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EPON and EPoC:

A Unified Fiber and Coax Network Solution for Business Services

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

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Introduction

Cable operators continue to pursue the business services market by targeting the small and medium size business (SMBs). The quantity of SMBs and the associated relatively relaxed service requirements make the DOCSIS® network and the SMB suitable mates. The current state of the art in coaxial-based access network technology – DOCSIS 3.0 – supports downstream service bit rates of 250 Mbps or more. Although this bit rate is normally more than adequate for SMBs, the bit rate is typically a peak rate, is not guaranteed, and the upstream bit rate is typically much less. Furthermore, the services provided over a DOCSIS 3.0 network remain best effort services instead of guaranteed services that are backed with a Service Level Agreement (SLA). Nevertheless, DOCSIS 3.0 technology has shown it is more than capable of meeting the bandwidth and latency requirements for most SMB customers.

More recently cable operators have begun targeting the large enterprise businesses in addition to the SMBs. Enterprise customers tend to require higher symmetric bandwidth, and they tend to require service level guarantees. To meet these growing needs, cable operators are deploying Ethernet Passive Optical Networking (EPON) technology, which provides symmetric one (1) Gbps or ten (10) Gbps bit rates over optical fiber. EPON as part of a solution implementing the DOCSIS Provisioning of EPON (DPoE™) specifications provides even more operational expense saving by using the same provisioning servers and network management systems as used by DOCSIS networks.

Deploying DPoE (EPON) technology to support enterprise businesses represents a relatively inexpensive and capable solution for cable operators who need to deploy a fiber-based solution. Many businesses, however, require the same level of service as that provided by a fiber-based DPoE network, but they are connected to a coaxial network. With the emerging EPON Protocol over Coax (EPoC) technology being standardized by the IEEE and CableLabs, cable operators will be able to provide the same type of business services to customers connected to either fiber or coax. The services will be provisioned in the same way, managed in the same way, and the service performance should be identical since the access network is terminated by nearly identical devices which are scheduled and controlled by the same central controller.

Access Networks for Business Services

The current state of the art in cable access network technology results in three types of networks typically deployed by cable operators to support business customers, shown in Figure 1. These are the DOCSIS network, EPON network, and point-to-point (P2P) fiber network.

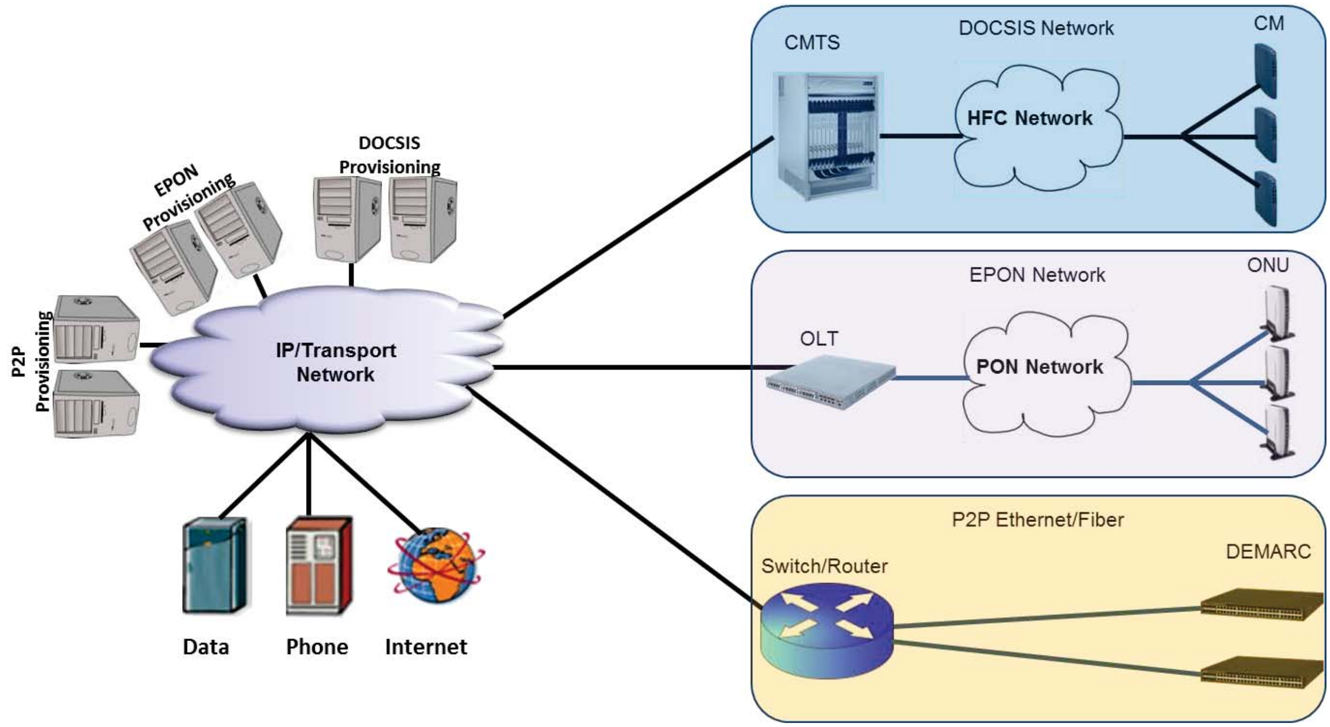

Figure 1: Three access network types used to provide services to business customers.

The first type of access network technology is based on the well-known DOCSIS specifications over a hybrid fiber coax (HFC) plant. The HFC plant uses fiber optic cables to transmit signals to an optical node, and then the optical node converts the optical signaling to radio frequency signaling for transmission over the coaxial cable portion of the network. Since the optical nodes and downstream amplifiers require electrical power, the HFC network is considered to be an "active" network. Furthermore, the HFC network is considered a point-to-multipoint (P2MP) network architecture in which a centralized device called the cable modem termination system (CMTS) is the arbitrator of the upstream transmission channel. Registered cable modems (CMs) are informed by the CMTS when they are allowed to transmit their data upstream. The most current version of the DOCSIS specifications, version 3.0, allows for the bonding of multiple downstream or upstream channels (a.k.a. channel bonding) to significantly increase the downstream speed delivered to a CM, or increase the upstream speeds from a CM. An effort is currently underway to define the next version of DOCSIS specifications which promises to increase speeds even more.

The second type of access network technology deployed for business services is called passive optical networking (PON). As the name implies, this network architecture extends fiber optical cabling all the way to the premise while using no electrically powered components in the network. Passive optical splitters split the downstream optical signal from an Optical Line Terminal (OLT) and delivers to each connected Optical Network Unit (ONU). In the upstream direction, optical combiners combine optical signals from ONUs for delivery to the OLT. Like the DOCSIS/HFC network, a PON is a P2MP network with the OLT, located in the head end or hub, dictating the upstream transmission opportunity to each ONU. There are two PON standards that compete for market share: Ethernet PON (EPON) standardized by the IEEE, and Gigabit PON (GPON) standardized by the ITU. Readers are encouraged to explore these two PON types by consulting the abundance of literature available. The paper will focus on EPON as the preferred PON technology.

The third type of business services access network technology is the P2P fiber topology. This network architecture typically requires a single fiber optic cable to connect a port on a switch or router in the head end directly to the business customer demarcation device. While the DOCSIS and PON networks share the fiber and/or coax medium and require upstream transmission arbitration, the P2P network architecture runs in a full duplex environment in which the downstream and upstream bandwidth is dedicated to a single endpoint. As one might imagine, installing a single dedicated fiber from the head end to each customer can be a costly endeavor, but this architecture typically provides the high bandwidth and lowest latency of any of the access network solutions.

One of the challenges associated with having multiple access network technologies is the corresponding myriad of provisioning systems associated with each technology type. Historically, only the DOCSIS network used a standardized operations and support systems (OSS) interface, allowing different DOCSIS vendors to provide nearly the same provisioning and management system interfaces. For EPON and P2P fiber solutions, the provisioning and management interfaces were vendor specific, so in many cases once the cable operator chose a vendor, they were locked in to that vendor, at least from a network management perspective. More recently, the DOCSIS Provisioning of EPON (DPoE™) specifications addressed this challenge for EPON networks by providing a standardized set of requirements that result in an EPON network to “look and feel” like a DOCSIS network. The resulting head end device was renamed the DPoE System, and the EPON network built to the DPoE specifications is called a DPoE network. The P2P network provisioning and management systems remain vendor specific.

Metro Ethernet Services

The services defined by the Metro Ethernet Forum (MEF), such as Ethernet Private Line/LAN/Tree and Ethernet *Virtual* Private Line/LAN/Tree continue to be one of the fastest growing service segments provided by cable operators to business customers. These services capitalize on the desire of business customers to connection two or more company sites. For the purposes of this paper, we can simplify the discussion without losing technical substance by focusing on the simplest type of Metro Ethernet service – the Ethernet Private Line (EPL) service.

The EPL service is defined by the MEF as a connection between two User Network Interfaces (UNIs). A UNI is simply an Ethernet port that connects to the customer equipment. An EPL is intended to operate as though the two endpoints (UNIs) were connected together with a category 5 cable. Figure 2 shows two EPL services. For the red EPL service, one customer site is connected to a DPoE Network while the other customer site is served by a DOCSIS network. The green EPL service has one customer site connected to a DPoE network while the other customer site is served by a P2P fiber network.

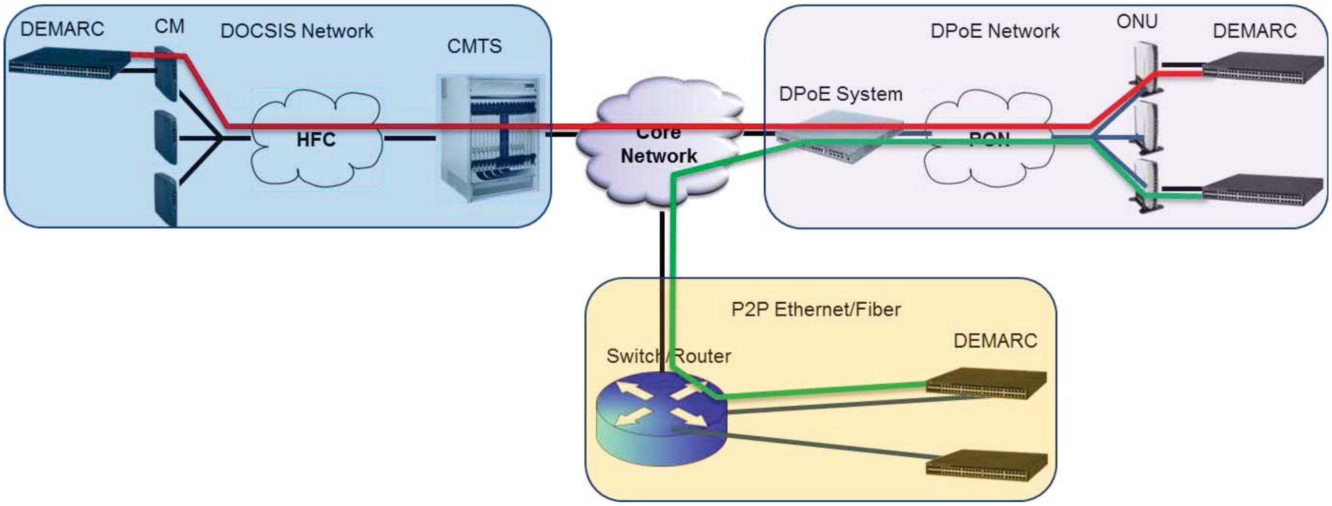

Figure 2: Two EPLs connected across different access network technologies.

Metro Ethernet services are typically sold to business customers with a specific service level agreement (SLA) that normally contains parameters such as Committed Information Rate (CIR), Committed Burst Size (CBS), and other rate and burst parameters. Additionally, the SLAs may contain maximum values for frame delay (FD) and frame delay variation (FDV). All of these parameters taken in aggregate define the *quality of service* (QoS) for the service. The challenge faced by service providers that deploy more than one access network type is whether the various access networks can provide the same level of QoS, and whether that QoS can be applied in a consistent manner.

The Role of Media Access Control in Fulfilling SLAs

Any type of network technology contains a method that dictates how devices access the media, called the media access control (MAC). As the name implies, the MAC controls how devices connected to the network access the network media for the purpose of transmitting data in their queues. Without a MAC protocol all devices on the network could transmit at one time, causing chaos and collisions on the network. Indeed, the early Ethernet technology used a MAC called Carrier Sense Multiple Access with Collision Detection (CSMA/CD). For CSMA/CD, devices on the network would first listen to determine if other devices were transmitting. Upon determining no other devices were transmitting the device would transmit its data. While transmitting, the device would continue to listen for other transmissions and detect data collisions with other transmitting devices. If a collision was detected, the device would attempt a retransmission at some random point in the future. Naturally, this type of MAC could result in a network device having to retransmit its data multiple times, leading to large FD and large FDV.

At the other end of the MAC spectrum are those network technologies in which a network device does not share the channel with another network device. In such a full duplex network technology, there are no collisions because there is only a single transmitter. Network devices are free to transmit whenever they have a frame in their queue that is ready for transmission. The P2P Ethernet over fiber access network technology is an example of this type of network. A full duplex P2P Ethernet over fiber network typically provides the lowest FD and FDV.

In the middle part of the MAC spectrum are those network technologies referred to as point-to-multipoint (P2MP) networks. In P2MP networks there is typically a single downstream transmitter located in a centralized controller placed in the head end whose transmissions reach all connected endpoint devices. Consequently, there are no downstream collisions. However, the endpoint devices cannot transmit in the upstream direction whenever they want because a collision may occur. Instead, the centralized controller schedules the endpoints for upstream transmission. In this way the centralized controller guarantees no upstream collisions by scheduling the endpoints at different times. DOCSIS and DPoE networks are P2MP networks. For DOCSIS networks, the centralized controller is called the cable modem termination system (CMTS) while the endpoints are called cable modems (CMs). In DPoE networks a DPoE System fulfills the role of the centralized controller while the endpoints are called optical network units (ONUs). For purposes of this paper the combination of the scheduler and the messages used to communicate the upstream transmission times to endpoint devices will be collectively referred to as the MAC.

The ability of a network technology to meet SLAs is largely dependent on the MAC employed by the network. The P2P access network technology is typically considered the best network technology for meeting low FD and FDV requirements because the transmitters transmit whenever they want, and there are no collisions. Unfortunately, it is also considered the most expensive network technology because it requires a dedicated connection between the head end and the business customer.

Contrast the P2P technology with the P2MP network technologies, where the endpoints cannot transmit when they want, but instead they transmit according to the MAC. The ability of the CMTS or DPoE System to learn the transmission requirements of a CM or ONU, respectively, schedule the CM or ONU, and communicate the transmission time to the CM or ONU determines the network's ability to meet SLAs.

Unfortunately, the MACs associated with DOCSIS and DPoE networks are different and can lead to inconsistent support of SLAs. Both network types may be able to meet the peak data rate required, but they may not meet the FD and FDV requirements because of the variability in scheduling algorithms or interpretation of the SLA parameters. The ideal scenario is to deploy a networking technology that is suitable for both fiber and coaxial cable so QoS is consistent regardless of media type.

Convergence of the Access Network

Historically the only P2MP network technology used over the HFC network is the DOCSIS technology. For over twenty years millions of residential customers have been provided with their high speed data services through a CM. Additionally, SMBs have also been adequately served with DOCSIS technology, albeit in an asymmetric and best-effort manner.

Over the past several years the requirements for business have become more stringent, and it has become more difficult for DOCSIS networks built to earlier DOCSIS specifications to support the requirements. Businesses are requiring higher data rates that DOCSIS technology cannot support in a guaranteed manner. Furthermore, businesses are requiring symmetric data rates – something DOCSIS networks may also be unable to guarantee. To support the more stringent requirements for business services the trend is toward deploying EPON networks to meet the symmetric high data rates and low latency demands. The DPoE specifications provide the specific device and provisioning interface requirements. The fact remains, however, that not all customer sites will be connected to a fiber network, but instead will be fed by a coaxial cable.

Ideally, service providers would like to expect the same performance and support of SLAs whether the customer's network is connected to an optical fiber or a coaxial cable. Indeed, a service provider's "holy grail" of network convergence is a single network that can support all the services required by the business customer, irrespective of media type, number of employees, etc..

A new physical layer technology is currently being standardized by the IEEE called *EPON Protocol over Coax*, or EPoC. In the IEEE standard a Coax Line Terminal (CLT) will be defined that is analogous to an EPON OLT, except that the CLT will transmit its signals over coaxial cable instead of fiber. Similarly, a Coax Network Unit (CNU) is analogous to an ONU and will terminate the coaxial cable on the customer premise. CNUs are granted access to the upstream channel on the coaxial cable using the same MAC protocol that OLTs use to grant ONU access to the fiber for upstream transmission.

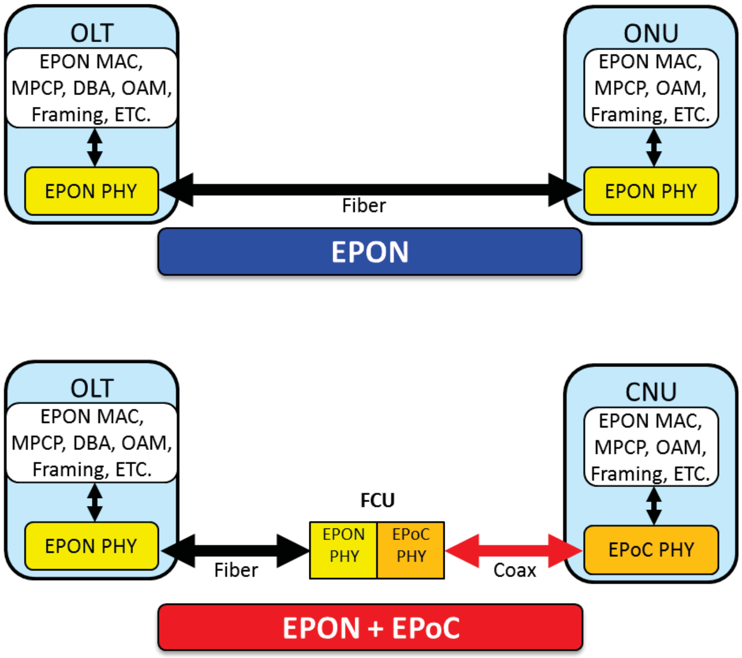

Figure 3: EPON OLT with ONU, and EPON OLT with CNU.

The benefit of using the EPoC technology can be seen by examining Figure 3. Through the EPoC System specifications, CableLabs, cable operators, and vendors are integrating the EPoC PHY into a device called the Fiber Coax Unit (FCU). With the deployment of a repeater-type FCU, a CNU can be registered and granted upstream access in a manner identical to an ONU. In fact, the OLT will not necessarily know to which type of device it is granting upstream access. Consequently, one can expect a high degree of commonality and consistency between fiber networks based on EPON and coaxial cable networks based on EPoC. This will translate into a consistency in the way QoS and SLAs are enforced for business customers.

Deployment of network devices based on EPoC technology will be as part of a DPoE network. Specifically, a DPoE System will support both EPON OLTs and EPoC CLTs. In addition to managing the ONUs and CNUs, the DPoE System will also manage and configure the FCU. This will allow a single head end device, the DPoE System, to control termination devices (i.e. ONUs and CNUs) regardless of whether they are connected to a fiber network or a coaxial network. ONU and CNU registration, configuration, scheduling, and QoS are controlled through the DPoE System as part of a DPoE network. Such a DPoE network is shown in Figure 4.

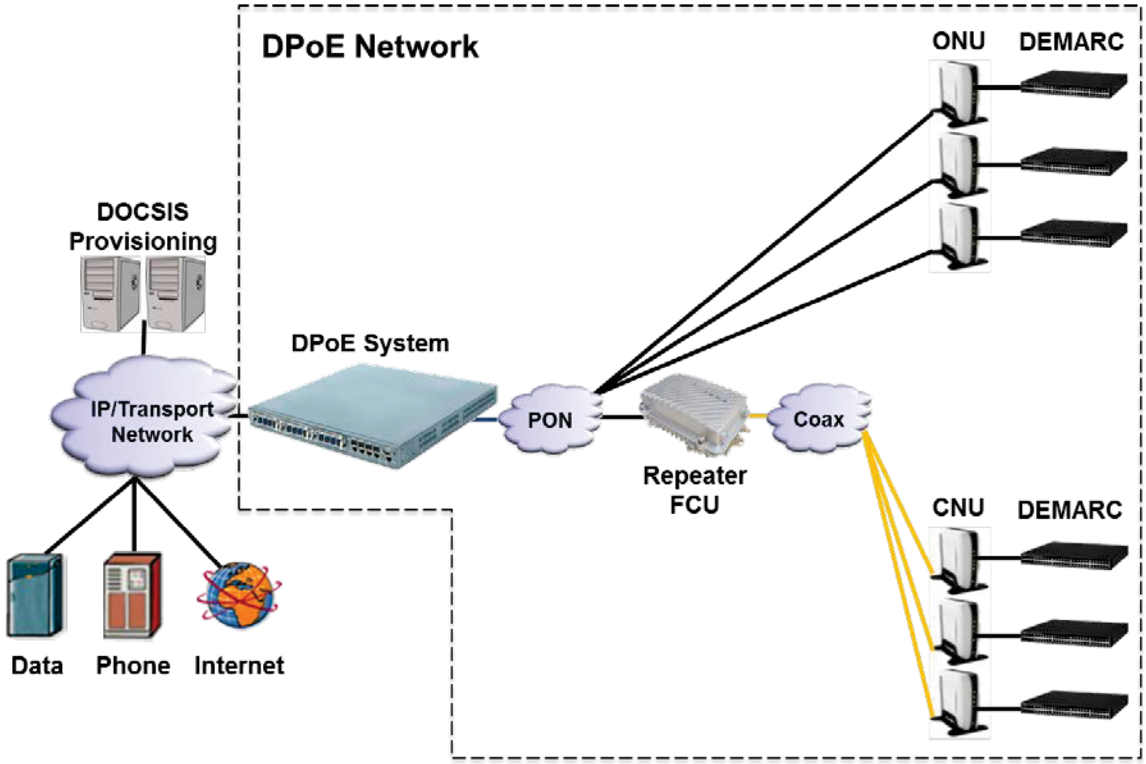

Figure 4: DPoE network supporting both EPON and EPoC technologies.

The nature of the repeater FCU is such that the MAC domains of the fiber and coaxial networks are converged to form a single MAC domain. This is represented conceptually by the blue shape in Figure 5. Thus, the OLT in the DPoE System will grant upstream bandwidth to both ONUs and CNUs in an equivalent manner. As mentioned before, this will allow a single head end device (i.e. the DPoE System) to manage and control business services whether the business is connected to a fiber network or a coaxial network. This level of network convergence has never been accomplished before by any service provider in any industry!

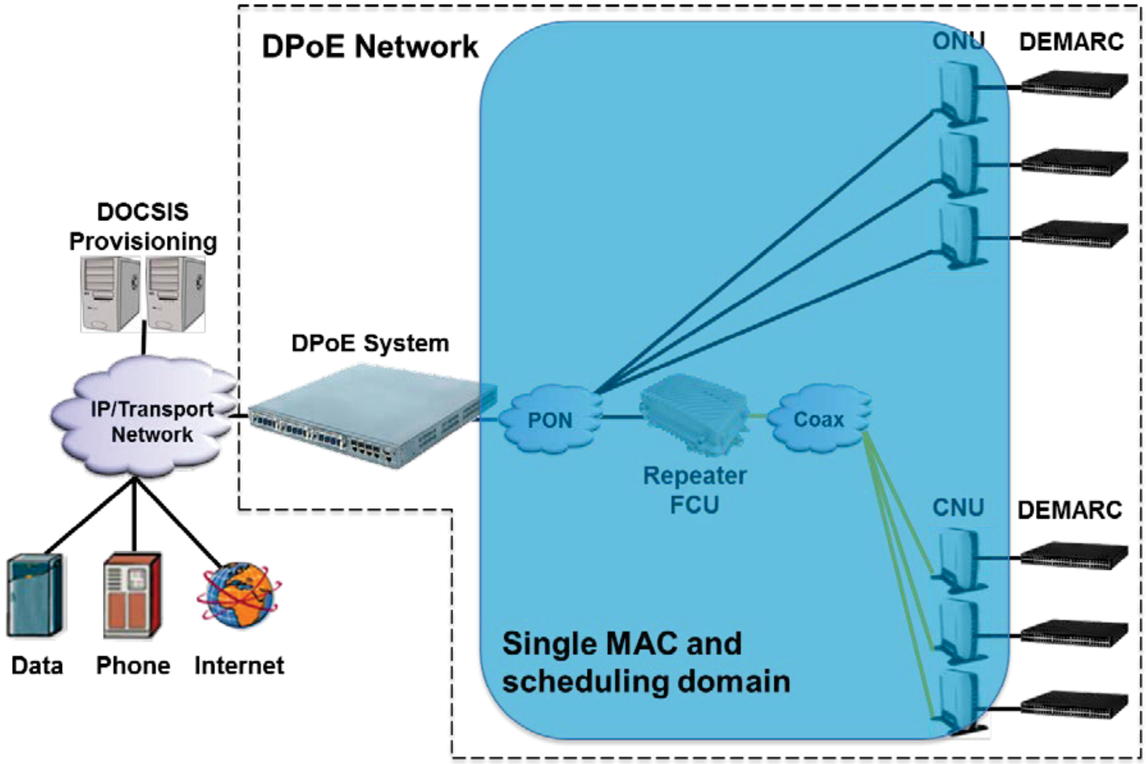

Figure 5: Converged fiber and coax MAC and scheduling domains.

Conclusions

Service providers have a strong desire to maintain a level of consistency in their service offerings regardless of the type of access network to which the business is connected. An EPL service to one customer connected to one part of the service provider network should provide the same performance that another EPL service provides even though it may be connected to another part of the network. This is desired and expected regardless of the flavor of access network technology.

Historically, different types of access network technology required its own type of provisioning. A necessary consequence of this is potentially an imprecise translation of QoS parameters contained in an SLA to what the technology requires or equipment requires. For example, the MEF bandwidth profile uses parameters like the CIR and CBS to define the QoS for a service, while DOCSIS networks uses parameters such as Maximum Sustained Traffic Rate and Maximum Traffic Burst parameters. Translating between the parameters of multiple network technologies does not always result in the same level of QoS behavior.

The provisioning servers and network management systems typically vary between different access network technologies as well, including interface differences between vendors. This requires network technicians to learn new interfaces and new methods for configuring the network. Requiring common provisioning and network management methods saves service providers operational expenses.

Figure 6 demonstrates the level of network convergence that can be obtained using the EPON and EPoC technology together in a DPoE network. Convergence starts at the top with the BSS/OSS, where the DPoE specifications dictate how the DPoE System and ONUs or CNUs are provisioned to provide specific services, regardless of whether the services travers fiber or coax. With a DPoE System providing the central control point for both fiber and coax networks, the scheduling of upstream resources and the application of the provisioned QoS parameter set are one and the same. Aside from having either a fiber or coax interface, the access network termination equipment (ONUs and CNUs) are basically the same device, and they will respond in the same manner to the MAC being executed on the DPoE System. Finally, the demarcation devices and the corresponding service frames carried as part of a Metro Ethernet service are provided with the same consistent performance.

Operators will be able to choose between deploying business services over either fiber or coax, and they will benefit from the consistencies derived from using a single media access control protocol, a single scheduler, a single provisioning system, a single network management system, and an ability to meet every single data service provided by cable operators.

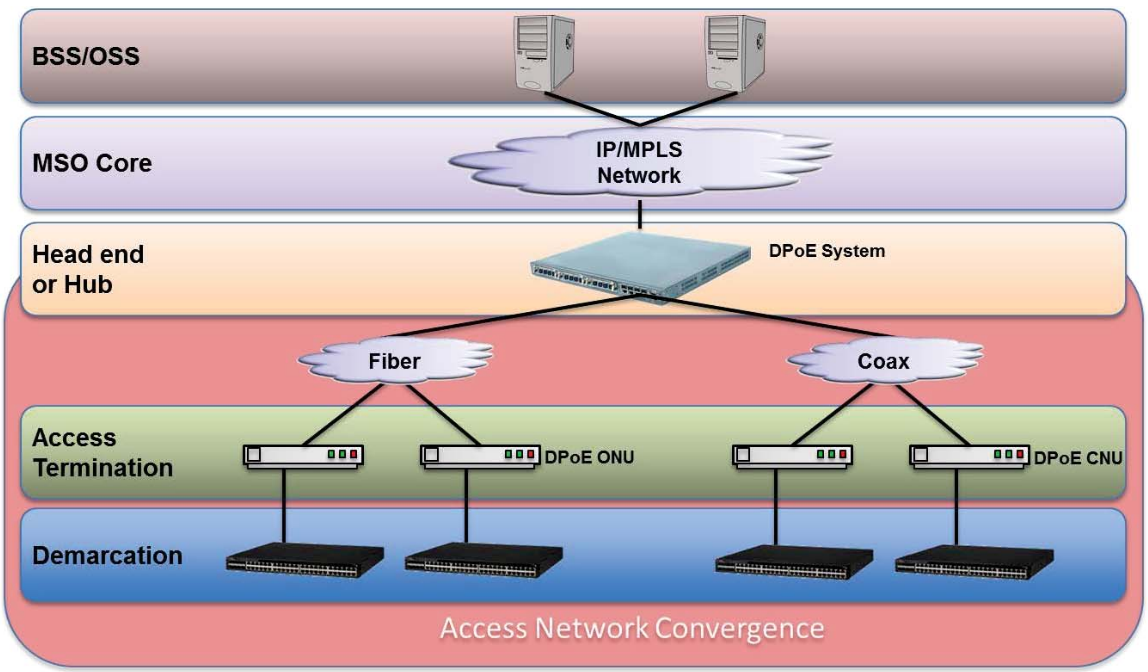

Figure 6: Converged layers in a typical service provider network.

Abbreviations and Acronyms

BSS	Business Support Systems
CBS	Committed Burst Size
CIR	Committed Information Rate
CLT	Coax Line Terminal
CM	Cable Modem
CMTS	Cable Modem Termination System
CNU	Coax Network Unit
DPoE	DOCSIS Provisioning of EPON
EPL	Ethernet Private Line
EPoC	EPON Protocol over DOCSIS
EPON	Ethernet Passive Optical Network
FCU	Fiber Coax Unit
FD	Frame Delay
FDV	Frame Delay Variation
HFC	Hybrid Fiber Coax
IEEE	Institute of Electrical and Electronics Engineers
MAC	Media Access Control
MEF	Metro Ethernet Forum
OLT	Optical Line Terminal
ONU	Optical Network Unit
OSS	Operations Support Systems
P2P	Point to Point
P2MP	Point to Multipoint
QoS	Quality of Service
SLA	Service Level Agreement
SMB	Small or Medium Business
UNI	User Network Interface