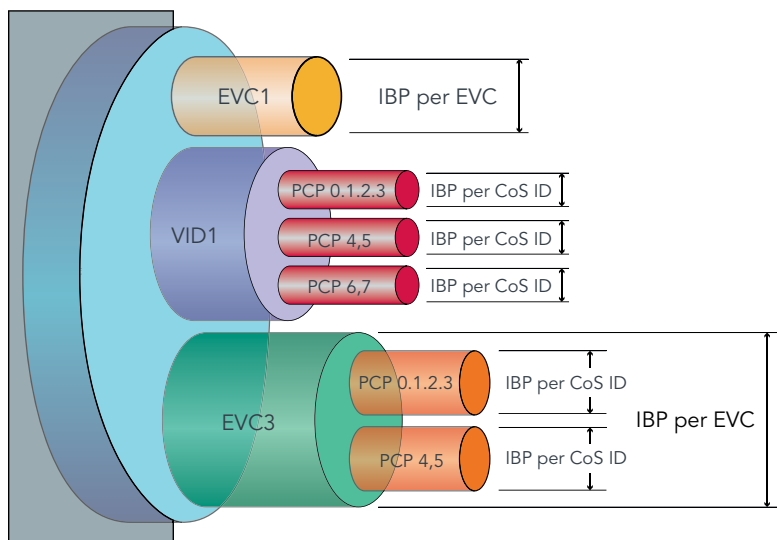
Figure 13: QoS functions enabling the prioritization of MBH traffic types

## MOBILE BACKHAUL AS A SERVICE (MBHAAS)

One of the more interesting trends in the mobile networks industry is the emergence of the MBHaaS market, in which wholesale MBH network services are offered to MNOs between their cell sites and MTSOs, which helps MNOs minimize their capital expenditures, and ideally their ongoing operational expenses as well. This business model also helps MNOs accelerate their time to revenue in areas where they do not have backhaul network connectivity. MBHaaS requires that the small and macro cells have reliable, low-latency, and typically redundant mobile backhaul connectivity-core values of Carrier Ethernet-based networks. Going forward, MBHaaS will leverage the benefits of SDN and NFV to further increase MBH network agility and flexibility by intelligently configuring, managing, and monitoring MBHaaS network connections with the promise of reduced costs. Figure 14 shows an example of a typical MBHaaS architecture.

Figure 14: MBHaaS architecture and domains of responsibility

## MBHAAS BUSINESS OPPORTUNITY

MBHaaS is an economically viable solution for MNOs that want to outsource their MBH connectivity needs, especially in regions where existing network operators already have network footprint, resulting in lower MBH costs and quicker time to market. The initial cost and complexity of laying new fiber or mounting microwave transceivers in dense urban environments makes it a cost-prohibitive opt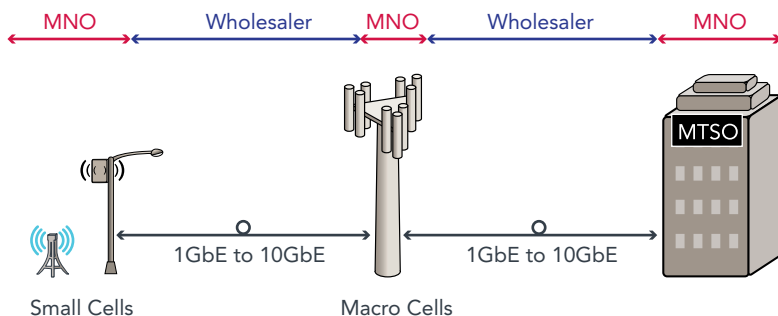ion in many markets, whereas leasing a redundant, high-bandwidth MBH service from existing network operators is relatively straight-forward and increasingly cost-effective. As always, reliability and constant availability of these leased network services from end to end are crucial MBH service requirements.

MBHaaS represents a new business opportunity for many MNOs, wholesale network operators, cable MSOs, and tower operators interested in reducing costs and/or increasing revenue streams. As the mobile network infrastructure market matures, new North American macro cell site installations are relatively flat, with the total mobile backhaul equipment market only growing from US$8.4 billion in 2013 to US$8.5 billion in 2014[4]. With macro cell site installations slowing, some industry players are actively seeking new growth opportunities by expanding their service offerings. MBHaaS represents a lucrative opportunity for operators with networking expertise and an existing footprint in areas where MNOs already have macro cells, are building new macro cells, or are expanding their reach/capacity by rolling out small cells.

Large MNOs are typically more focused on the marketing and customer service aspects of their business. Building and maintaining MBH networks is a task MNOs commonly performed themselves in the past, especially in North

[4] Macrocell Mobile Backhaul Equipment Highlights, 2014 (Infonetics)

America. But as the mobile networking market has matured over the past decade, MNOs have come to realize that, although MBH is indeed a critical part of their greater network, it is perhaps better served by outsourcing it to third-party MBH network wholesalers. If wholesalers can alleviate the deployment and maintenance burdens of owning and operating MBH networks, MNOs are willing to outsource this part of their network to operators able to meet their stringent MBH network SLA. Beyond MBHaaS, other opportunities are emerging for MBH network wholesalers via bundling additional new NFV-based services, such as encryption or application assurance, for further differentiation beyond the lowest offered price.

As with any emerging technology, the MBHaaS market is still in its infancy in many markets, especially in some countries. However, visionary companies and industry observers have already identified MBHaaS for connectivity services to both small cells and macro cells as a lucrative business opportunity for the mobile communications market. The two primary business cases related to the emerging MBHaaS market are as follows:

- MNOs in markets other than North America that currently install and manage their own MBH networks who want to explore the financial and competitive benefits associated with purchasing wholesale MBHaaS offerings

- Tower and wireline operators who do not currently offer wholesale MBHaaS offerings

Ideally, these two business cases can and likely will occur at the same time, with MNOs creating the demand for MBHaaS, while tower and wireline operators introduce MBHaaS in an effort to increase and diversify their services offerings.

## BUSINESS CASE: MNOS AND MBHAAS

North American MNOs have outsourced much of their MBH networking needs to wholesale MBH network operators. By removing the cost and complexity of MBH networks from their ongoing operations, MNOs can better focus on their core business of developing and marketing mobile communications products to their customers, which is especially critical given the hyperconnectivity in this particular market segment. MNOs around the world are seeking better, faster, and more cost-effective ways to upgrade and maintain their MBH networks to maintain pace with ongoing bandwidth growth and the performance requirements related to 4G wireless services. MBHaaS is a

great opportunity to further these goals for both small cells and macro cells in regions where MNOs are still managing their own MBH networks.

## BUSINESS CASE: MBHAAS FOR TOWER AND WIRELINE OPERATORS

The associated business case for MBHaaS comes from the perspective of the network wholesalers by providing MBH network services to MNOs. Wholesale operators can provide MBHaaS relatively easily and can even bundle it with macro tower maintenance and real estate leasing to further increase revenues. The emergence of SDN and NFV will allow wholesalers to bundle even more services, such as deep packet inspections and firewalls, to name just a few.

## CARRIER ETHERNET AND THE METRO ETHERNET FORUM (MEF)

The Metro Ethernet Forum, founded in 2001, is a nonprofit international industry consortium dedicated to the global adoption of Carrier Ethernet networks and services applicable to a very broad range of applications, which can include MBHaaS offerings. The MEF publishes standards to ensure that certified Ethernet services are very well understood by both the wholesaler and purchaser (MNOs in this case), so that both have an upfront understanding of the performance expectations of MBHaaS offerings and the associated SLA. Carrier Ethernet (CE) 2.0 certification benefits include such key attributes as standardized services, scalability, reliability, QoS, and service management, which makes it much easier for MNOs shopping around to compare and choose from the available MBHaaS wholesalers in their regions.

There are many different CE 2.0-certified services available in the market that are readily applicable to MBHaaS, including those shown in Figure 15, that allow for interconnecting cell sites to cell sites and cell sites to MTSOs. These services can be port-based or VLAN-based to support a wide variety of MBH network applications. For example, E-LINE services can connect a macro cell to another macro cell or a macro cell to an MTSO. E-TREE services can connect multiple small cells to one macro cell or multiple macro cells to an MTSO. The many associated benefits of CE 2.0 certified services are one of the reasons why Ethernet bandwidth surpassed all legacy bandwidth combined in 2012[5].

[5]New Global Milestone for Carrier Ethernet, Vertical Systems Group, 2013

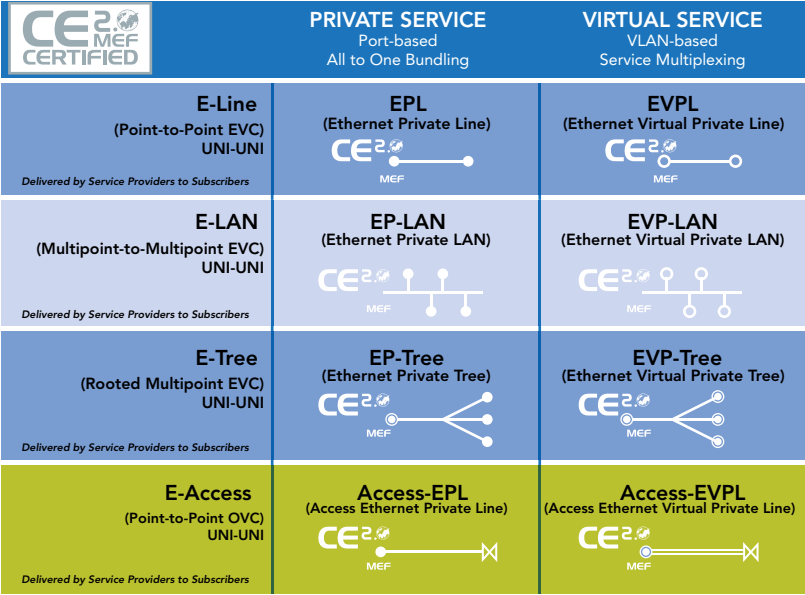| CE 2.0 CERTIFIED | PRIVATE SERVICE Port-based All to One Bundling | VIRTUAL SERVICE VLAN-based Service Multiplexing |
|---|---|---|
| **E-Line** (Point-to-Point EVC) UNI-UNI *Delivered by Service Providers to Subscribers* | **EPL** (Ethernet Private Line) | **EVPL** (Ethernet Virtual Private Line) |
| **E-LAN** (Multipoint-to-Multipoint EVC) UNI-UNI *Delivered by Service Providers to Subscribers* | **EP-LAN** (Ethernet Private LAN) | **EVP-LAN** (Ethernet Virtual Private LAN) |
| **E-Tree** (Rooted Multipoint EVC) UNI-UNI *Delivered by Service Providers to Subscribers* | **EP-Tree** (Ethernet Private Tree) | **EVP-Tree** (Ethernet Virtual Private Tree) |
| **E-Access** (Point-to-Point OVC) UNI-UNI *Delivered by Service Providers to Subscribers* | **Access-EPL** (Access Ethernet Private Line) | **Access-EVPL** (Access Ethernet Virtual Private Line) |

Figure 15: Metro Ethernet Forum CE 2.0 Services[6]

## SUMMARY

The mobile network is increasingly the preferred on-ramp for end-users wanting to access content, which usually resides within large, distant web-scale data centers. This has resulted (and will continue to result) in massive increases in bandwidth demand across the entire mobile network infrastructure, including the MBH network. The MBH network connects RAN air interfaces at cell sites to the inner core network that connects users to content, so it is increasingly a critical part of the global network infrastructure and is the primary reason why MNOs and wholesaler operators alike are intensely focused on it as a key part of their short- to long-term business strategies. The entire mobile network infrastructure, from wireless to wireline, is increasingly packet-based, so migrating legacy TDM-based MBH networks to Carrier Ethernet packet-based MBH networks is an obvious choice. SDN and NFV technologies and services will soon infiltrate the entire global network infrastructure, so it will be interesting to watch how MBH networks evolve over time.

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[6] Metro Ethernet Forum

## ACRONYMS

| | |
|---|---|
| 1G | 1st Generation |
| 2G | 2nd Generation |
| 3G | 3rd Generation |
| 3GPP | 3rd Generation Partnership Project |
| 4G | 4th Generation |
| BBU | Baseband Unit |
| BTS | Base Transceiver Station |
| CDMA | Code Division Multiple Access |
| CE | Carrier Ethernet |
| CO | Central Office |
| CoMP | Coordinated Multipoint Transmission |
| CoS | Class of Service |
| CPRI | Common Public Radio Interface |
| C-RAN | Cloud or Centralized Radio Access Network |
| DAS | Distributed Antenna System |
| EDGE | Enhanced Data rates for GSM Evolution |
| eNodeB | Evolved Node B |
| EVC | Ethernet Virtual Circuit |
| FDD | Frequency Division Duplexing |
| FMO | Future Mode of Operation |
| GbE | Gigabit Ethernet |
| Gb/s | Gigabits per Second |
| GPRS | General Packet Radio Services |
| GPS | Global Positioning System |
| GSM | Global System for Mobile Communications, originally Groupe Spécial Mobile |
| HFC | Hybrid Fiber-Coax |
| HSDPA | High-Speed Download Packet Access |
| HSPA | High-Speed Packet Access |

| | |
|---|---|
| HSPA+ | High-Speed Packet Access Plus |
| IBP | Ingress Bandwidth Profile |
| ID | Identification |
| IP | Internet Protocol |
| IPv6 | Internet Protocol version 6 |
| ITU | International Telecommunications Union |
| kbps | Kilobits per second |
| LOS | Line-of-Sight |
| LTE | Long Term Evolution |
| LTE-A | Long Term Evolution Advanced |
| MBH | Mobile Backhaul |
| MBHaaS | Mobile Backhaul as a Service |
| MME | Mobile Management Entity |
| Mb/s | Megabits per Second |
| MEF | Metro Ethernet Forum |
| MNO | Mobile Network Operator |
| MSO | Multi-Service Operator |
| MTSO | Mobile Telephone Switching Office |
| N/A | Not Applicable |
| NFV | Network Functions Virtualization |
| NLOS | Non-Line-of-Sight |
| OAM&P | Operations, Administration, Maintenance and Provisioning |
| OTT | Over the Top |
| PBX | Private Branch Exchange |
| PCP | Priority Code Point |
| PMO | Present Mode of Operation |
| PPB | Parts per Billion |
| PTP | Packet Timing Protocol |
| QoE | Quality of Experience |
| QoS | Quality of Service |

| | |
|---|---|
| RAN | Radio Access Network |
| RF | Radio Frequency |
| RNC | Radio Network Controller |
| RRH | Remote Radio Head |
| SDN | Software Defined Network |
| SGM | Serving Gateway |
| SyncE | Synchronous Ethernet |
| TDD | Time Division Duplexing |
| TDM | Time Division Multiplexing |
| US$ | American Dollars |
| Usec | Microseconds |
| VID | VLAN (Virtual Local Area Network) Identifier |
| WCDMA | Wideband Code Division Multiple Access |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |

## Brian Lavallée
Director, Product &
Technology Marketing

Brian Lavallée is the Director of Technology & Solutions Marketing with global responsibility for Ciena's packet networking solutions. He has over 20 years of telecommunications experience with previous roles in Product Line Management, Systems Engineering, Research & Development, and Manufacturing. During his career, he has worked in various areas of optical networking including access, metro, regional, long haul, and submarine networks. He holds a Bachelor of Electrical Engineering degree from Concordia University and an MBA in Technology Marketing from McGill University, both located in Montréal, Québec, Canada.

*How can you address Mobile Backhaul (MBH) bandwidth demand to drive greater bottom-line results?*

This guide explains how the evolution of wireless access technologies is altering the MBH network landscape. These networks connect mobile users to their applications and content residing in distant data centers. Migrating from traditional TDM to packet-based MBH solutions is the best method for network operators to keep pace with voracious mobile bandwidth demands, reliably and cost-effectively.

If soaring demand for your MBH resources is putting strain on your network's capacity and performance, it's seriously time to examine viable options for the road ahead.