DOCSIS® 3.1 and EPoC Technologies: A Comparison

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

Matt Schmitt
CableLabs
858 Coal Creek Circle, Louisville CO 80027
Phone: +1 303-661-3386
m.schmitt@cablelabs.com

Curtis Knittle, Ph.D.
CableLabs
858 Coal Creek Circle, Louisville CO 80027
Phone: +1 303-661-3851
c.knittle@cablelabs.com

Introduction

Two simultaneous technology efforts are underway that, on the surface, appear to be on a collision course with each other: DOCSIS® 3.1 and EPON Protocol over Coax (EPoC) technologies. The DOCSIS 3.1 specifications are the next iteration of a technology that helped usher in the Internet Era and has been an integral part of the cable industry for over 15 years. EPoC is a developing Ethernet-over-coax technology that expands the reach of the IEEE Ethernet Passive Optical Network (EPON) solution from fiber to networks using coaxial cable.

DOCSIS currently provides high speed data to more than 100 million subscribers worldwide. Through combinations of extending fiber deeper, modulation improvements, channel bonding, and plant upgrades, the DOCSIS solution has cost effectively kept pace with increasing demand for high speed Internet service. At the same time, small and medium businesses (SMBs) have come to realize that DOCSIS services provide a better solution for their business needs compared to traditional T-1 service provided by Telcos.

More recently, cable operators in the U.S. have begun targeting larger business customers which require higher symmetric bit rates and service guarantees. To meet these needs, cable operators have started to deploy passive optical network (PON) technology. At the same time, competition from other fiber-based service providers, and residential developers who demand a fiber solution, have forced cable operators to selectively deploy fiber to the premises (such as PON or RFoG (RF over Glass)). EPoC has emerged as a solution that allows operators to re-use their EPON head end equipment and extend their EPON services to customers using their existing coax network without incurring the expense of running fiber all the way to the home.

Is one solution better than the other? How will operators choose? The answer is “It depends.” This paper will provide some high level details around both technologies, and then discuss the benefits associated with deploying each of the technologies.

Technology Background

In this section, we will provide some basic background information regarding DOCSIS 3.1 and EPoC technologies.

DOCSIS 3.1 Technology

DOCSIS 3.1 technology is the next generation of the DOCSIS protocol, which has evolved through multiple generations including the DOCSIS 1.0, DOCSIS 1.1, DOCSIS 2.0, and DOCSIS 3.0 specifications. Each generation built upon the previous generations by adding additional capabilities, such as improving Quality of Service, enhancing upstream spectral density, and increasing total capacity, all while still maintaining backward compatibility. DOCSIS compliant devices have been in deployment since the late 1990s, and are the predominant technology world wide for delivering broadband over cable networks.

The DOCSIS 3.1 specifications define a new physical layer, intended to permit easier scalability to very high data rates (multiple gigabits per second). They also include media access control (MAC) layer enhancements to support this new physical layer, along with some additional feature and performance enhancements. In addition, as with previous versions of DOCSIS technology, DOCSIS 3.1 devices will be backward compatible with previous versions; as a result, DOCSIS 3.1 modems will operate with DOCSIS 3.0 CMTSs, and vice versa.

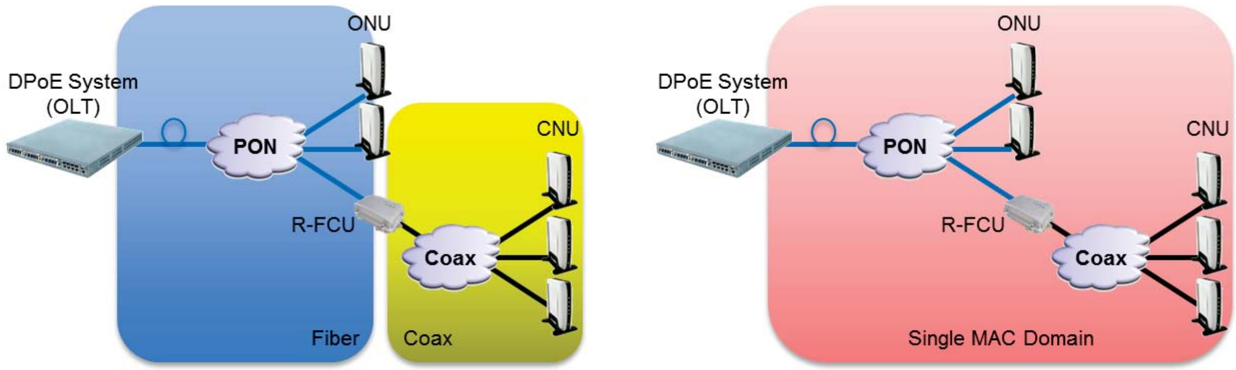
EPoC Technology

The IEEE EPoC standard, simply stated, creates a new coax-specific physical layer which will operate with the existing EPON MAC layer. This serves to allow an EPON network to operate not just on fiber, but also over coax, so that a single Optical Line Terminal (OLT) can support customers connected via fiber and coax simultaneously. It is a new technology, currently under development by the IEEE 802.3bn Task Force.

In parallel to the IEEE activity, CableLabs is leading an effort to standardize the use of the EPoC physical layer. The EPoC System Specifications, an effort that includes CableLabs members and technology partners, will define the requirements and capabilities of devices which incorporate EPoC physical layers, as well as the network topologies supported.

The embodiment of EPoC technology most interesting to cable operators will be as part of a DOCSIS Provisioning of EPON (DPoE™) network. The original DPoE specifications included only IEEE 802.3 EPON technology, and the purpose of the DPoE specifications is to make the EPON technology “look like” DOCSIS from the perspective of the back office. With the development of EPoC technology in the IEEE 802.3bn task force, the DPoE network will be extended to support EPoC technology if the devices are built to the CableLabs EPoC System Specification.

The CableLabs specifications will define multiple device types to meet different cable operator use cases. One device type, and the corresponding network topology, is of particular interest for discussion in this paper. A “repeater” Fiber Coax Unit (R-FCU) is being defined that simply converts the signaling on the fiber optic media to signaling on coaxial cable media. Since the MAC protocol in EPoC is based on the EPON MAC, converting the optical signal to an RF signal conducive to coaxial cabling will allow a coax network unit (CNU) to register with an optical line terminal (OLT) and participate alongside optical network units (ONUs). In effect, an R-FCU unifies the fiber and coaxial domains to create a single MAC domain controlled by the DPoE System (OLT) in the head end, as shown in Figure 1.



(a) ONUs and CNUs connected to same OLT (b) Single MAC domain regardless of media

Figure 1: Separate physical domains, but a single MAC domain.

The Common Ground

The evolving EPoC technology, and the corresponding system specifications, share many similarities with the emerging DOCSIS 3.1 specifications, both in terms of technology and performance targets. As a result, in many conditions we expect that EPoC and DOCSIS 3.1 technologies will provide similar performance at the physical layer.

This paper does not seek to identify and examine each one of these similarities in extensive detail, as it is not central to this paper and others are already examining that topic in great detail. However, to substantiate our basic contention that similar physical layer performance can be expected, this section will outline a few of the key commonalities between these two access network alternatives.

Network Topology

Both the DOCSIS and EPoC networks are point-to-multipoint (P2MP) networks. P2MP networks are also called "one-to-many" networks because there is a single downstream transmitter, but many upstream transmitters. The lone downstream transmitter reaches all endpoints and experiences no contention or collisions on the network. On the other hand, upstream transmissions from network endpoints can collide with other endpoint transmissions. An arbitration scheme is therefore required to avoid upstream collisions. A centralized controller is responsible for allocating upstream transmission opportunities to the network endpoints. In DOCSIS networks, the network endpoints and the centralized controller are known as cable modems (CMs) and the cable modem termination system (CMTS). In EPoC networks, the respective devices are referred to as coax network units (CNUs) and coax line terminal (CLT). Figure 1 shows the topology similarities between the two networking technologies. The reader can see that other than functionality of the endpoint devices, there is no different in network topology.

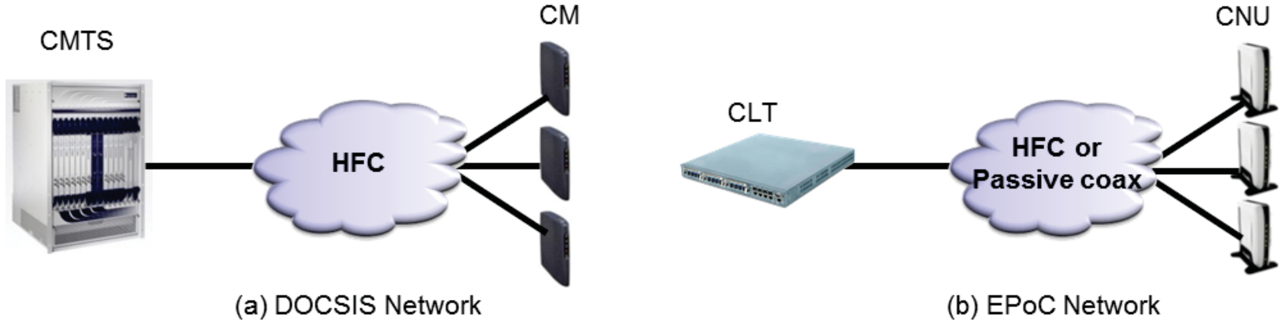


Figure 2: Point to multipoint network topology for DOCSIS and EPoC.

Modulation Technology

Both DOCSIS 3.1 and EPoC technologies are using a technique known as Orthogonal Frequency Division Multiplexing or OFDM. In OFDM, rather than transmitting one or more Single Carrier QAM (SC-QAM) channels that are either 6 MHz (J.83 Annex B) or 8 MHz (J.83 Annex B) wide, devices transmit a large number of very small "sub-carriers" that can be treated – in some respects – as a single wide channel. This has the advantage of allowing you to customize the transmission on a very granular basis, yet at the same time to cost effectively transmit over very wide bandwidths. OFDM is being used by both technologies for both the downstream (forward) direction, as well as the upstream (return) direction.

More specifically, both technologies have adopted 192 MHz wide OFDM "channels" in the downstream; if more than a single 192 MHz OFDM channel is needed, another 192 MHz channel can be added. Note that due to the flexibility of OFDM it is not necessary to use the entire OFDM channel, as it is possible to turn off one or more OFDM sub-carriers to fit into a smaller spectral region; however, whatever number of sub-carriers is actually used, an OFDM channel is used up to a maximum spectral coverage of 192 MHz. Note that there is a slight difference between the two in the upstream: DOCSIS 3.1 devices will be required to support 96 MHz OFDMA channels, while EPoC devices will support a 192 MHz OFDMA channel.

Additionally, both technologies have adopted two choices for sub-carrier spacing: 25 kHz and 50 kHz. The 25 kHz sub-carrier spacing corresponds to an 8k FFT for a 192 MHz OFDM channel, and a 40 μs symbol period; the 50 kHz sub-carrier spacing corresponds to a 4k FFT for a 192 MHz OFDM channel, and a 20 μs symbol period.

Forward Error Correction and Supported Modulation Orders

Another key technology for both the DOCSIS 3.1 and EPoC specifications is the choice of Forward Error Correction (FEC) technology, and the Modulation Orders (resulting in the number of bits/s/Hz) that can be supported.

Here again, both technologies have chosen to use an FEC technique known as Low Density Parity Check, or LDPC. While each technology has chosen slightly different variants of LDPC technology, they are both very similar, with very similar performance characteristics.

As a result of this, both technologies also include a requirement for devices to support 4096 QAM, which provides 12 bits/s/Hz. This is in contrast to DOCSIS 3.0 technology, which only supports up to 256 QAM in the downstream (or 8 bits/s/Hz); both DOCSIS 3.1 and EPoC technologies will therefore support a roughly 50% increase in spectral efficiency as compared to current DOCSIS devices.

Common Ground Summary

As you can see, the core underlying technology being used in both the DOCSIS 3.1 and EPoC specifications is very similar: they are both based on OFDM, use 192 MHz OFDM channels, use the same sub-carrier spacing, support an LDPC based FEC, support similar modulation orders, and can therefore be expected to support similar data rates.

Therefore, you might be wondering what's different between the two technologies, why they both exist, and how you might choose between the two of them. The next section will discuss that topic further.

The Un-Common Ground

As mentioned in the previous section, there are a number of similarities between EPoC and DOCSIS 3.1 technologies, primarily related to the Physical (PHY) Layers being utilized by each technology. As a result, at least at the physical layer you should be able to expect similar performance out of each.

This is not to say that the PHY layers between them are the same, and that there won't be differences in performance. For example, DOCSIS 3.1 technology includes the concept of Multiple Modulation Profiles, which allow different modems to receive different modulation orders at the same frequency in the downstream, whereas EPoC with Frequency Division Duplexing (FDD) will only support one. There are other differences as well. However, some of the benefits are yet to be proven in a real network, and others are relatively minor. Therefore, we would argue that these will not be the primary determining factors for an MSO when choosing between them.

Another distinct difference between the two technologies is the MAC layer that each one uses. As noted above, DOCSIS 3.1 technology builds upon the existing DOCSIS MAC layer; similarly, EPoC technology utilizes the EPON MAC layer. In general, the EPON MAC layer is considered simpler, whereas the DOCSIS MAC layer is considered more complex and feature rich. This may ultimately result in a cost difference between devices based on each technology, although the volume of devices produced may have an even greater impact on costs. So while cost could be a significant consideration for an operator in choosing between these technologies, since no DOCSIS 3.1 or EPoC devices have yet been built for commercial sale, we will refrain from speculating and will not consider this as a differentiator in this paper as well.

Instead, as noted in the introduction our belief is that the primary drivers for an operator to choose one technology over the other will relate to deployment scenarios. For example:

- What is the starting point in terms of deployed devices and services?
- What types of services will these faster broadband networks be used to support?
- What is the target end point in terms of network design and services?
- How long is it expected to take to get to this longer term vision of the network?

Put another way, migration scenarios – where you are, and where you want to end up and when – will likely play the determining role in deciding which technology to adopt. Further, for different operators, the answer to these questions could be different, resulting in a different choice.

In this section, we will look at some of these differences between DOCSIS 3.1 and EPoC technology affect services and migration strategies.

DOCSIS 3.1 Benefits

Central to the development of the DOCSIS 3.1 specifications has been the question of migration strategy: how to ease migration from a DOCSIS network today to a DOCSIS 3.1 network. There are several components to this migration strategy.

Backward Compatibility

One of these core concepts is that of “Backward Compatibility”, or the ability to operate different versions of DOCSIS devices on the same network at the same time.

For example, a DOCSIS 3.1 CM will be required to operate not just on a DOCSIS 3.1 CMTS, but also on DOCSIS 1.1, 2.0, and 3.0 CMTSs. When operating on those previous generation CMTSs it will not have the full capabilities that it will have when operating on a DOCSIS 3.1 CMTS, but it will be able to operate. In fact, DOCSIS 3.1 CMs will be required to support as many upstream and downstream SC-QAM channels as the current generation of DOCSIS 3.0 CMs. As a result, you can deploy DOCSIS 3.1 CMs without upgrading the CMTS and still provide equivalent services. Then, once an operator makes a business decision to upgrade their CMTS to DOCSIS 3.1 technology, they will be able to take full advantage of the capabilities of that DOCSIS 3.1 CM.

Similarly, a DOCSIS 3.1 CMTS will be required to support DOCSIS 1.1, 2.0, and 3.0 CMs. While those modems will not see any benefit from operating on a DOCSIS 3.1 CMTS, they also will not see a degradation in performance as a result of the change, and therefore operators will not be forced to replace those modems unless customers wish to move to a higher tier of service that is only supported by DOCSIS 3.1 devices.

Downstream Channel Bonding

Another of the key concepts for enabling easy migration in the DOCSIS 3.1 specifications is that of Downstream Channel Bonding.

Downstream Channel Bonding was originally introduced to the DOCSIS world in the DOCSIS 3.0 specifications. It permitted devices to bond multiple physical SC-QAM channels together to form a single larger "logical" pipe, thereby enabling much higher burst speeds than in previous versions of DOCSIS technology. In DOCSIS 3.0 devices, this bonding took place at the DOCSIS MAC layer, allowing a flexible assignment of devices to different downstream channels, and a flexible distribution of packets across those channels so that the CMTS could effectively balance load between them.

In DOCSIS 3.1 technology, we've extended this same methodology to also cover OFDM channels. More specifically, in addition to bonding between SC-QAM channels, DOCSIS 3.1 CMs and CMTSs will also be required to support bonding between OFDM channels, and between SC-QAM and OFDM channels. Bonding between OFDM channels will allow different modems to support different numbers of OFDM channels in the future, permitting capabilities to scale up based on operator needs; bonding between OFDM and SC-QAM channels will enable operators to incrementally add OFDM capabilities.

This last one is particularly important for migration, as with even a minimal amount of OFDM spectrum (say, 24 MHz), a DOCSIS 3.1 customer will be able to achieve higher speeds – and therefore superior service – to a DOCSIS 3.0 customer, because they will be able to use all of the same SC-QAM channels as the DOCSIS 3.0 customer in addition to the additional DOCSIS 3.1 only OFDM channel. Without this capability, operators would be forced to dedicate significant additional spectrum to the new device just to provide an equivalent service relative to DOCSIS 3.0 customers.

Upstream Spectrum Sharing

While channel bonding can be used to address the issue of migration in the downstream, the upstream presents some different and unique challenges.

Operators with DOCSIS deployments are already typically using multiple upstream channels, and it is likely that the number of upstream channels in use will increase over time. Therefore, it would be a reasonable assumption that an operator might have 4 upstream channels in use (if not today, then very soon), with 3 of those channels covering 6.4 MHz of spectrum, and one of them cover 3.2 MHz worth of spectrum. That results in 22.4 MHz worth of spectrum being consumed for legacy DOCSIS services, out of a total of 37 MHz worth of available spectrum in North America (5-42 MHz), or 60 MHz worth of spectrum in Europe (5-65 MHz). Additionally, operators often still have other signals in the upstream, such as out of band return channels for set top boxes and other services, further restricting the amount of available spectrum.

Ignoring non-DOCSIS services, in North America this leaves only about 14 MHz worth of free spectrum. In addition, the existing channels are generally occupying the best quality spectrum available; therefore, this remaining 14 MHz is generally in frequency regions with more noise and which are harder to operate in (such as below 20 MHz). The flexibility of OFDMA on the upstream will allow you to operate in these regions, but if a DOCSIS 3.1 device were restricted only to these small pieces of spectrum, they would receive an inferior service even to a DOCSIS 3.0 device.

One solution to this is to use channel bonding just as was done in the downstream, and the DOCSIS 3.1 specifications will include the ability to do just that. However, the incremental capacity from this small amount of challenging spectrum won't allow for a significant differentiation for DOCSIS 3.1 devices; in addition, it would be highly desirable to be able to utilize the greater efficiency of DOCSIS 3.1 technology across the entire upstream band.

Fortunately, unlike the downstream (which is broadcast in nature), the upstream is "bursty" in nature, and those bursts are controlled by the CMTS scheduler. Since in a DOCSIS 3.1 CMTS both OFDMA and SC-QAM channels will be scheduled by a single device, it is possible for the CMTS to schedule transmissions from different devices using different modulations on the same frequency, but separated in time. Further, it can make these decisions independently for different frequencies, as a result of which we refer to this feature as Time and Frequency Division Multiplexing (TaFDM).

Note that DOCSIS 3.1 technology does also include the ability to operate the upstream at higher splits than 42/65 MHz: both 85 MHz and 200 MHz upstream splits are supported. However, one of the objectives for DOCSIS 3.1 was to extract as much capacity from the existing upstream split as possible, so that operators are not forced to move the split in order to deploy DOCSIS 3.1 devices, and therefore can do success-based network upgrades if and as necessary. TaFDM allows DOCSIS 3.1 devices to coexist and share spectrum with legacy DOCSIS devices, and therefore ease that transition.

EPoC Benefits

After reading the last section, you may come away feeling that selecting DOCSIS 3.1 technology for operator networks is an easy choice. However, there are definitely scenarios which favor EPoC over DOCSIS 3.1 technology, and which are likely relevant for some operators.

Unified Network for Business Services

Cable operators have historically targeted small to medium size businesses because their service requirements are more conducive to the capabilities of DOCSIS networks. Typically the SMB community is content with a best-effort non-symmetric data service with downstream bit rates in the 10-100 Mbps range, and upstream bit rates in the 5-10 Mbps range. These bit rates fit comfortably into the capabilities of a DOCSIS network. The asymmetric nature of the Hybrid Fiber Coax (HFC) network easily accommodates the disparity between downstream and upstream bit rate requirements.

Large enterprise customers, and a growing number of SMB customers, require higher bit rate services – 100 Mbps and higher. Additionally these customers require the data service to be symmetric – offering equivalent upstream and downstream bit rates.

Another growing trend in business service offerings is the guarantee of service backed up with a Service Level Agreement. DOCSIS networks struggle to meet these growing service requirements for business customers.

More and more fiber is being installed to accommodate the increasingly stringent business services requirements. The two network topologies typically favored are point-to-point (P2P) active Ethernet and point-to-multipoint (P2MP) Passive Optical Networks (PON). A P2P active Ethernet topology is comprised of a full-duplex, unshared fiber link between the head end or hub site and the customer premise. In a P2MP PON network, a single home-run fiber connects the head end central controller to an optical splitter/combiner, from which drop fibers connect to the customer premise. The majority of cable operators use the IEEE Ethernet PON (EPON) technology for their P2MP deployments.

The triumvirate of DOCSIS, EPON, and active Ethernet networks are deployed by cable operators to meet business services requirements. Fortunately, with the DOCSIS Provisioning of EPON (DPoE™) specifications, at least the DOCSIS and EPON network choices share back office provisioning and management servers and policies. The active Ethernet network currently requires a separate provisioning and management system, and these are usually specific to the vendor providing the equipment. With three different access networks deployed for business services, the quality of service on each network is typically not the same. The active Ethernet network typically provides the lowest frame delay and frame delay variation, but the DOCSIS network provides the most ubiquitous coverage.

Deploying EPON and EPoC technology in the same access network allows cable operators an opportunity to provide business customers to both fiber-connected and coax-connected customers using the same network endpoints. This results in a consistent treatment of services and quality of service regardless of whether the customer is connected to a fiber or coax network.

Converged Business and Residential Network

Cable operators have long coveted the single converged network that accommodates the requirements of both residential and business customers. Certainly the DOCSIS network provides services to both residential and SMB customers, but the trend is to deploy fiber to meet the growing demands of business customers. The trend toward DOCSIS for residential and EPON for business essentially separates the residential network from the business services network, potentially doubling the capital and operational expenses associated with deploying and maintaining each type of network.

The key characteristics of symmetric, high speed, and guaranteed QoS in a combined EPON/EPoC network allows for deployment of a single network to service both residential customers and all tiers of business customers. With an EPON/EPoC network, cable operators are presented with an unprecedented opportunity to use a single head end device and customer premise device to provide connectivity to both residential and business customers.

Migration path for EPON FTTH

One of the most interesting benefits of deploying EPoC technology alongside EPON technology is the easy migration to a fiber to the home (FTTH) network. The competitive push from service providers to provide increasing bandwidth to the home shows no abatement. Consequently, many cable operators are already considering future FTTH solutions. The EPoC solution can be leveraged when one considers the initial build out scenario shown in Figure 3. The revenue from providing service to the businesses will likely justify the build out of fiber to the building, but not to the residential neighborhood. The residential customers can stay connected to the coaxial network by installing an R-FCU connected to the PON network. At this point the cable operator is using a single head end device to provide services to both business and residential customers, and in fact all the endpoint devices are part of the same MAC domain.

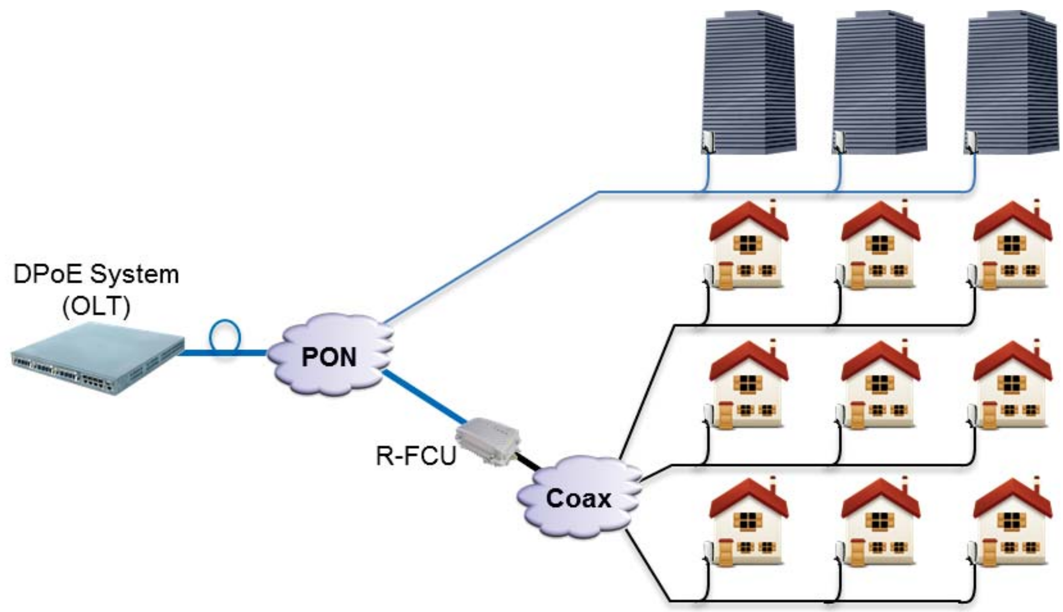


Figure 3: Initial build out of businesses (on fiber) and homes (on coax).

As the competitive market changes to require an FTTH solution, cable operators can quickly provide an all-fiber solution to homes by extending a fiber from the nearby splitter/combiner to a group of coax-fed home and then cutting the coaxial cable, as shown in Figure 4. The head end equipment is already in place to support the FTTH deployment, and in fact the provisioning of the devices connected to the PON network is also in place because the original deployment of EPoC was based on the DPoE specifications. The transition from providing residential services via an FTTH solution couldn't be easier.

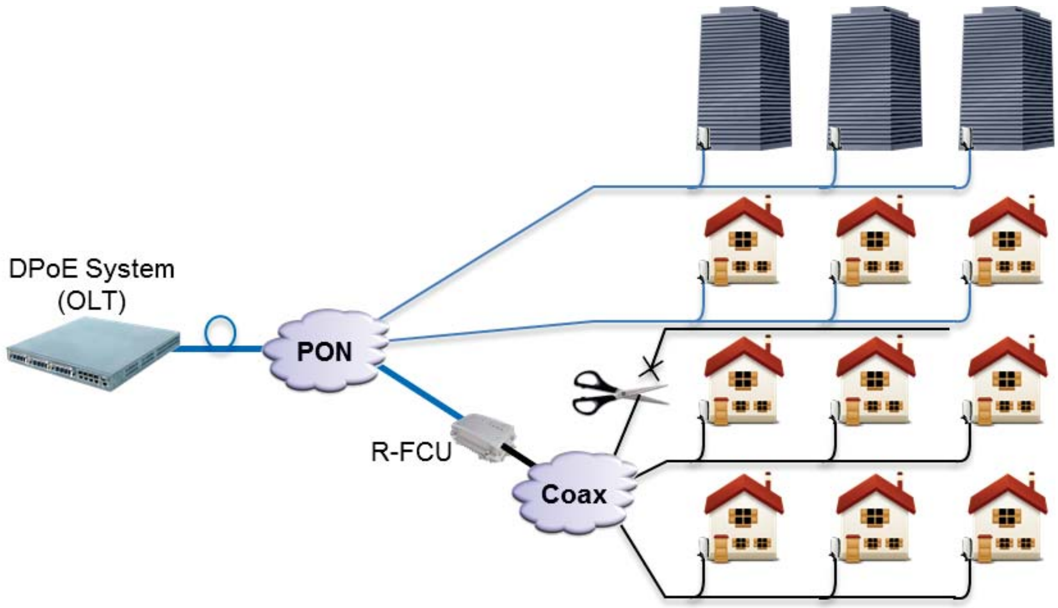


Figure 4: Replacing a coaxial segment with a fiber segment.

Conclusions

The selection of which technology to deploy is not as easy as one might believe for cable operators. A DOCSIS 3.1 CMTS will support DOCSIS 3.0 cable modems, which allows MSOs to avoid the cost of replacing modems unless and until there is a financial reason to do so (for example, a customer deciding to pay for a higher tier or service). Additionally, this backward compatibility – combined with channel bonding – allows operators to minimize the need for additional spectrum to support higher data rate services, and to incrementally add bandwidth with a "success based" approach. This makes the upgrade path to higher bandwidth over coax easy to envision with a DOCSIS 3.1 solution.

On the other hand, many operators are already deploying EPON to support business services, and in some cases for greenfield residential services. Making purchasing decisions for network equipment that they know will carry them into the future is likely an easier decision. Network build-out that will also carry them into the future also may make the decision easier.

In the end, we believe the choice of technologies boils down to strategic decisions related to future network directions. Put another way, what is a given operator's vision of their future network, and when do they expect to get there? If an operator believes the FTTH solution is further into the future, and they would like to delay the need for FTTH for as long as possible, a DOCSIS 3.1 solution likely is a better fit. For operators who are already deploying EPON, are planning to deploy EPON in the near future, or believe that they will need a fiber based solution sooner rather than later, EPoC may be more appealing as it may better leverage their fiber investments and align them with that longer term vision of the future. With each cable operator being an independent entity, the choice will be different for each. In fact, in many cases an operator may choose both, with selective deployment of EPoC in areas where EPON is already being deployed, or as a part of an EPON focused business offering. Therefore, our conclusion is that these technologies are not mutually exclusive, and each likely has a role to play in the market to come.

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
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
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