Virtual Fiber – 100 Gbps over Coax

Coaxial Cable: The once and Future King

A Technical Paper Prepared for SCTE/ISBE by

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Introduction

Much debate has been made about the medium used in the last mile of the access network. Fiber is attractive because of the low cost/bps of the equipment used to deploy it. However, fiber-to-the-home (FTTH) deployments have demonstrated that deploying fiber in the last hop is expensive. This is primarily due to factors other than the cost of capital equipment such as the cost labor and right-of-way. Fortunately, technologies such as data over cable system interface specification (DOCSIS®) 3.1, full duplex DOCSIS (FDX), and distributed access architecture (DAA) will allow operators to continue to leverage their installed coaxial cable to provide multi-gigabit symmetrical services.

In order to deploy DAAs, such as remote physical layer (R-PHY) and remote media access control (MAC) and PHY (R-MACPHY), operators are pushing the distribution network deeper into the plant to reach DAA nodes. The physical media to reach these nodes has been assumed to be strands of fiber. However, just like in the access network fiber can also be cost prohibitive in the distribution network.

This paper will discuss a technological solution called "virtual fiber." Virtual fiber will allow operators to leverage the in-place coaxial cable that typically would be bypassed by a fiber link to connect DAA nodes. The first generation of virtual fiber will soon be available and will be able to achieve symmetrical speeds of 10 Gbps. Future generations of virtual fiber will be able to achieve speeds of 25 Gbps and higher providing operators with a deployment roadmap that can keep pace with demand.

Acknowledgements: Virtual fiber and virtual segmentation are technologies that I stumbled upon and to which I am lucky to have been exposed. Hans Wambach, Director of Access Engineering at Liberty Global and Jan Ariesen, Chief Technology Officer (CTO) at Technetix deserve much credit for incubating the ideas and products upon which this paper is based.

1. Access vs. Distribution and DAA

For the purposes of this paper the access network consists of the infrastructure and technologies used to attach subscribers to an operator's network. It can be a Wi-Fi network, a cellular network, digital subscriber line, DOCSIS, etc. For data services over hybrid fiber-coaxial (HFC) networks that are built on centralized access architectures (CAA) the access network begins at the cable modem termination system (CMTS). The subscribers are attached to the access network which is located on the cable side interface (CSI) of the CMTS. The distribution network is attached the network side interface (NSI).

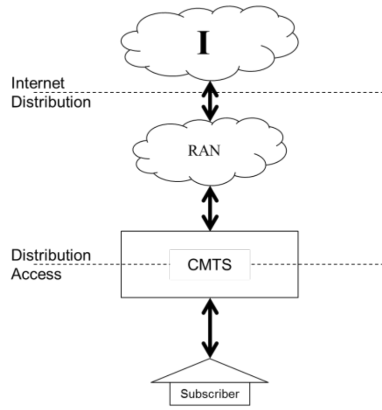

Figure 1 – CAA Networkks

DAA comes in two primary flavors, R-PHY and R-MACPHY. In an R-PHY network the CMTS is split between MAC functions and PHY functions. In the simplest form of an R-PHY system, the MAC portion of the CMTS remains at the same location as the CMTS in a CAA network and the PHY portion is located closer to the subscriber. Between the MAC and the PHY is the converged interconnect network or the CIN. For the purposes of this paper the CIN in an R-PHY system will be considered as part of the distribution network.

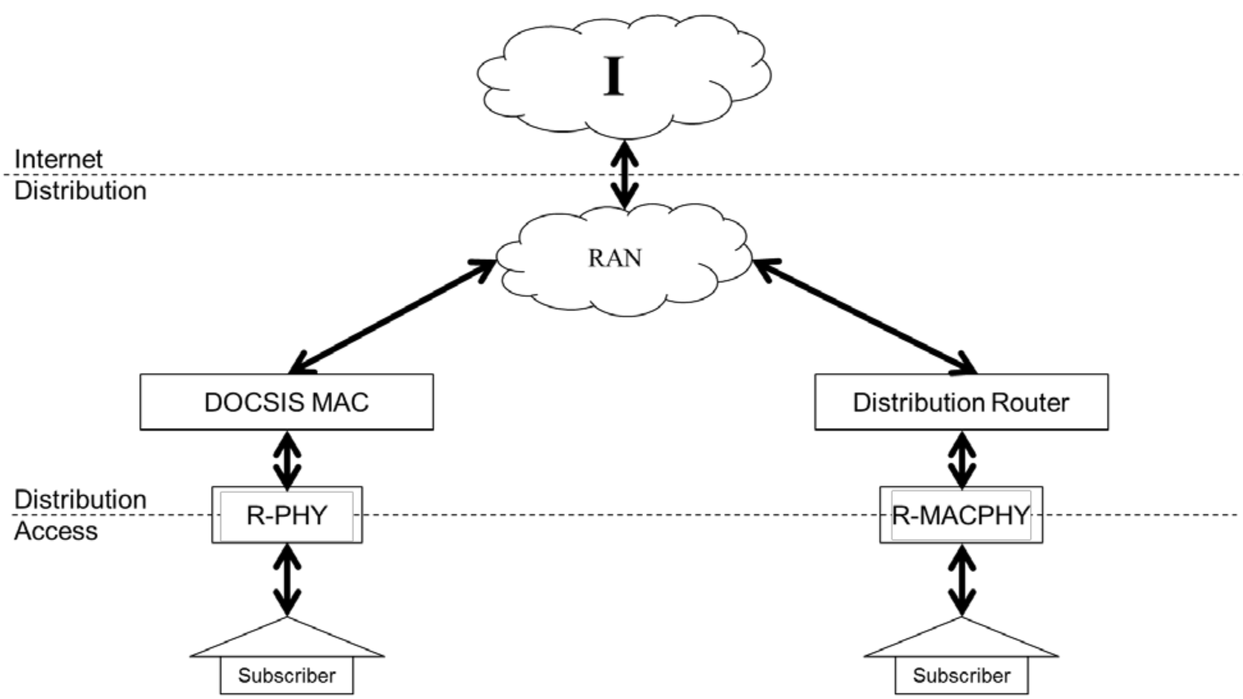

Figure 2 – DAA Networks

It is expected that the link between the DOCSIS MAC and the R-PHY will consist of fiber with either dedicated or shared wave lengths. Likewise, an R-MACPHY solution is also assumed to have a fiber link between it and the last distribution router or switch in the operator's network.

The idea of virtual fiber is complementary to DAA, R-PHY and R-MACPHY. For an in-depth discussion of CAA and DAA architectures see [EMMENDORFER], for a great intro to R-PHY and its benefits see [CHAPMAN], and for an excellent discussion of why and how operators are deploying R-PHY see [SALINGER].

2. Introduction to Virutal Fiber

It has been noted that deploying fiber to the home can be expensive compared to reusing existing attachments such as coaxial cable, twisted pair, or even power lines [EMMENDORFER 2]. The same cost argument can be made for a portion of the backhaul links in an operator's network. For example, many urban communities require all cabling to be hidden or buried. In these areas labor costs can be prohibitive to deploying new network infrastructure. In these areas there is a large incentive to be able to reuse existing cabling, much of which is coaxial cable.

Virtual fiber is a technology that is being developed that can eliminate the need to dig up streets. Instead the existing coaxial cable is used to transmit 10 Gbps Ethernet signals in a point to point topology.

Consider the network in **Figure 3** below:

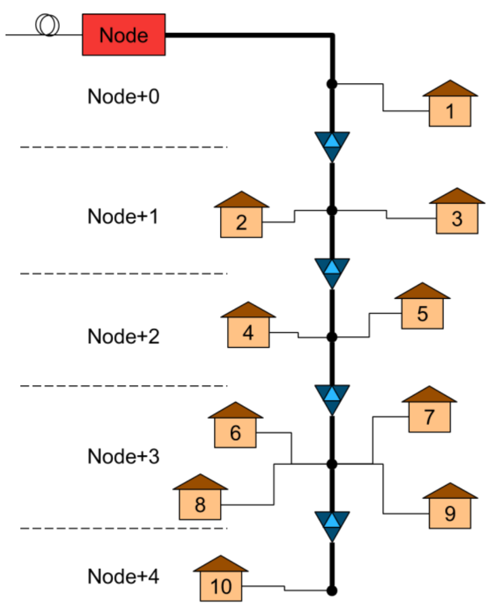

Figure 3 – Example Coaxial Cable Plant

It consists of a node and several line extenders. 10 homes passed are drawn for simplicity. The node consists of single downstream service group (DS-SG) and a single upstream service group (US-SG). At some point the operator determines that this node should be split. It would traditionally be done in the following manner shown in Figure 4 below:

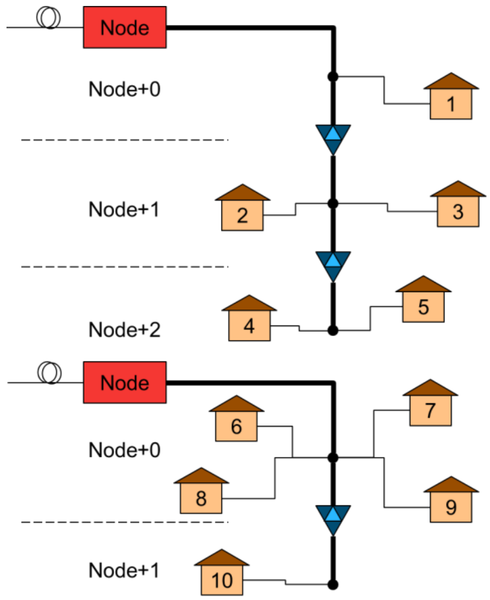

Figure 4 – Example Coaxial Cable Plant after node Split

A second node has been added and new fiber has been pulled to that node. After the split half of the homes are connected to the old node and half of the homes are connected to the new node. This type of split is typical. Operators may perform these splits in an as-needed fashion or they may proactively deploy a number of nodes at once in a fiber deep fashion [HOWALD].

A virtual fiber adaptor (VFA) is a device that takes in 10 Gbps Ethernet on one port and emits a radio frequency (RF) signal on another port. Essentially it is a media converter or bridge connecting Ethernet and RF networks. With a pair of VFAs a point-to-point 10 Gbps coaxial connection could be created such as the following in Figure 5.

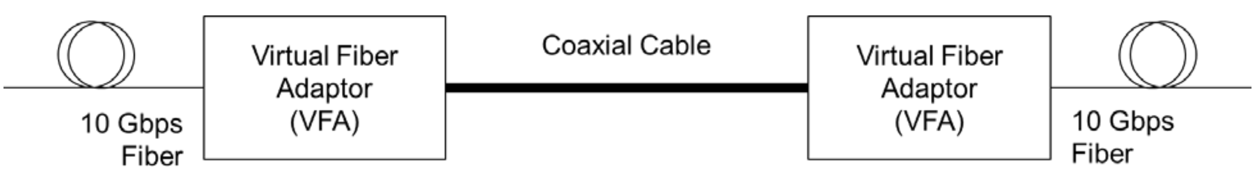

Figure 5 – Point-Point Virtual Fiber System

Virtual fiber signals can coexist with traditional HFC signals. In a typical deployment the RF spectrum of system will look like the following:

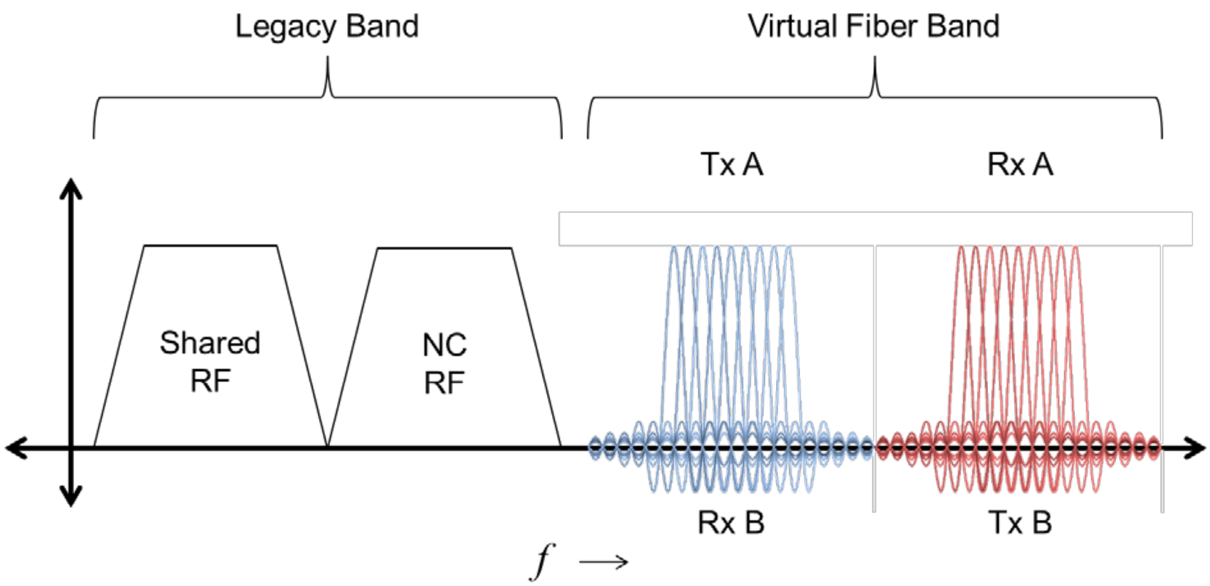

Figure 6 – Virtual Fiber Spectrum Example

From the above you can see that the virtual fiber band is divided in to two bands, Tx A and Tx B. This allows for simultaneous transmission and reception via frequency division duplex (FDD). Alternatively, a time division duplex scheme could be used. In the above example the first VFA, VFA A, transmits on the lower portion of the virtual fiber band, and the second VFA, VFA B transmits on the upper portion of the virtual fiber band. During link establishment the two VFAs can negotiate which portion of the spectrum they will use.

With virtual fiber the split network from Figure 4 can now look like the following:

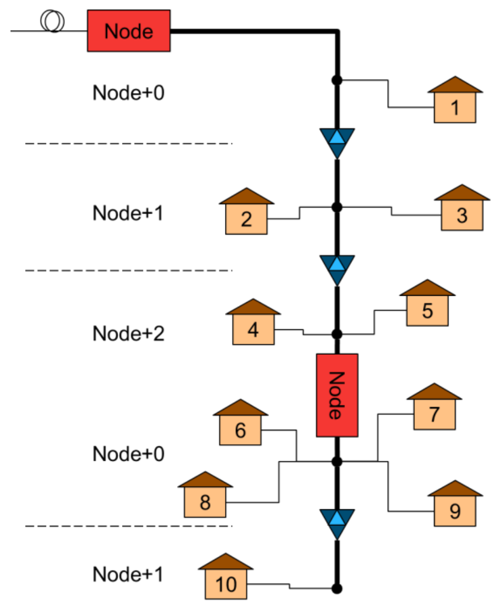

Figure 7 – Example Coaxial Cable Plant After Virtual Fiber Note Split

The network in Figure 7 is logically identical to the network in Figure 4. The same DS-SG exists in both. The difference is the RPD in the second node in Figure 4 is fed via fiber, whereas the same node in Figure 7- is fed its 10 Gbps link via the coaxial cable.

3. Overlay Virtual Fiber Example

In most if not all HFC deployments today there is a combination of broadcast or shared signals which are identical in frequency and content for multiple DS-SGs and there is a set of narrowcast (NC) RF signals which are unique in content for each DS-SG. The NC signals typically are at the same frequency in each DS-SG.

Prior to deploying virtual fiber and any node splits the existing cable plant is able to serve the needs of the attached subscribers for both broadcast and narrow cast services. Nodes splits are performed when the quantity of NC signals is no longer enough to meet demand. Increasing NC content is the driver for node splits. It is important to understand that the same broadcast signals that existed prior to the node split are usually adequate to meet demand for broadcast services after the node split.

Virtual fiber deployments can leverage the constant demand for broadcast services in a system by overlaying unique NC signals for each DS-SG, but simply repeating the broadcast signals. The block diagram of a virtual fiber node is shown in Figure 8. It shows the logical combining of signals for the first node in a virtual fiber system:

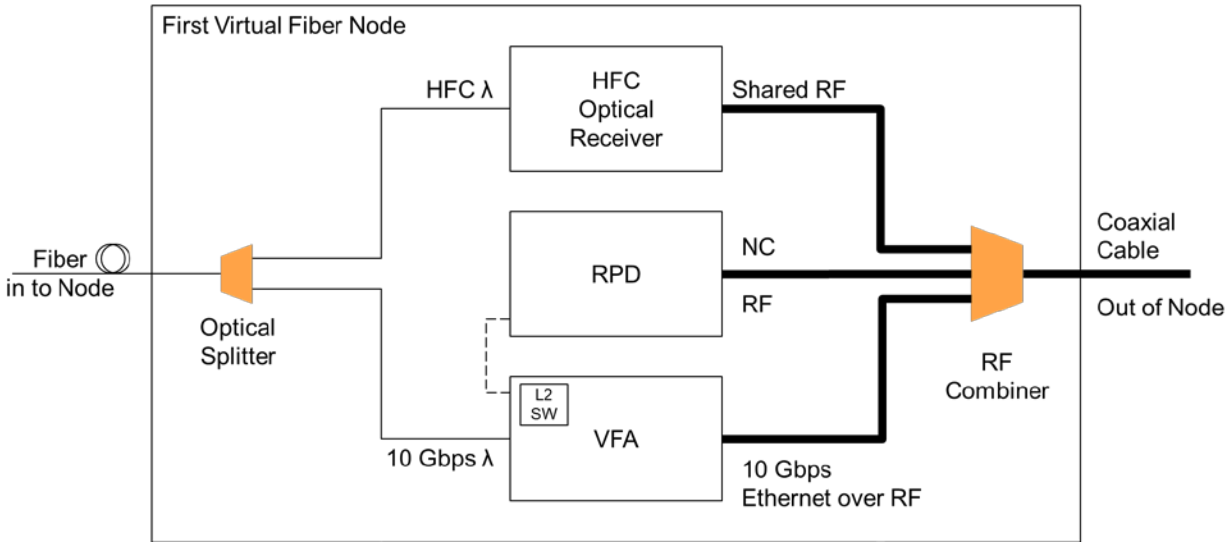

Figure 8 – First Virtual Fiber Node Block Diagram

In the above a layer two switch (L2 SW) has been added to the VFA. This allows packets to go to either the coaxial cable output of the VFA or to a second 10 Gbps port. In this example the second 10 Gbps port is the dashed line connected to the R-PHY device (RPD). This device is collocated in the same node housing. An HFC optical receiver is shown. It connects to a separate λ after the optical splitter. This λ is a carrying traditional analog modulated signal used in HFC systems and provides broadcast services in this instance. The optical receiver is optional if all the broadcast signals are digital as the RPD can generate both broadcast and NC digital signals. However, if the broadcast signal contains an analog TV signals then the HFC optical receiver would be required.

The second node in Figure 7 needs to receive the 10 Gbps signal sent by the first node and generate its own local RF signal. The following is the block diagram of this second node.

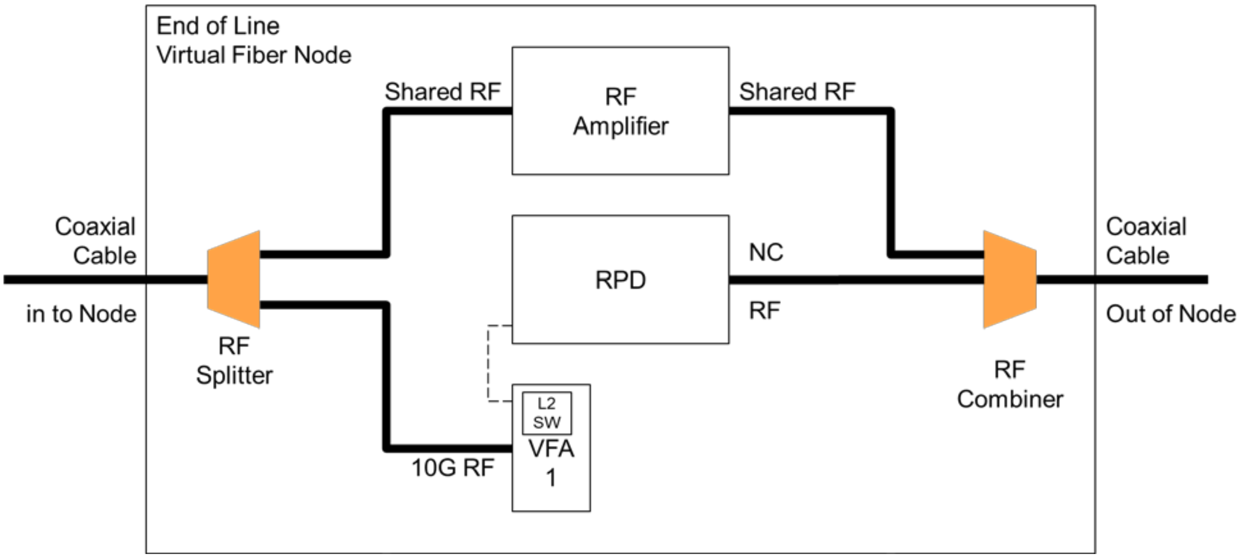

Figure 9 – End of Line Virtual Fiber Node Block Diagram

The block diagram above contains a VFA which receives the 10 Gbps signal and sends these signals to the collocated RPD. This RPD generates any NC for the local DS-SG. If the operator wishes to share any RF signals between the service groups this can be accomplished with the RF amplifier shown. As stated above an example would be broadcast video signals or analog video signals which cannot be generated by the RPD.

Note that Figure 7 only contains two nodes and two DS-SG. This is why the node in Figure 9 is titled "end of line." Many deployments will require more than two nodes and more DS-SG. To accommodate multiple DS-SG from a single coaxial plant an in-line virtual fiber node is used. Its block diagram looks like the following:

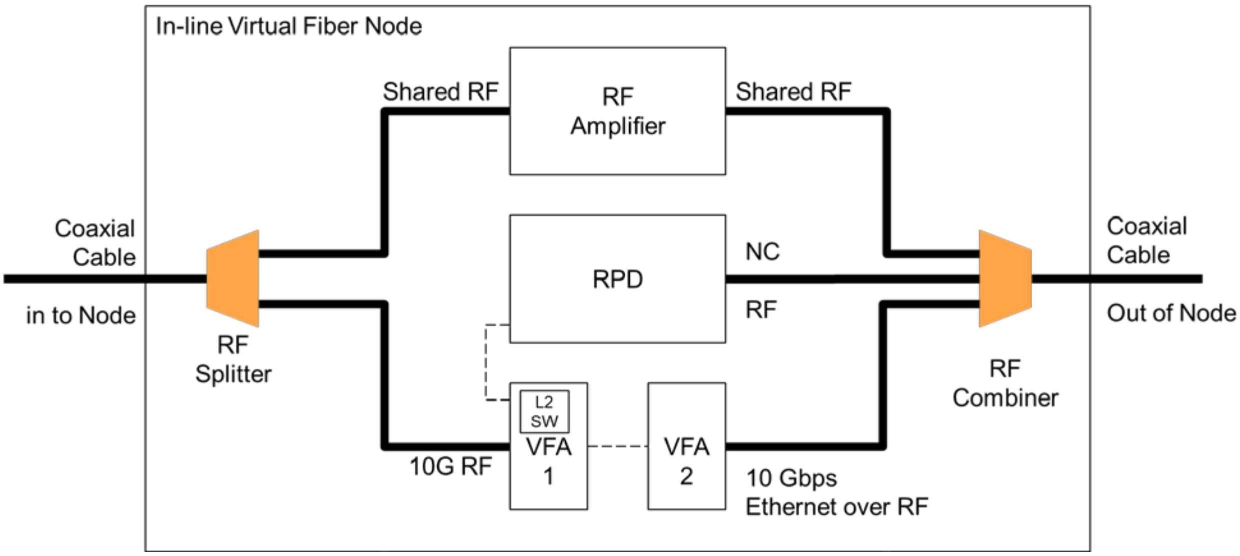

Figure 10 – In-line Virtual Fiber Node Block Diagram

The in-line node contains an RF amplifier for the same reason as the end-of-line node, but instead of a single VFA, a second VFA is used to propagate the 10 Gbps to the next node in the system.

The last component of a virtual fiber deployment that needs to be discussed is the virtual fiber line extender. In Figure 7 RF line extenders are shown in the network. These are two-way amplifiers and most likely they are limited to spectrum that does not include the RF spectrum associated with the virtual fiber band shown in Figure 6. Thus, in order for the line extenders to propagate the virtual fiber signals each will need to be updated. The following figure shows the block diagram of the line extender after it has been updated to become a virtual fiber line extender:

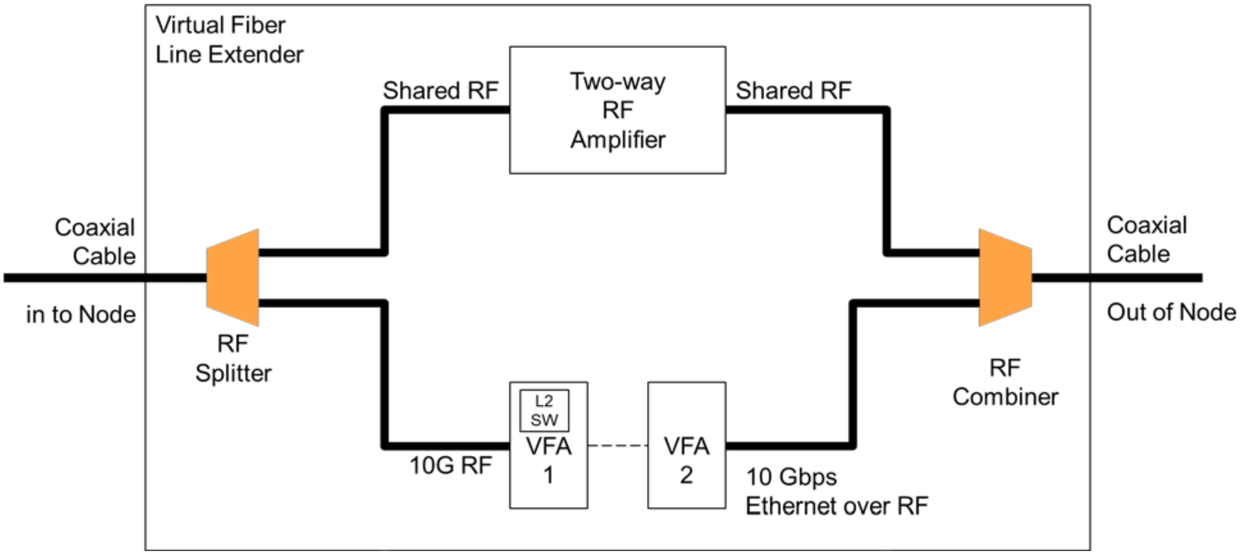

Figure 11 – Virtual Fiber Line Extendor Block Diagram

There is no RPD in the virtual fiber line extender. The coaxial cable before the line extender and after the line extender is part of the same DS-SG and US-SG. The RF amplifier in this case is a two-way amplifier as both upstream and downstream signals will need amplification. This is unlike the virtual fiber nodes where it is assumed the RPD terminates any upstream signals. Like the in-line virtual fiber node, there are two VFAs used to propagate the 10 Gbps virtual fiber signal.

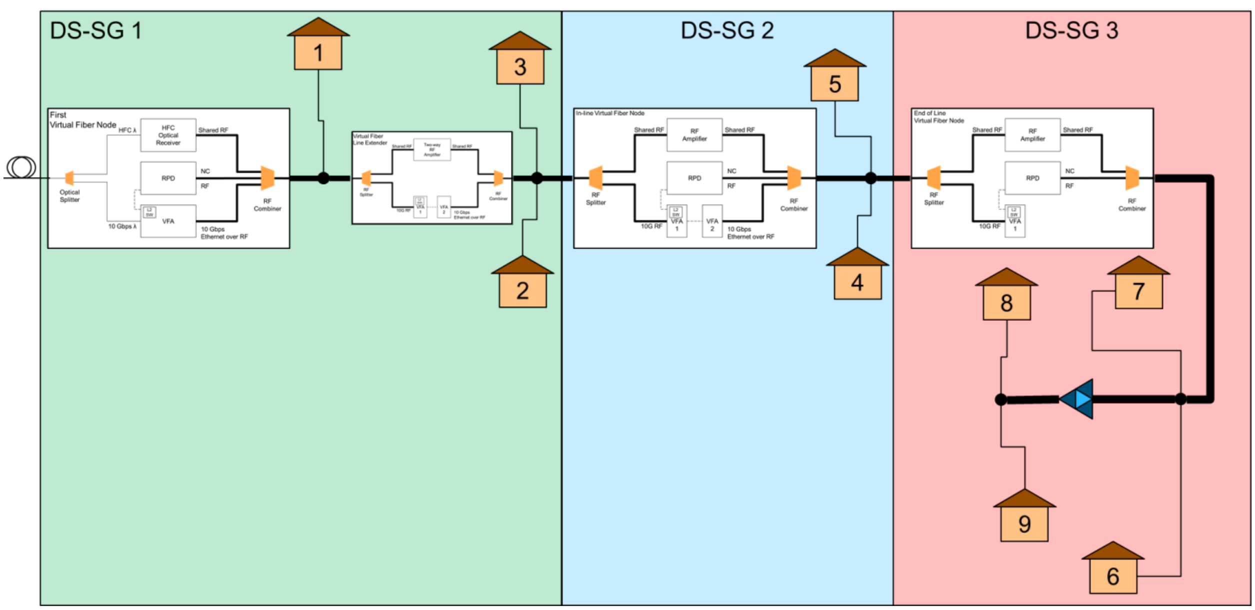

Figure 12 – Three DS-SG Virtual Fiber Network

Figure 12 represents a three DS-SG virtual fiber network that consists of all four elements discussed above. Home 1 is in DS-SG 1 and is serviced by a first virtual fiber node from Figure 8. Homes 2 and 3 are also in DS-SG 1 but they are farther away and a line extender is required to service them. The line extender shown is a virtual fiber line extender shown in Figure 11. After homes 2 and 3 there is an in-line virtual fiber node from **Error! Reference source not found.**. This node is tapping off of the virtual fiber 10 Gbps link on the coax to feed its RPD and generate the local NC signals for DS-SG 2. It serves homes 4 and 5. The last virtual fiber element is an end of line virtual fiber node from Figure 10. It serves DS-SG 3 and homes 6, 7, 8 and 9. It is also tapping off of the virtual fiber 10 Gbps signal. This signal and its bandwidth are shared between DS-SG 2 and DS-SG 3. The last active element in Figure 9 is a standard HFC line extender. It's needed to boost signals to homes 8 and 9; however, it does not need to be a virtual fiber line extender because there are no more consumers of the virtual fiber 10 Gbps signal after it in the network. Thus, a standard line extender will suffice.

4. Virtual Fiber and Timing

RPDs require timing synchronization with the CCAP core. IEEE 1588 and the precision time protocol (PTP) specified by it is used on 10 Gbps fiber links to provide the needed synchronization. PTP and how it relates to DOCSIS has been covered in depth by [JIN]. The reader should take away that a virtual fiber system supporting RPDs will need to support PTP and that this can be accomplished with the VFA acting as a PTP transparent clock. At a very high level, a layer two switch that supports a PTP transparent clock passes a PTP sync message from one port to the other ports on the switch. Since the time spent in the switch can be non-deterministic the switch provides the time each sync message was in the switch. It can do this either by appending the duration to the sync messages, or by sending a follow up message that contains the duration of time that the sync packet was in the switch.

5. How Fast can Virtual Fiber Go

Virtual fiber like all communication systems is speed limited by two main factors: spectral efficiency of the channel (bps/Hz), and the channel width (Hz). With available technology it is possible to readily achieve 10 Gbps bidirectional communications with a signal that is located above traditional HFC signals. Thus, both overlay and non-o verlay systems can be accommodated.

Achieving faster speeds up to around 25 Gbps can be accomplished simply via channel stacking. A brute force way to support channel stacking is by ganging multiple VFAs onto a single coaxial cable with each VFA's signal located at a different portion of the spectrum. However, advances in technology should allow a single VFA to support more MHz than the current generation and thus achieve 25 Gbps speeds in a single albeit wider channel.

While wider channels, either achieved via channel stacking or simply growing the MHz per channel, are interesting, there are diminishing returns. When using coaxial cable as a medium the system designer must deal with the fact that signal loss increases with the square root of the frequency of the signal. This can be overcome if the designer is willing to reduce QAM order and distance. [CLOONAN] shows that speeds of 100 Gbps are achievable, albeit for very short distances of about 100 feet.

Conclusion

Virtual Fiber allows for 10 Gbps symmetric links over coaxial cable in its initial form. With a proper VFA implementation virtual fiber will be transparent to the DAA devices which it serves including support for PTP. Thus, virtual fiber can support both R-PHY and R-MACPHY solutions. Faster data rates beyond 10 Gbps are possible with improved spectral efficiency and increases in total Hz used by the virtual fiber solution. This provides operators with a roadmap such that virtual fiber can be utilized to deploy cost effectively future proof R-PHY and R-MACPHY systems in areas where new fiber builds would be cost prohibitive.

While virtual fiber was initially conceived for high fiber cost areas, it can be used in typical HFC plants as an alternative to fiber. Virtual fiber is still in its infancy so it is not yet known if it will be effective or desired in all areas of the network. However, if virtual fiber is successful, there will be one less reason to replace coaxial cable with fiber and coax will continue to reign.

Abbreviations

bps	bits per second
CAA	Centralized Access Architecture
CIN	Converged Interconnect Network
CMTS	cable modem termination system
CSI	cable side interface
CTO	chief technical officer
DAA	distributed access architecture
DOCSIS	data over cable service interface specification
DS-SG	downstream service group
FDD	frequency division duplex
FDX	full duplex DOCSIS
FTTH	fiber-to-the-home
HFC	hybrid fiber coaxial
L2 SW	layer 2 switch
MAC	media access control layer
NC	narrowcast
NSI	network side interface
PHY	physical layer
PTP	precision time protocol
RF	radio frequency
R-MACPHY	remote mac-phy
RPD	remote phy device
R-PHY	remote phy
US-SG	upstream service group
VFA	virtual fiber adaptor

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