Mobile Broadband Backhaul Network Migration from TDM to Carrier Ethernet

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ABSTRACT

With the rollout of Long Term Evolution the capacity of the radio access network backhaul needs to be upgraded to 100–150 Mb/s. Next-generation mobile networks, such as LTE Release 10, will increase the requirement for backhaul capacity to gigabits per second. In order to increase network utilization and decrease operating expenses, carrier Ethernet transport infrastructure (MPLS and carrier grade Ethernet) will be deployed and maintained at a lower total cost of ownership than legacy TDM transport infrastructure. This article discusses different migration scenarios from the circuit-switched legacy backhaul networks toward packet-based networks.

INTRODUCTION

Mobile networks are undergoing major changes. The main driving force behind this is the introduction of mobile broadband services. The narrowband circuit-switched data networking that supported the deployment of general packet radio service (GPRS) in second-generation (2G) systems has now, with the deployment of high-speed packet access (HSPA) in third-generation (3G) systems, evolved to broadband data networking that can support various multimedia services. A few years after its deployment, the volume of HSPA packet data traffic has exploded to the point where it has now exceeded circuit-switched voice traffic. This huge take-up of broadband data services has led to a major shift in the composition of mobile traffic from voice-dominated circuit-switched traffic to packet-switched data traffic. The deployment of Long Term Evolution (LTE), which can support a theoretical peak downlink data rate of 330 Mb/s (i.e., peak rate of LTE radio base stations [RBSs] with 4 × 4 multiple-input multiple-output [MIMO] antenna configuration), will further increase the ratio of packet data traffic to TDM traffic in the backhaul. Besides, operators also need to consider next-generation (fourth generation, 4G) mobile systems when planning future backhaul networks. LTE Release 10, which is now being specified by the Third Generation Partnership Project (3GPP) as the 4G mobile system, will support wider channel bandwidth and up to 8 × 8 MIMO antenna configurations in order to reach the targeted peak data rates of 1 Gb/s downlink and 500 Mb/s uplink [1]. Legacy backhaul networks are optimized for circuit-switched voice traffic in which the transmission from RBSs to a base station controller (BSC) is realized using static time-division multiplexing (TDM) circuits. Such networks are, however, not optimal for the delivery of packet traffic; therefore, supporting these huge data traffic rates while maintaining low operations expenditure (OPEX) will be one of the biggest challenges for mobile network operators.

In fixed wireline networks the narrowband data network that was deployed for residential ADSL has now evolved to broadband access, metro, and core networks supporting broadband multimedia services. As a result, fixed-mobile operators (i.e., operators who provide fixed and mobile services) have already adapted their fixed networks to cope with the huge data traffic demand in order to support fixed broadband services such as IPTV, video on demand, and high-speed Internet access. Many of these operators are now in the process of converging their fixed and mobile networks. Fixed-mobile convergence (FMC) is a framework for a common converged network capable of supporting both mobile and fixed services. By employing FMC, fixed-mobile operators will be able to use their fixed and mobile infrastructure base to leverage their service offering and reduce their OPEX. The bottom line is that fixed-mobile and mobile-only operators have to address the same challenge (i.e., supporting high data traffic while maintaining low OPEX). But since their deployed networks are different, operators need to analyze the different migration options and identify the migration steps that optimize the reuse of their existing network while lowering the total cost of ownership.

The migration to packet-based backhaul networks will also have important implications for network sharing, in which the resources of the network are shared among multiple, usually two or three, operators in order to reduce their cap-

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ital expenditure (CAPEX) and OPEX. Although static infrastructure sharing is possible in TDM networks, large volumes of packet data traffic in the network leads to inefficient use of network resources, since high capacity TDM links have to be maintained for each operator. In contrast, packet networks enable a dynamic resource sharing, in which the un-used resources of one operator can be used by the others leading to an efficient use of the network resources.

The article is organized as follows. After a brief description of mobile backhaul services and transport networking technologies, two categories of radio access networks (RANs), dedicated native RAN backhaul and converged fixed-mobile backhaul networks, are identified. Next, dedicated RAN backhaul networks are discussed, and three migration scenarios toward an IP backhaul network are presented. This is followed by a discussion of fixed-mobile converged backhaul networks after which two migration scenarios are presented. In the last section the implication of TDM for packet backhaul migration to shared networks is briefly discussed and a conclusion drawn.

EVOLUTION OF MOBILE BACKHAUL NETWORKS

A mobile backhaul network connects RBSs to RBS controllers. Typically, multiple RBSs are collocated at the cell site, and the traffic from these RBSs is consolidated using site aggregation nodes. The access network, which consists of the *first mile* part of the mobile backhaul, connects the RBSs in the cell site to the aggregation network and has a similar function as the first mile links in fixed access networks. Presently, RBSs are connected using copper and microwave $n \times$ E1/T1 plesiochronous digital hierarchy (PDH) links where n is usually less than 8. These link technologies, however, cannot support LTE and LTE Release 10 capacity requirements; therefore, high-speed optical fiber, microwave, and bonded VDSL links must be used. The access network is connected to the aggregation edge nodes, whose main function is to consolidate the traffic into high-capacity optical links. Because the aggregation network supports a large number of end users, this part of the network is protected from link and node failures. This is usually achieved by deploying synchronous optical network/digital hierarchy (SONET/SDH) ring topology, which has a recovery time of 50 ms. At the switch site the traffic from the different RBSs is segregated to the different RBS controllers.

MOBILE BACKHAUL SERVICES

The role of mobile backhaul is to transport user plane (UP) and control plane (CP) traffic between the RBSs and RBS controllers, while honoring the quality of service (QoS) requirements of the different applications. Related to the QoS requirements, the backhaul must also support clock distribution to RBSs for frequency and phase/time synchronization, and operation, administration, and maintenance (OA&M) for fault detection, service management, and performance monitoring. Over the years, the standardized RBS backhaul interfaces have evolved from TDM and asynchronous transfer mode (ATM) to IP/Ethernet interfaces. The main driver of this evolution is the need to migrate to a low OPEX backhaul capable of supporting the increasing volume of data traffic and compensate for the declining revenue per transported bit over the backhaul. Typically, the IP packets are encapsulated in Ethernet frames, which in turn are transported either natively or over other transport technologies. This combination of low-cost Ethernet interfaces and the statistical multiplexing capability of packet-switched backhaul networks, together with the availability of standardized OA&M capabilities in IEEE 802.1ag connectivity fault management (CFM) and International Telecommunication Union (ITU) Y.1731 performance management (PM), provides the required low-cost backhaul solution. Despite the evolution toward IP traffic over Ethernet interfaces, however, backhaul of legacy TDM and ATM traffic must still be supported for a while longer.

The Metro Ethernet Forum (MEF) has defined three types of Ethernet services that employ Ethernet virtual connections (EVCs): point-to-point E-LINE, multipoint-to-multipoint E-LAN, and point-to-multipoint E-Tree services delivered over carrier Ethernet transport networking technologies. Typically, SDH, Ethernet, and multiprotocol label switching (MPLS) networking technologies are used to transport these Ethernet services in backhaul networks [2].

ETHERNET OVER SONET/SDH

SONET/SDH is a scalable carrier-grade circuit-switched transport technology that supports fast failure recovery time and extensive OAM functionalities. Today, most incumbent operators have a large deployment base of legacy SONET/SDH networks. Legacy SONET/SDH is optimized for transport of constant bit rate voice traffic and is not efficient for transport of burst data traffic. However, the introduction of three significant enhancements, Generic Framing Procedure (GFP), Link Capacity Adjustment Scheme (LCAS), and Virtual Concatenation (VCAT), has transformed SONET/SDH into a flexible multiservice-capable transport technology:

- GFP: Maps Ethernet frames into SDH virtual containers (VCs)
- VCAT: Concatenates SDH VCs for flexible bandwidth provisioning
- LCAS: Provides dynamic hitless capacity adjustment of a VCAT group

Ethernet over next-generation SONET/SDH, which combines the capabilities of GFP, VCAT, and LCAS, is of particular interest to many mobile operators as it allows reuse of the installed base of SDH equipment, and takes advantage of the elaborate management functionalities and fast recovery features of SONET/SDH.

Because the aggregation network supports a large number of end-users, this part of the network is protected from link and node failures. This is usually achieved by deploying SONET/SDH ring topology, which has recovery time of 50 ms.

Dedicated native RAN backhaul networks are optimized for transport of voice, data, synchronization and OA&M traffic. They can be leased or self built and in most cases a mixture of the two, where all or parts of the access network is self built while the aggregation network is leased from a transport provider.

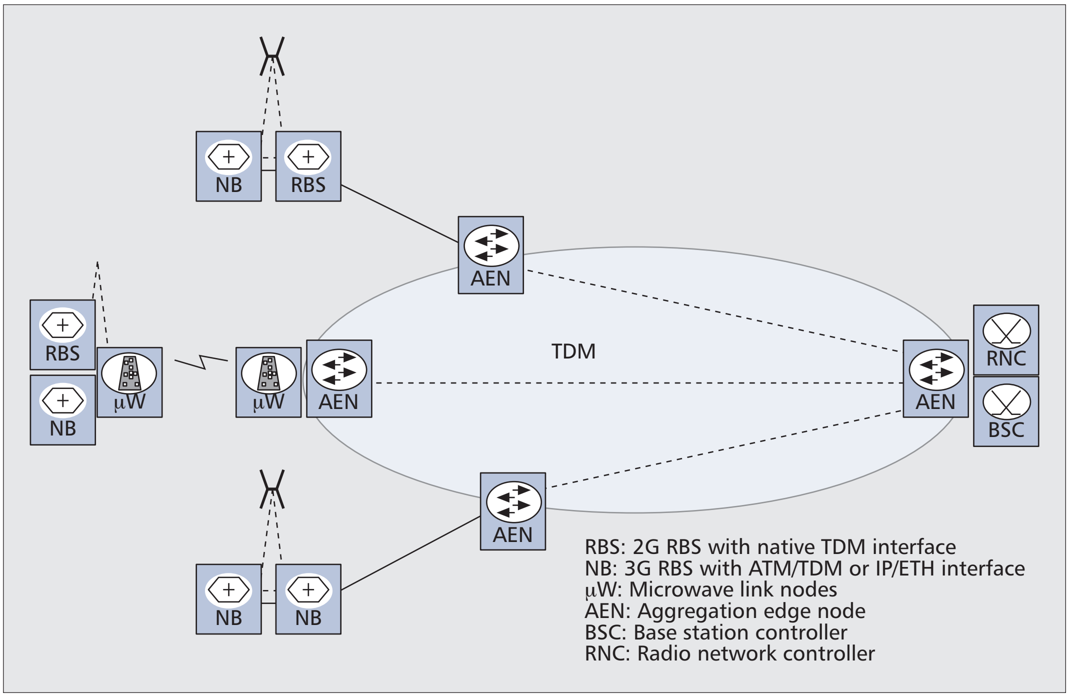

Figure 1. *Reference network for dedicated backhaul scenario 1 in which the legacy optical TDM aggregation network is used to support RBSs with native TDM, ATM, and Ethernet interfaces.*

Native Ethernet

Ethernet has been continuously enhanced to support new features in the form of virtual LAN (VLAN)-aware Q bridges, provider bridges (PBs), and provider backbone bridges (PBBs) [3]. With the completion of the PBB — Traffic Engineering (PBB-TE) specification in IEEE 802.1 Qay, Ethernet has now evolved from its origins in LAN technology to WAN transport technology supporting carrier-class features including standardized services, scalability, reliability, QoS, and OAM. This means that Ethernet E-LINE, E-LAN, and E-tree services as used in mobile backhaul can be supported using native Ethernet transport technology.

Ethernet over MPLS

MPLS is a highly scalable packet forwarding technology, which supports QoS, traffic engineering (TE), and fast recovery from link and node failures. Using pseudowire, IP/MPLS supports wire emulation for carrying ATM, Ethernet, TDM, and SONET/SDH services over packet-switched networks. Ethernet E-Line and E-LAN services are emulated using virtual private wire service (VPWS) and virtual private LAN service (VPLS), respectively. Many operators have now deployed MPLS to implement unified metro and core networks supporting different types of services.

TDM to Packet-Switched Backhaul Migration Scenarios

Mobile backhaul networks can be classified according to either their ownership: self-built and leased backhaul; or the type of services provided: dedicated native and converged fixed-mobile backhaul networks. Usually, an operator's network can include both of these in different parts of the network. In this article we focus on the latter classification and make a distinction between dedicated native and converged backhaul networks.

Migration Scenarios for Dedicated Native RAN Backhaul

Dedicated native RAN backhaul networks are optimized for transport of voice, data, synchronization, and OA&M traffic. They can be leased or self-built and, in most cases, are a mixture of the two, where all or part of the access network is self-built, while the aggregation network is leased from a transport provider. In the access network part, single- or multihop microwave links and optical fiber links are used to connect to the aggregation edge node in the aggregation network. In most cases the aggregation network consists of protected SONET/SDH rings, but other types of TDM-based optical transport technologies are also used to interconnect the access network to the RBS controllers. Depending on the volume of packet data traffic over the backhaul, three different migration scenarios can be identified.

Dedicated Backhaul Scenario 1

Dedicated backhaul scenario 1 is the first step to transform the operator's legacy TDM backhaul networks to support both TDM and packet traffic. In this scenario the operator uses its existing TDM infrastructure to support both TDM and packet data traffic. The reference network for scenario 1 is shown in

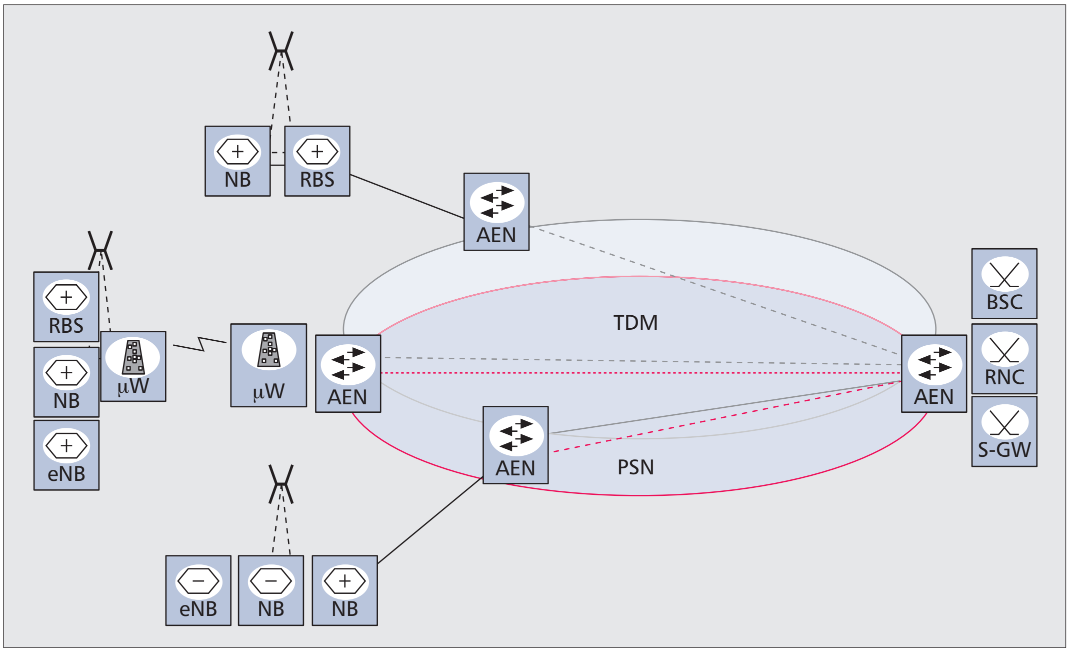

Figure 2. *Reference network for dedicated backhaul migration scenario 2, which supports TDM and Ethernet traffic using MSPP to create separate TDM and packet-switched aggregation networks.*

In the access network, the hybrid transport capability of microwave and optical fiber links can be upgraded to a higher bit rates for sites with high capacity requirements. Again, the underlying TDM transport network can be used to synchronize the RBSs.

Fig. 1. In the access network the hybrid, TDM, and Ethernet transport capability of both microwave and optical links is used to support TDM and Ethernet traffic. In the aggregation network the operator maintains its legacy TDM network and builds a high-capacity packet overlay network to support data traffic. For example, if the operator's aggregation network consists of SDH, an Ethernet overlay over SDH virtual containers (VCs) is created using GFP mapping. The inherent support for TDM clock distribution over an SDH network is also used to synchronize sites with RBSs. For example, to comply with Global System for Mobile Communications (GSM) and wideband code-division multiple access (WCDMA) frequency specifications and guarantee proper network function, the RBSs must maintain a stable and controlled radio frequency over the air interface. The frequency synchronization requirement for these RBSs is in the range of 50 ppb, and a clock delivered by TDM over an SDH transport network can typically achieve an accuracy of 16 ppb, which, with added wander and a holdover budget, is well within the requirements for the air interface.

For an operator with a TDM transport network, this is the obvious first step to transform a legacy TDM network to carry data traffic; thus, this migration scenario is already taking place in many operators' networks. Since there is no multiplexing gain, the bandwidth utilization is not optimal, so this scenario is appropriate as long as the volume and growth of packet traffic is low or moderate.

Dedicated Backhaul Scenario 2

In scenario 2 the aggregation part of the network is built of two separate transport networks, TDM and packet-based. As the volume of packet data traffic increases, operators may choose to offload low-priority high-bandwidth data traffic to a separate packet-switched aggregation network using the multiservice capability of their transport network. In most cases the operators' legacy networks consist of multiservice provisioning platforms (MSPPs) with digital cross-connection (DXC) and packet switching functionalities capable of interfacing both TDM and packet-switched networks. Using MSPPs, separate aggregation networks are deployed to support the TDM and Ethernet backhaul traffic as shown in the reference network in Fig. 2. The actual deployment of scenario 2 will depend on the availability of fibers, wavelengths, type of transport network, MSPP functionalities, and so on. For example, operators with SDH legacy networks may, depending on the expected volume of data traffic, deploy 1 GbE or 10 GbE packet-switched aggregation networks to offload low-priority data traffic using either a separate wavelength or separate fiber.

In the access network the hybrid transport capability of microwave and optical fiber links can be upgraded to higher bit rates for sites with high capacity requirements. Again, the underlying TDM transport network can be used to synchronize the RBSs. For sites with RBSs that have only Ethernet interfaces (e.g., sites with HSPA), the RBSs' synchronization signal from the TDM network can still be terminated in the sites. Alternatively, GPS or packet-based synchronization methods can be used. At the switch site, the TDM and packet traffic is connected to the appropriate controller nodes. In switch sites where several Ethernet aggregation networks are terminated, the site switch must be able to handle the traffic from all the RBSs connected to these networks.

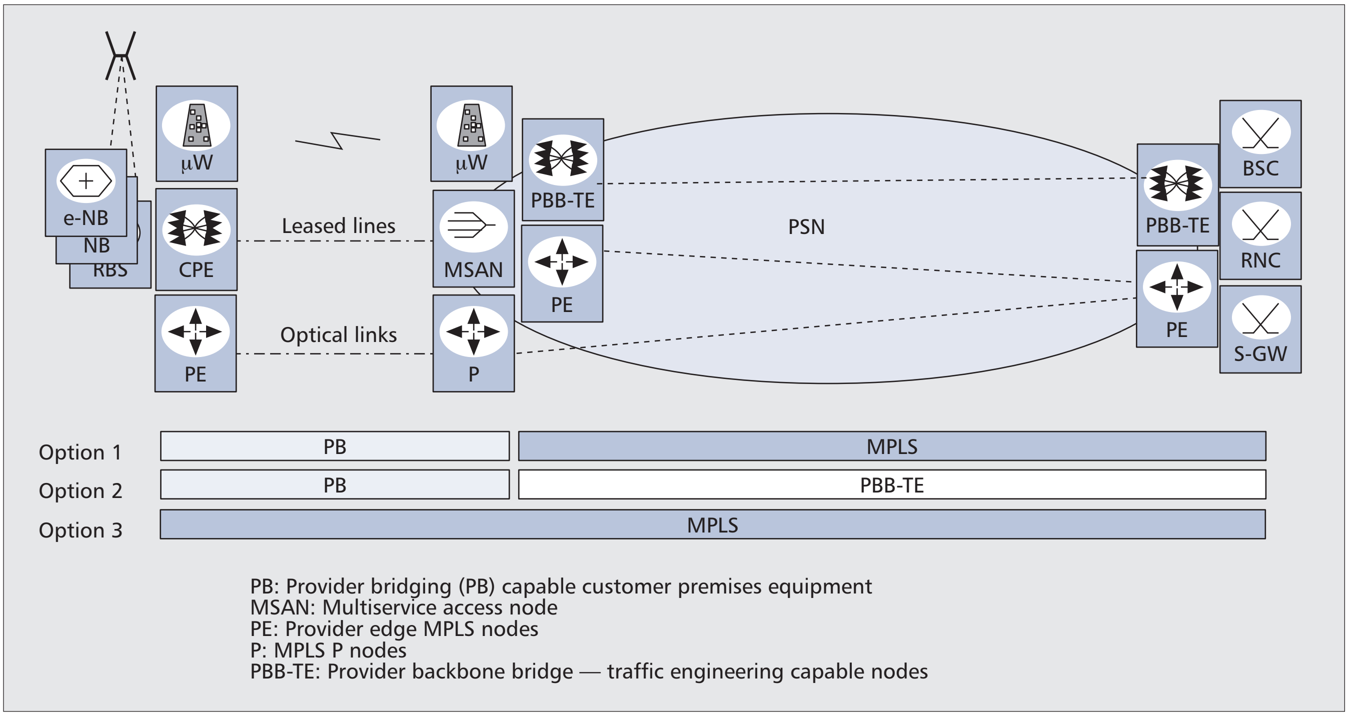

Figure 3. *Dedicated backhaul scenario 3, packet-based transport technology delivering Ethernet services and the different options for transport networking technologies: PB, PBB-TE, and MPLS.*

Dedicated Backhaul Scenario 3

In scenario 3 the mobile backhaul network only transports Ethernet traffic. This scenario applies to both greenfield operators' new network rollout and when the TDM connectivity of scenario 2 networks is retired. As shown in Fig. 3, different combinations of Ethernet (PB and PBB-TE) and MPLS transport networking technologies can be used in this scenario. The main issues in this case are the continued support of legacy RBSs with TDM and ATM interfaces, and the synchronization of the RBSs, which can be addressed in a number of ways. One straightforward method to minimize TDM support is to upgrade the RBS equipment to use IP/Ethernet interfaces. For example, GSM RBSs can use the Abis over IP solution, in which the TDM traffic that carries voice, data and signaling is mapped into IP packets using a minimum of repacking and reformatting. Similarly, RBS ATM interfaces can be upgraded to IP/Ethernet. These upgrades will enable RBSs to share low-cost Ethernet transport services and make use of statistical multiplexing gain by deploying a cell site aggregating node.

Operators who plan to make use of the multistandard radio (MSR) capability of RBSs will also benefit by upgrading their TDM and ATM RBSs to IP/Ethernet interfaces since it will enable them to create unified interfaces and a common backhaul transport solution. MSR enables the reuse of the same hardware radio unit for different radio access technologies (i.e., for GSM, WCDMA, and LTE) operating in the same frequency band.

A second alternative is to use circuit emulation and pseudowire services to support TDM and ATM traffic by emulating point-to-point and point-to-multipoint connectivity over packet-switched networks. Circuit emulation and pseudowires emulate the essential attributes of a telecommunications service, such as T1 and E1 leased lines, over a packet-switched network by supporting the minimum necessary functionality to emulate the wire or circuit. By incorporating a pseudowire or circuit emulation interworking function at the cell sites and controller sites, TDM and ATM traffic is carried over the packet backhaul network. The Internet Engineering Task Force (IETF) has specified pseudowire (PWE3) and circuit emulation service (CES) for transport of TDM and ATM services over packet-switched networks [4–6]; similarly, the MEF has also specified CES of TDM services over a carrier Ethernet network in MEF-8. TDM services have strict timing requirements; therefore, when emulating TDM services, delay in the backhaul can be reduced by encapsulating a single TDM frame into a single Ethernet frame. But doing so reduces the bandwidth efficiency of the network. Therefore, operators need to make sure that the latency and efficiency trade-off is set properly to support TDM services while still maintaining high bandwidth efficiency [7].

For synchronization of the RBSs in scenario 3, any of the packet-based synchronization methods, such as Network Time Protocol (NTP) and Precision Time Protocol (PTP), IEEE 1588 v2, or Ethernet physical layer timing infrastructure-based ITU — Telecommunication Standardization Sector (ITU-T) G.8261/G.8262/G.8264 synchronous Ethernet (SyncE), can be used. In NTP or IEEE 1588 v2, the timing information is provided by protocol-specific packets with hardware-based timestamps in combination with algorithms to determine phase information used to lock a

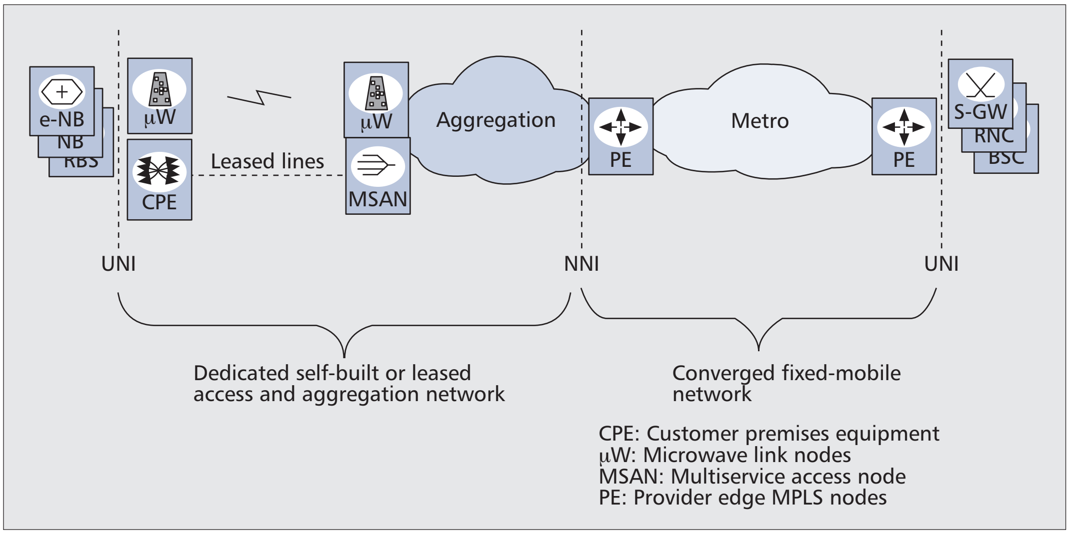

Figure 4. *Converged scenario 1, in which the operator's metro network supports fixed and mobile traffic, while the access and aggregation parts can be self-built or leased from a transport provider.*

The Network to Network Interface between the Aggregation and the metro network is Ethernet interface with a C-VLAN or S-VLAN awareness. The converged metro network can be deployed using Ethernet Provider Bridge (PB) or IP MPLS.

local oscillator. Both NTP and IEEE 1588 v2 are sensitive to packet delay variation (PDV); therefore, to ensure that the impact of the network remains as small as possible, the PDV should be kept to a minimum. The PDV will depend on QoS configuration, link speed (store-and-forward delay), maximum transmission unit (MTU) size, and so on. It is essential that synchronization traffic is handled as highest-priority traffic and by strict priority. The buffer depth of a queue handling synchronization traffic should be kept to a minimum since synchronization mechanisms are generally better at handling lost synchronization packets than synchronization traffic with large PDV.

Migration Scenarios for Converged Fixed-Mobile RAN Backhaul

Converged networks are run by incumbent operators that provide both fixed and mobile services. For a combined fixed-mobile operator, the huge take-up of packet-switched mobile traffic presents an opportunity to leverage its fixed transport services by reusing transport links and networking technologies deployed in its fixed access and core networks. In this case the mobile backhaul service, which includes Ethernet and emulated TDM services, is part of its IP/Ethernet business services. The reference network architecture for the fixed-mobile convergence network consists of first mile links, an aggregation network, and a metro network. Depending on the level of convergence, several migration scenarios can be identified; in this article we limit our discussion to two migration scenarios for backhaul over fixed-mobile converged infrastructure.

Converged Network Scenario 1

This scenario reflects the early stage of convergence, and the only converged part of the network that carries both fixed and mobile traffic is the metro network. As shown in Fig. 4, in the first mile part of the network, dedicated self-built or leased microwave links and point-to-point fiber is used, while the aggregation network is usually leased lines connecting to the converged metro network. The network-to-network interface (NNI) between the aggregation and metro networks is an Ethernet interface with C-VLAN or S-VLAN awareness. The converged metro network can be deployed using Ethernet PB or IP MPLS.

Converged Network Scenario 2

This scenario covers a completely converged network, which means the first mile links, aggregation network, and metro networks are all used to support both fixed and mobile services. The main advantage of this scenario is that the different link technologies (e.g., xDSL, GPON, EPON, 10G-EPON, and the emerging 10GPON) developed to support broadband access for residential users can now also support mobile services [8]. Similarly, microwave links can also be used when available. As shown in Fig. 5, different combinations of Ethernet (PB and PBB-TE) and MPLS transport networking technologies can be used in this scenario. TDM and ATM RBS interfaces are preferably replaced by IP/Ethernet interfaces, since the fixed broadband access is optimized to support Ethernet services; otherwise, circuit emulation and appropriate pseudowire services that span the whole backhaul network must be used. The support of packet-switched technology from the cell site to the switch site ensures high bandwidth utilization by means of statistical multiplexing gain at the cell and switch sites.

Network Sharing

Another driver for TDM to packet migration is the need for efficient network sharing. In shared networks the resources of the mobile network are shared among multiple, usually two or three, operators in order to reduce OPEX and CAPEX. In the case of fluctuating packet traffic

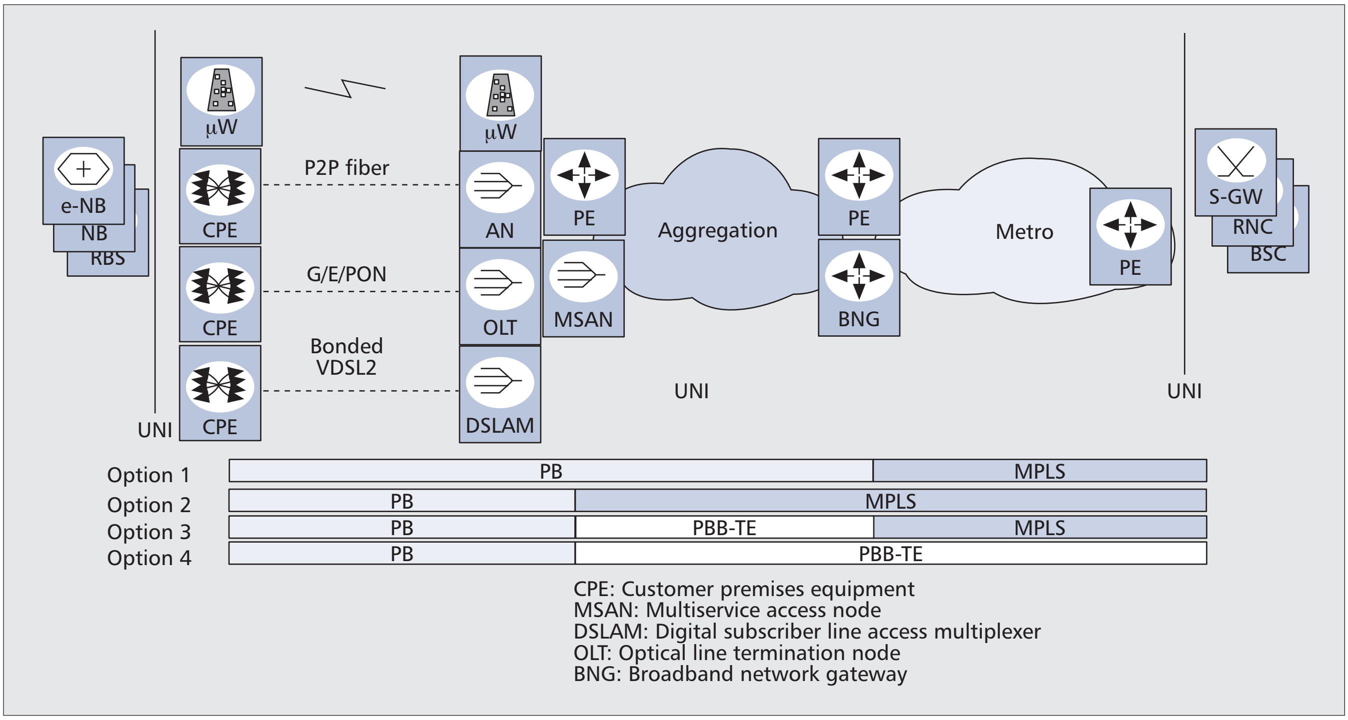

Figure 5. *Converged fixed-mobile scenario 3, packet-based transport technology delivering Ethernet services and the different transport networking technology options. Note that other options are also possible.*

with high average traffic volume, if the unused resources of one operator can be reused by another, better network utilization can be achieved. In other words, less bandwidth will be needed to handle the same amount of total traffic if sharing is possible.

In TDM backhaul networks only network infrastructure sharing is possible; for example, when the same network infrastructure (e.g., SDH links) is used by different operators, properly configured add/drop multiplexers (ADMs) groom low-capacity links from different operators to a common aggregation link. However, due to the static configuration of the TDM aggregation nodes, the unused bandwidth of one operator cannot be used by other operators, so there is no bandwidth sharing; similarly, no statistical multiplexing gain can be achieved in TDM networks. If the network supports a large amount of data traffic, this leads to inefficient network operation, since high-capacity TDM links have to be maintained to each operator, which results in high OPEX.

Pure packet backhaul networks facilitate efficient network sharing, since strict bandwidth guarantees and effective usage of free resources as well as fairness can be guaranteed at the same time. According to the MEF service specification, each operator can define its committed information rate (CIR), which determines the guaranteed capacity of the operator. However, in contrast to a TDM network, this bandwidth is not necessarily *dedicated* exclusively to a certain operator. For example, two operators, A and B, share the network resources with their respective committed information rates. Now during periods of low traffic from operator A, the unused bandwidth in the network can be used by operator B who might already have reached its guaranteed capacity. Operator B uses this *borrowed* bandwidth to transport lower-priority best effort traffic marked with drop precedence. Any time operator A wants to use its guaranteed capacity or in case of network congestion, this extra traffic from operator B is dropped first, preventing operators from starving each other while providing fairness and efficient use of the network resources.

Conclusions

The landscape of mobile networking is changing very fast. A few years after the deployment of HSPA, the volume of mobile packet data traffic has exploded to the point where it has now exceeded circuit-switched traffic. Furthermore, with the coming deployment of LTE and 4G mobile systems, the ratio of packet traffic over TDM traffic in the backhaul is expected to increase even more. To cope with the changed traffic composition, operators need to migrate their legacy TDM networks to packet-switched backhaul networks capable of supporting high volumes of packet traffic while maintaining low OPEX. Inspection of the different migration options shows that there is no silver bullet solution or single migration path that fits all types of networks. Operators need to make careful analyses of their deployed networks, present and future traffic demands, link technologies, and capability to support TDM, packet, and hybrid traffic.

Figure 6 summarizes the migration options for TDM backhaul networks and TDM RBS interfaces to packet-switched networks and IP/ETH RBS interfaces. As a first migration phase, operators have already deployed packet overlay on TDM backhaul networks to support low volumes of data traffic; as the volume of data traffic increases, operators may deploy separate packet-switched networks to offload packet traffic, maintaining hybrid TDM and packet-switched networks. With the deployment of LTE and LTE Release 10, operators may opt to migrate to a pure packet-switched backhaul network by retiring their TDM networks while upgrading their ATM and TDM RBSs to IP/Ethernet interfaces. This option has efficient network resource utilization and lower OPEX for leased lines. Alternatively, operators can deploy a packet-switched backhaul network, and use pseudowire and CES interworking functions to support their ATM and TDM RBSs.

For operators with fixed-mobile converged networks, the migration steps should be aligned with the degree of convergence assumed in the network. Fixed-mobile network convergence at the metro, aggregation, and access networks will enable operators to leverage on their xDSL, GPON, EPON, 10EPON, and emerging 10GPON access networks to support mobile services as well. The multiple backhaul solutions described provide operators with a choice of backhaul migration paths to suit their individual situations, decreasing operating expenses while increasing the transport capacity required to support graceful TDM to IP migration.

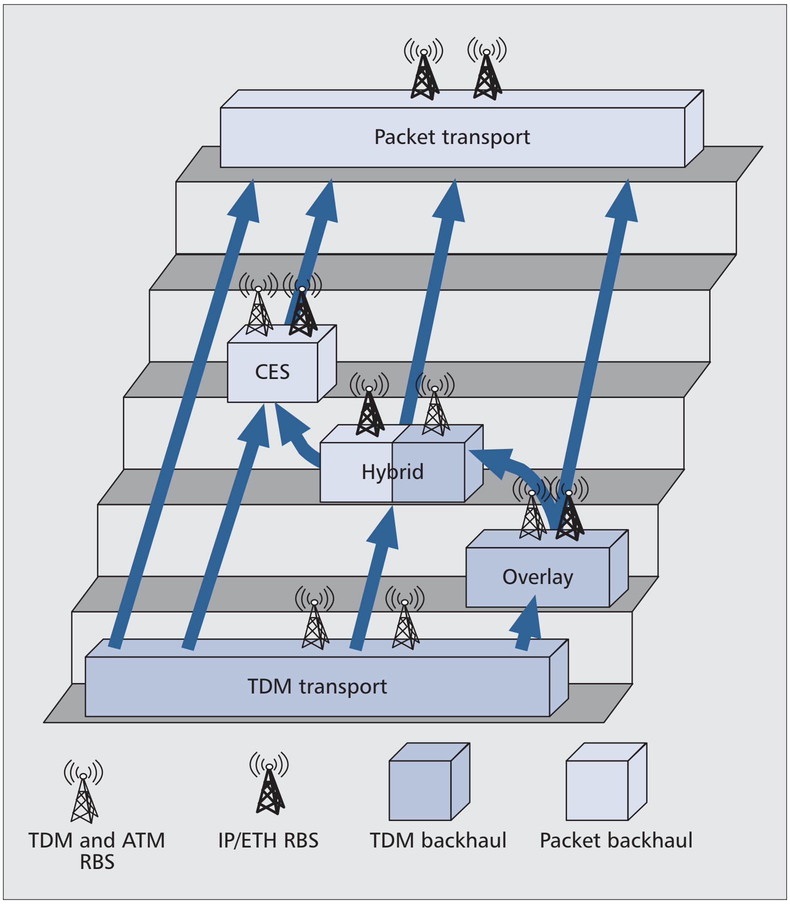

Figure 6. *Transformation options of TDM backhaul network and TDM RBS interface to packet-switched network and IP/ETH RBS interface.*

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