An All-Fiber Diet for Growing Cable Networks

(Fiber Deeper: Migrating from N+5 to N+0 HFC Networks)

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1 INTRODUCTION

We can all think of numerous creative or humorous euphemisms, puns or innuendos that could apply to the topic at hand. Instead, we'll just start with the simple statement: "Just like fiber is a good thing dietary-wise, the on-going introduction of more fiber, deeper into HFC networks will result in improved health for cable operator's business."

The migration from Node+n HFC networks is already taking place and is accelerating as we speak (the numeric digit in "Node+n" refers to the number of downstream amplifiers on the coax cable past the HFC fiber "Node"). Sub-dividing nodes to facilitate more bandwidth per subscriber or pushing nodes deeper to eliminate amplifiers are resulting in traditional "HfC" networks becoming "HFc". The natural evolution of those strategies is eventually for fiber cable to extend to the premises resulting ultimately in an "HF_{c} "network. There are two major types of technology (PON & Point-to-Point) which exist for "all fiber" access networks.

With careful planning network operators can start gradually, generate additional revenue, and move to continuously evolving levels of bandwidth and functionality. This paper will summarize the state of fiber access networks in North America (deployments, technology alternatives and benefits), the drivers for cable operators, and deployment scenarios and migration strategies for matching the technology with the application, with a focus on building for revenue – ensuring that network investments will begin generating revenue as quickly as possible.

2 ALL-FIBER ACCESS AROUND THE WORLD

The final step of existing "Fiber Deep" migration is all-fiber access or fiber to the subscriber, better known as Fiber to the Premises (FTTP) or FTTH ("H" is for Home). Worldwide, there are approximately 25 million FTTP subscribers of which about 90% are PON (Passive Optical Networks) and about 10% are Point-to-Point. Table 1 summarizes the breakdown of the approximately 4.4 million fiber access connected subscribers in North America of the 15 million or so homes that are passed by a fiber access network today.

Table 1
Fiber Access Deployment in North America

	BPON	EPON	GPON	Point-to-Point
Total Subs, 3/09	2.4M	0.2M	1.4M	0.4M
4Q ’08 Share	24%	2%	71%	3%

Source: RVA LLC / Broadband Properties, Infonetics

3 FTTP TECHNOLOGY ALTERNATIVES

The aforementioned two major types of technology can be categorized as follows:

- Point-to-Point
  - and its derivation using active switch nodes in the field called “Active Ethernet” (leading technology in Europe)
- Passive Optical Networks (PON) including:
  - BPON (2nd generation technology; deployments slowing or capped)
  - GPON (3rd generation technology; leading technology in North America)
  - EPON (leading technology in Asia)
  - DPON (DOCSIS compatibility overlayed on top of primarily EPON)
  - RF over Glass (RFoG)

Among cable operators, two technology choices initially have predominated, EPON (Ethernet Passive Optical Network) and GPON (Gigabit Passive Optical Network). One Tier 1 MSO uses GPON today targeting business subscribers (Cox). Several Tier 2/3 cablecos also use GPON for both business and residential applications. Buckeye Cable, Falcon Broadband and Prime Time are examples. One major Tier 1 MSO uses EPON for business customers (Bright House).

About two years ago, a new PON concept, called RFoG (Radio Frequency over Glass), emerged as a third option. Currently, RFoG has been deployed by Tier 2/3 cable providers and is being tested or trialed by most MSOs and dozens of other cable operators.

And, most recently, another derivative of the PON alternatives has been introduced: DOCSIS PON. This technology is now being tested within vendor and operator labs.

Point-to-point is selectively used by cable operators, as well as competitive access providers called CLECs (Competitive Local Exchange Carriers) and municipal government networks especially for business end-customers. It is much more popular in Europe due to demographic and other considerations significantly different from most operator situations in North America. This paper won't focus on this technology option. Suffice it to say, that it is primarily used when the situation is constrained by the following combination of characteristics:

- end subscribers are not very far from the Headend or POP/CO facility

and

- end subscribers are usually densely packed (i.e. business customers in pockets of concentration like office parks or multi-use/mixed-use urban developments)

and

- the service provider has easier access to electric power, land, facilities and locations where active electronics can be installed (reducing right of way and leasing entanglements) (i.e. city government or power utility)

or in some cases by

- end subscriber customers that are very security conscious or "anti-shared network" (usually use private line type services, i.e. banks, governments, etc.)

Even though there are numerous FTTP technology alternatives, the common factor is their use of fiber. This is because of the inherent benefits of networks that operate over fiber cables, whether on very long, backbone networks or shorter distance FTTP links.

4 BENEFITS OF FTTP NETWORKS

Very little argument remains that fiber to the subscriber is the ultimate network infrastructure. The advantages of fiber are well known:

- virtually unlimited bandwidth
- secure: intrusion is physically very difficult; nigh impossible with encryption
- quality: not susceptible to interference from EMI sources or noise build-up
- reliability
- fiber connected subscriber have greater proven service satisfaction
- forward compatible outside plant: built to parameters such as 20km reach and 1:32 splits (or 1:64) supports current RFoG/PONs as well as the next generation
- cost per bit transmitted (example: $0.7 - $1.0/Mbps GPON; $10/Mbps QAM)
- operates without amplification over large distances (maintenance, opex savings)
- environmentally friendly

Due to space constraints, I'll only briefly touch on three of the above qualities, the first one and last two.

4.1 Bandwidth Scalability

Considering bandwidth scalability, Table 2 below summarizes the state of electronics technology that drives fiber or coax cables in service provider networks. In the coming years, fiber will support multiple Terabits per second. But considering this paper's focus on access networks, the comparison shows that "Current Technology" can economically support from 2.5Gbps or 10Gbps in fiber access networks to 1.2Tbps in fiber metro or long-haul networks. In contrast, DOCSIS 3.0, which is transitioning from the "State of the Art" stage to becoming a "Current Technology" within the next year or two, supports 150Mbps over coax.

Table 2
Technology Bandwidth Capacity

Technology Level	Transport Fiber (metro, long-haul)	Access Fiber	Access Coax
Current[1] Technology	1.2 Tbps (120 λs x 10Gbps)	20G[3] / 10G / 2.5G (WDM[4] / P2P[5] / PON)	150 Mbps (DOCSIS 3.0)
State of the Art[2]	8 Tbps (80 λs x 100Gbps)	160G[6] / 100G / 10G (WDM[4] / P2P[5] / PON[7]	10Gbps (1024QAM @ 1Ghz)

1 Generally accepted, widely deployed technology

2 Lab test, "hero" experiment, field trial, advanced technology

3 8 λs X 2.5Gbps or 16 λs X 1Gbps

4 WDM of Point-to-Point Ethernet or of EPON/GPON

5 Point-to-Point (optical Ethernet)

6 16 λs X 10Gbps

7 Next Generation PON (NG PON): either 10G EPON or 10G GPON.

4.2 Long Distances Without Amplification: Maintenance & Opex Benefits

Because fiber can extend for considerable distances without amplification, "passive" optical networks (PON) offer a tremendous opportunity to save money in amplifiers, power and maintenance. For instance, the need to sweep, balance or tune the HFC network is eliminated. Table 3 shows one comparison of total operating costs for field maintenance. RFOG and PON FTTP solutions realize a 2.5X savings compared to FTTN deployments and 7X lower costs versus HFC. Other sources, including cable operators own studies, confirm similar savings or even higher. Also, a study by The Broadband Group showed a reduction in opex costs of 6X – 7X for networks extending fiber all the way to the premises.

Table 3
Field Maintenance Cost Comparison

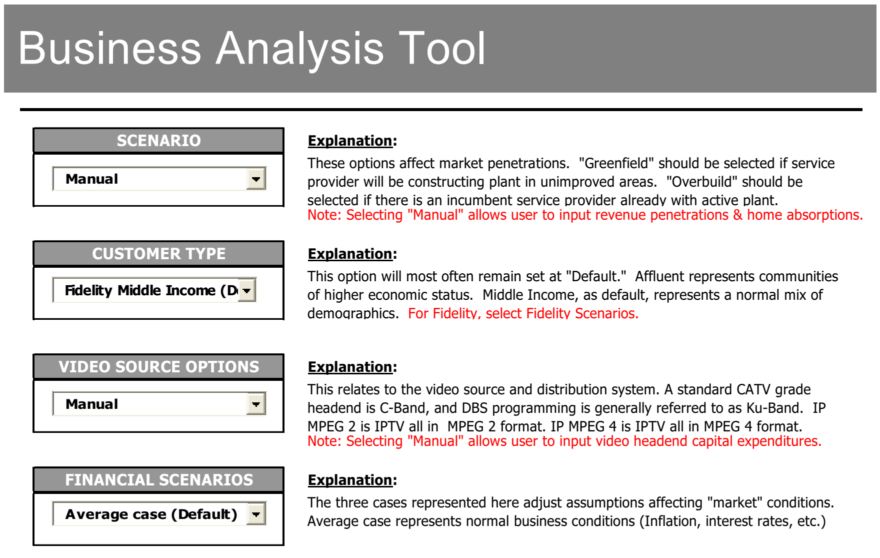
Characteristic	HFC	FTTN	RFoG/PON
Power Supplies	55	20	0
RF Amplifiers	1,100	0	0
Optical Nodes	33	200	0
Total Active Devices	1,133	200	0
Actives per Mile	>5	~1	0
Cascaded RF Amps	5	0	0
Network Availability	99.98	99.995	99.995
Power Cost (10 years)	$564,170	$278,373	0
Maintenance Cost (10 years)	$871,500	$229,500	$208,850
Total Operating Cost (10 years)	$1,435,670	$507,873	$208,850

Source: Heavy Reading / Hitachi

Hitachi has developed modeling tools to help operators analyze and project the feasibility of FTTx network deployment options. As an example, Hitachi uses a tool that provides estimates for capex, opex, ROI and other factors required to develop a business analysis and ROI projection. Inputs include multiple cost factors such as take rates, demographics, geography, etc. Some available variables of this tool are listed below and Figure 1 shows one of the input pages:

- Number of homes and distribution (urban/rural)
- RF plant type (550 MHz, 750/860 MHz, 1 GHz)
- Penetration rates
- CMTS details
- Nodes
- Amplifiers
- Cable characteristics and outside plant configuration
- Powering cost

Figure 1



This tool is designed to compare HFC networks against RFoG and PON options, including migration from HFC to RFoG. Outputs include comparisons such as the following shown in Figure 2 and Figure 3:

Figure 2

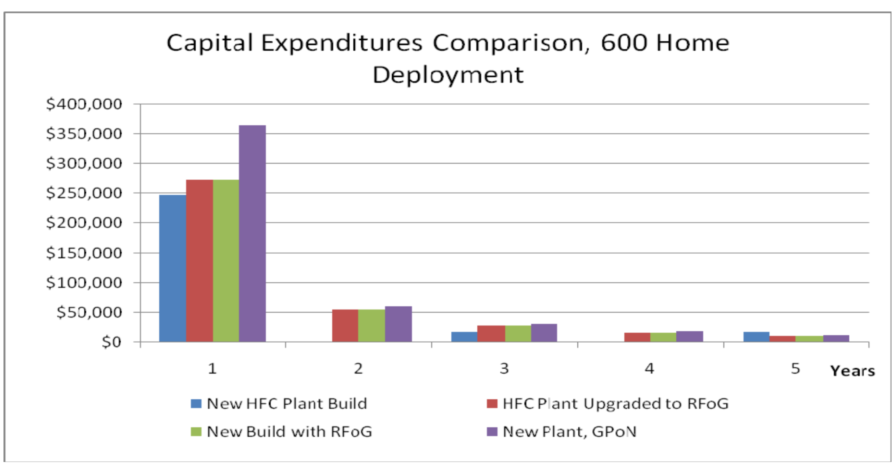
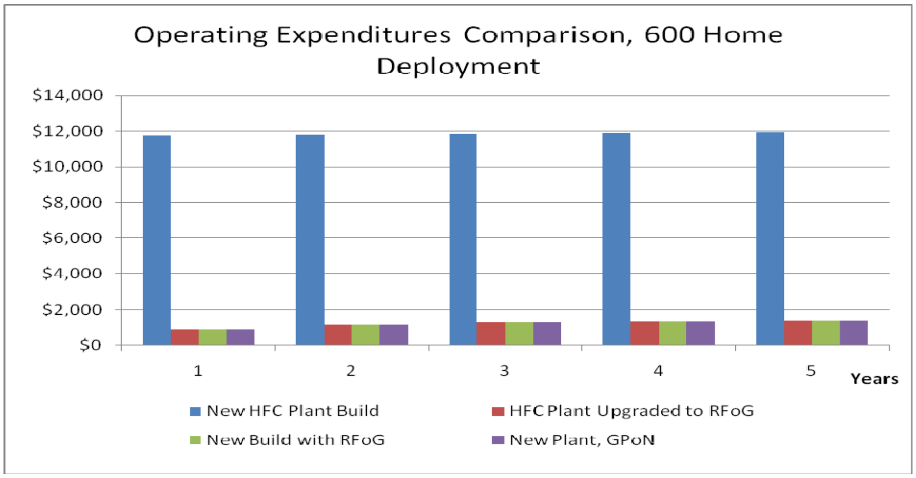


Figure 3



4.3 Environmental Considerations

Finally, another significant advantage of FTTP is that it has large benefits environmentally. In this age of increasing need to reduce environmental impact, including scrutiny of consumptive and emissions generating activities, the long-term benefits of fiber technology will become increasingly important. For a sample network of 24 subscribers as shown in Figures 4 and 5 below, the savings in electricity generated and associated CO_2 emissions is summarized in Table 4. Since approximately 70% of all electricity generated in the USA is through fossil fuels (coal, natural gas, oil), this comparison was based on calculations for electricity generated using coal.

Figure 4
HFC Sample Network

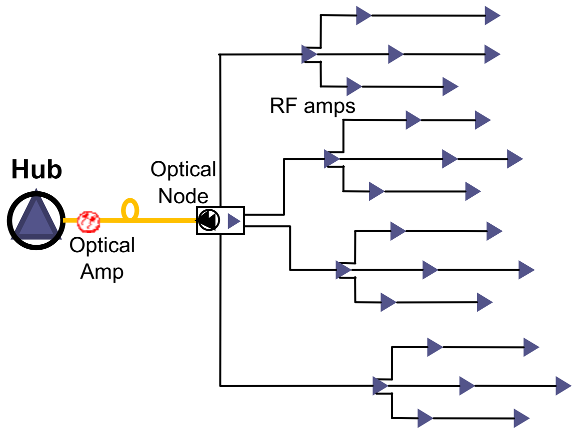


Figure 5
FTTP Sample Network

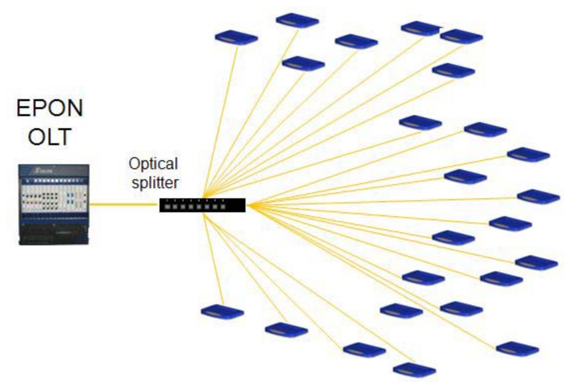


Table 4
Electricity Consumption and CO_2 Emissions Comparison

	HFC	PON
Number of customers	24	24
Number of ONUs	–	24
Number of active devices	12	0
Electricity per plant mile per year ($)	$446.81	0
Electricity per plant mile per year (KWh)	2,482.28 KWh	0
CO_2 generated per plant mile per year (lbs)	2,565.62 pounds	0
CO_2 generated per year, sample network (lbs)	30,787.44 pounds	0

5 DRIVERS OR MOTIVATORS FOR FTTP DEPLOYMENT

Besides the basic technological advantages of fiber based networks, there are several market conditions that are motivators for cable operators to start selective deployments of FTTP. These drivers would include:

- Optimal cost/performance solution for greenfield construction
- Solution in response to real estate developer demand for fiber to the home
- Responsiveness to competitive service provider threats
- Addressing the changing demand of users and changing nature of CPE
- Availability of Broadband Stimulus funds
- Expanding triple play services to low density, or rural, or outlier customers
- Strategy to increase market share and revenue from business customers
- Addresses SMB and the increasing number of “power” or “super” users
- Addressing niche high bandwidth demands (like cell backhaul or 4G femtocell)

I’ll expand on the first set of these drivers. The last three will be covered in the final section of this paper on how to selectively and incrementally evolve from today’s HFC networks to all fiber in the access network.

5.1 Greenfield Construction and Real Estate Developer Demand

Since fiber cables are significantly cheaper than coax, the generally agreed strategy is to use FTTP as the best solution for greenfield, new construction situations. Real estate and master planned community developers recognize that the value of a single family home goes up when it is served by a fiber broadband access network. A FTTH Council sponsored RVA LLC study concluded that home values increase about $5000 when they are fiber connected. Therefore, starting around 2005 or 2006, increasingly these developers were insisting that either telco or cableco service providers install fiber access in order to serve their new subdivisions or communities. This was probably the main driver that initiated cable operator interest in analyzing FTTP alternatives. However, with the economic slow down and housing credit crunch in North America, housing starts have dropped to one-third of their historic levels. But in the last 5 months housing starts have been on the increase (about 30%). So it is realistic to expect that soon service providers will again be facing, with regular frequency, demands from real estate developers for fiber to the home build outs in new communities.

5.2 Competition

As highlighted in Section 2, FTTP build outs in North America continue to grow at a pace much faster than any other broadband access technology. It is estimated that about 25 million homes will be passed by fiber within three years. And the homes "connected" take rate has increased from 25% to 30% within the last year. This forecasted growth of FTTP is not just due to a few large telcos. About two-thirds of Tier 2/3 telcos that are not currently already deploying FTTP plan to do so within the next three years. So the competitive pressure will be increasing from large telcos, smaller telcos, CLECs and municipal networks.

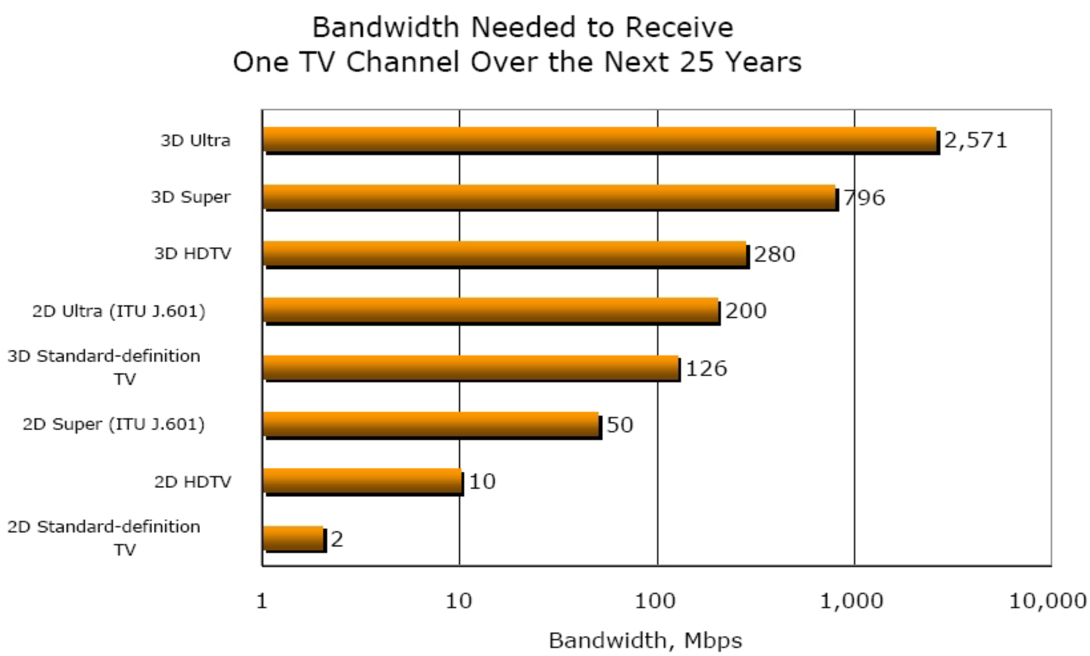
5.3 Bandwidth Demand: The Changing Nature of Users, Applications, CPE

End users, the applications they use, and the types of CPE in the home continue to evolve. New applications with increasing popularity, such as Skype with video, place higher bandwidth demands especially on current broadband technologies with limited upstream capacity. And users will be attracted to better quality video and audio. Social networking with video/photo sharing, peer-to-peer applications, videoconferencing and telepresence will likewise have similar effects on data rate requirements from end users. And the service provider(s) who offer bandwidth to support the best quality (bandwidth and error rate) will have a significant competitive edge. The changing nature of CPE in the home is also raising demand for higher data rates both downstream and upstream. Examples would include:

- more sophisticated and powerful home routers
- more common availability of 1GbE ports on PCs
- higher capacity WiFi access points in the home
- terabyte storage drives

not to mention, the availability of 4G femtocells on the technology horizon. Also, the nature of consumer electronics devices continues to change. The on-going decrease in pricing of high definition TV sets with large sizes and thinner cases continues to drive HD TV adoption rates and homes with multiple HD sets. And neither the consumer electronics industry nor the content/entertainment industry is content with the recent acceptance of HD. The advancement of even higher quality video technologies continues within R&D labs and standards organizations. Figure 6 summarizes the bandwidth that will be required from these new, developing video formats. Super HD TV will start appearing in a few years. And further into the future . . . . . just imagine the equivalent of R2D2 projecting Princess Leia into your living room: "Help me, Obiwan Kenobi!!!"

Figure 6



Source: FTTH Council

5.4 Broadband Stimulus Funding

Finally, another imminent, short term factor driving the advent of FTTP networks will be two different federal government activities. The combined $7.2B Broadband Stimulus funding projects of the National Telecommunications and Information Administration (NTIA) called BTOP (Broadband Technology Opportunities Program) and the Rural Utilities Service (RUS) named BIP (Broadband Initiatives Program) will provide additional impetus for fiber based deployments especially for cable operators in smaller communities. Since the leading objective of Congress was clearly jobs creation, no other type of broadband project or technology can compare to fiber deployments considering the need for outside plant work. The approval processes for funds under those programs include weighting factors favoring projects that will create more jobs. So the current timing of many construction companies aggressively seeking work projects (with lower pricing) coincident with federal funds availability makes this an especially good time for cable operators in non-major metro areas to consider FTTP.

6 DEPLOYMENT SCENARIOS AND MIGRATION ALTERNATIVES

Much discussion continues about RFoG and PON options, with the prevailing opinion being that RFoG is a "bridge" technology, pending widespread implementation of PON. The reality may prove to be something else. Subscribers are not all "made from the same cloth." Many residential subscribers want only basic services, while businesses want higher bandwidth services with guaranteed quality of service (QoS). And there are special cases of both residential (like high density MDU) and business applications (like MTU or cellular network backhaul) that introduce additional variables or requirements. How do you deploy an infrastructure that meets these disparate needs yet is economical to build and maintain? The answer may be a hybrid of RFoG and PON. Before describing how to evolve the network using these technologies, let's briefly summarize the salient points of each.

6.1 RFoG

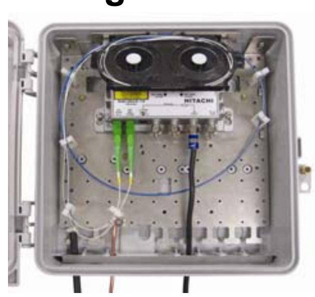
Simply, RFoG replaces the coax connection from the HFC node to the subscriber's premises with fiber. But all the existing headend and customer premises investment of the cable operator is maintained. This is the natural evolution of Node+5 reducing to Node+3 or Node+2 to ultimately Node+0. The immediate benefits realized being the opex and maintenance cost savings discussed previously as well as the security, quality, reliability, and environmental advantages.

RFoG is being standardized within the SCTE's Interface Practices Work Group 5. The IPS SP 910 standard is expected to be ready for approval near the end of this year.

An RFoG customer premises device (Optical Network Unit or ONU) is typically significantly less expensive than a PON Optical Network Terminal (ONT), and the headend equipment is simply a series of optical receivers and transmitters and electronics that convert the optical signal to and from RF at the headend. RFoG is, in most cases, transparent to DOCSIS and CMTS signaling taking place between the headend and the subscriber's set top box, cable modem and voice modem. A typical example of an RFoG ONU is shown in Figure 7 and Figure 8.

Figure 7

Figure 8



The disadvantage of RFoG is that it does not provide additional bandwidth over what was provided via coax in the original HFC configuration - most of today's RFoG devices provide around 1 GHz. However, on closer examination, is that so bad for a subscriber who only wants today's services? And with DOCSIS 3.0 coming online, additional bandwidth can be provided for the average user.

6.2 PON (EPON, GPON)

EPON is an efficient and IEEE standards-based solution for providing 1Gbps Ethernet links to subscribers derived from common Ethernet technology. Newer variants have been announced that provide DOCSIS functionality over EPON facilitating use of existing DOCSIS management and operations systems. DOCSIS managed GPON may also appear on the market as well. DOCSIS PON, EPON or GPON systems can coexist with RFoG systems and existing HFC networks, allowing cable operators to tailor their networks for maximum revenue potential versus lowest equipment and maintenance cost.

Like EPON, GPON operates over the same outside plant configuration as RFoG, with a 20km reach and splits of 1:32 or 1:64. GPON is a standard published by the ITU, a branch of the United Nations (UN). GPON differs from EPON in that the downstream data rate is 2.4Gbps and the upstream is 1.2Gbps. The GPON standard includes a transport protocol known as GPON Encapsulation Mode (GEM) that allows protocols such as Ethernet and TDM to be transported in their native formats as well as providing better packet throughput efficiency than other PON standards or GPON's predecessor BPON (Broadband PON), an ATM-based technology.

Next generation versions of EPON and GPON are currently being developed by the IEEE and ITU respectively. They will use today's outside plant configuration for RFOG or EPON/GPON and provide additional capacity by moving to 10Gbps transport or by implementing WDM techniques

6.3 Deploying RFoG

Figures 9 and 10 show the transition from an existing HFC network to RFoG. At the output of the Combiner, transmitters/receivers are added which convert the RF downstream/upstream signal to optical. These optical signals are then combined over upstream and downstream wavelengths by a Wavelength Division Mux (WDM). The coax cable is replaced with fiber, amps and taps are removed in the outside plant and their functionally replaced by a passive optical splitter. An RFoG module or ONU (Optical Network Unit) terminates the fiber at the premises and converts the signal back to RF on coax. The existing CPE in the home remain unchanged. Even though super high bandwidth capable fiber is in place, the services offered continue to be based on DOCSIS capabilities provided through the cable and voice modems in the premises.

Figure 9
Traditional HFC Network

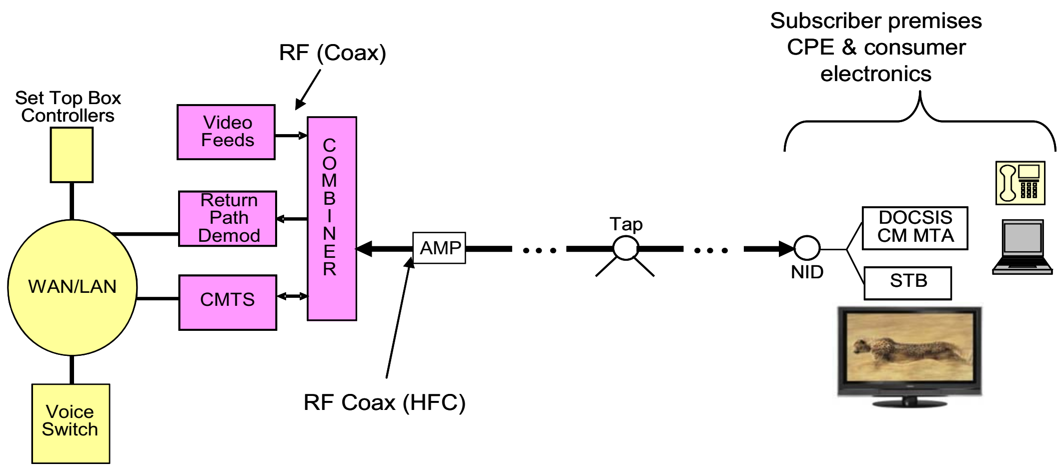
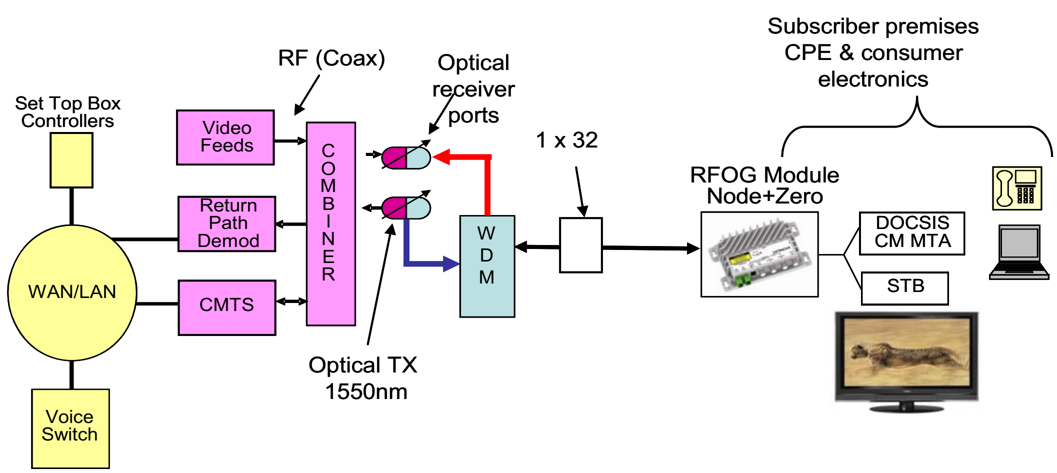
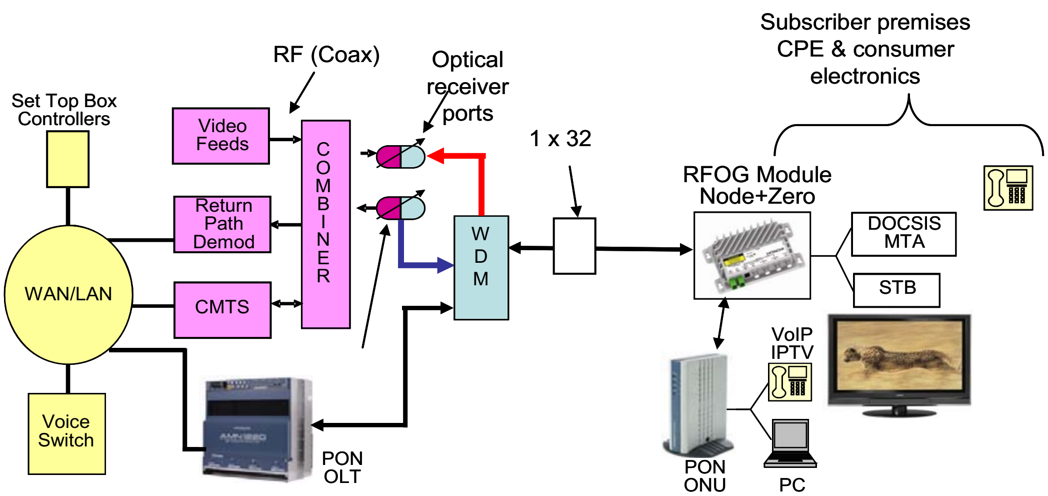


Figure 10
RFoG Network: Replacing HFC Coax with Fiber



When the cable operator wants to offer significantly higher data bandwidths, a PON OLT and ONU combination can be introduced as shown by Figure 11 providing 1Gbps throughput capacity by replacing the cable modem. In addition to supporting much greater high speed Internet services, the PON ONU GbE port can also handle very large volumes of IP video as cable operators choose to introduce it. However, existing voice and video CPE (STB) can stay the same or migrate to ONU types which have voice and/or RF video ports.

Figure 11



6.4 Scenarios for Using RFoG, PON or both

One size does not fit all when it comes to applying FTTP technologies in cable operator networks. There are several scenarios for introducing FTTP. Other than deployment situations described in Section 5, the best cases for FTTP briefly listed earlier include:

- capturing more business customers
- addressing special high bandwidth applications like cell backhaul
- targeting high end residential users

Figures 12 thru 16 demonstrate one sequence of deployment phases that address all three of the scenarios above. First RFoG is deployed to a selected area to gain maintenance savings benefits or provide fiber based business services with DOCSIS over RFoG.

Figure 12

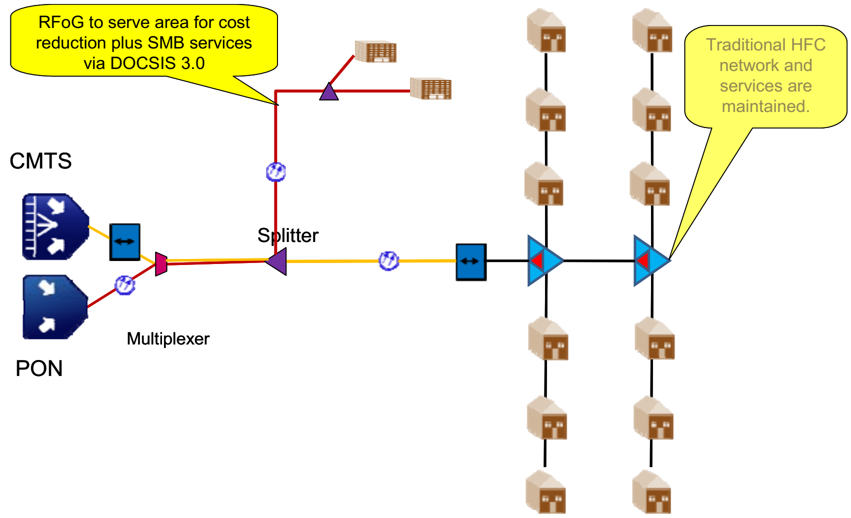
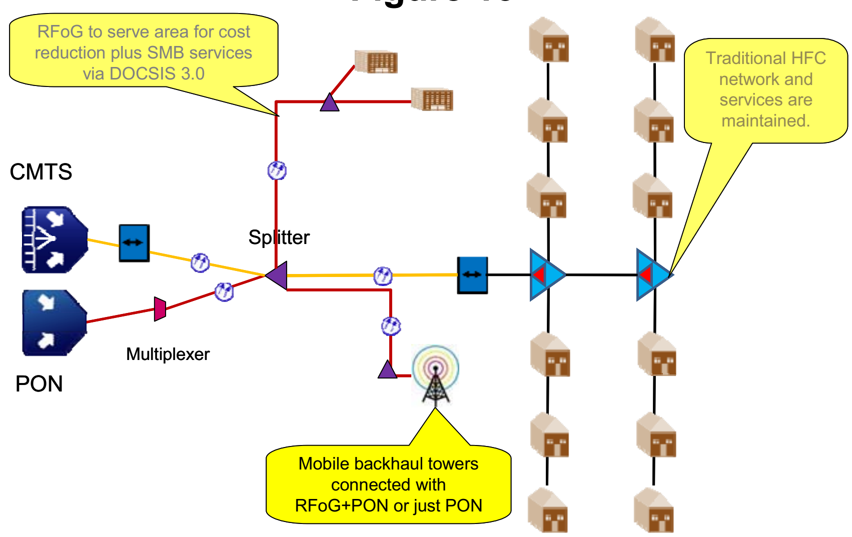


Figure 13 then shows the introduction of RFoG with a high-speed PON data ONU or PON alone to provide cell backhaul services.

Figure 13



In the next Figure, business customers near the cell tower site(s) are added onto the passive fiber network with the option of providing triple play services via DOCSIS over RFoG or via PON ONUs and a DOCSIS managed OLT.

Figure 14

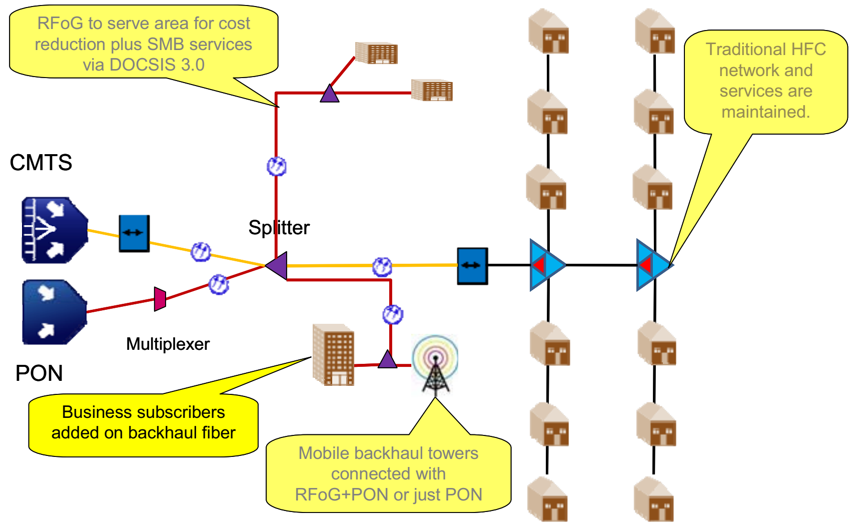
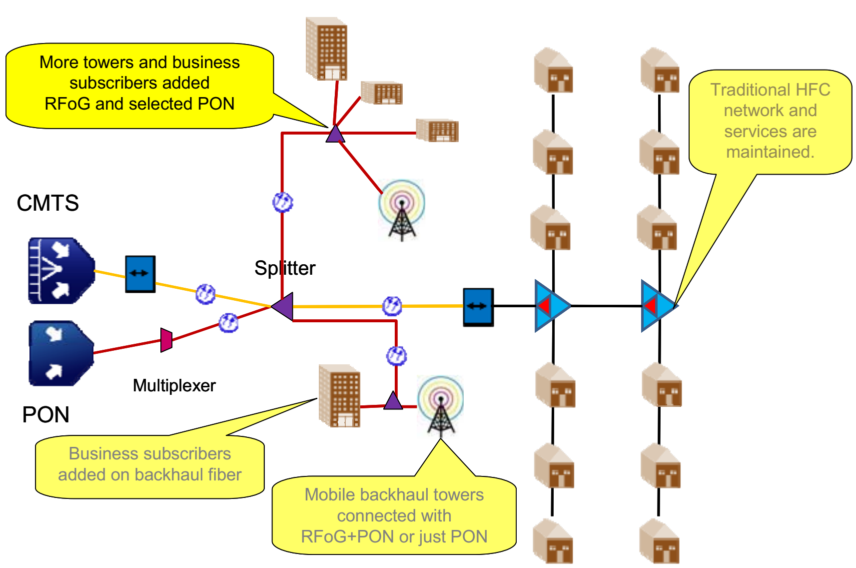


Figure 15 shows businesses and cell towers being added. DOCSIS triple play services can run over RFoG, or higher speed data services can be provided via PON with voice and video via DOCSIS, or all services can be provided from a triple play PON ONU.

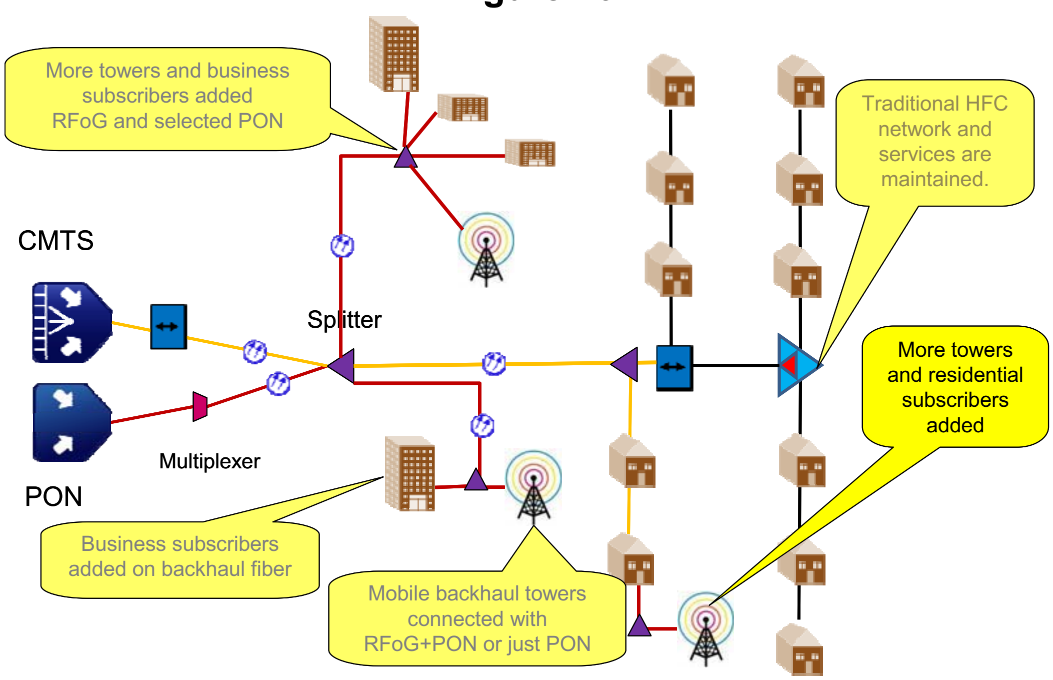
Figure 15



In the later case, the triple play ONU replaces the RFoG module, data ONU and DOCSIS CM/MTA (see Figure 11). Options exist for the PON ONU to support coax RF connections to standard STBs or to provide 1Gbps Ethernet connections to IP STBs. Also, looking to the future, there are proposals to implement the high speed data interfaces and voice interfaces in the ONU to mimic DOCSIS CM/MTA functionality.

Finally, Figure 16 represents build out of fiber to select residential areas either based on service demands of higher end subscribers or due to the critical mass of fiber connected businesses and cell sites in that area already.

Figure 16



The sequence described above can be varied or the target application can be rearranged to meet the specific needs of each cable operator's situation or region of coverage. Having several technology options like RFoG or PON which operate over the same outside plant network design gives service providers great flexibility in migrating to FTTP in incremental, selective fashion based on specific economic, competitive, revenue growth, or cost savings reasons. With the fundamental benefits of fiber and the technology lighting it up, each step the cable operator takes towards pushing fiber deeper in the network will position it for healthy business now and in the future.

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