Making FTTH Compatible with HFC

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Abstract

The evolution from Hybrid Fiber-Coax (HFC) to Fiber-to-the-Home is explored. The similarities between the technologies are noted, and we show how an operator who has been deploying HFC can start to deploy FTTH where it makes sense to do so, without excessive investment.

INTRODUCTION

Cable operators are starting to deploy fiber-to-the-home (FTTH) in Greenfields, as well as for business applications. The preferred deployment strategies employ one of two standards for FTTH: EPON or GPON. This paper applies to both. Since the FTTH deployments are small compared with the HFC deployments, it is important that minimal or no changes to the operator's processes or headend technology are necessary in order to integrate the new with the existing.

This paper will review recent experience in integrating FTTH into HFC systems. We'll cover such topics as data management, video in the two systems, and how voice is handled. There are certain architectural features of FTTH systems that can ease the initial cost of deployment. These features will be explored, showing how to make as much of the deployment cost as possible be based on success.

Cable TV HFC networks are much better equipped to provide all modern residential telecommunications services than are the telephone company's twisted pair networks. Therefore, we expect that cable operators will continue to use their HFC plants for some time where they exist now. However, HFC is not competitive with FTTH networks that are being installed now, so we recommend that cable operators seriously consider installing FTTH for Greenfield situations, where they must install something anyway. We shall show that it is easy to operate systems that are partially HFC and partially FTTH.

WHAT IS FTTH?

You can think of FTTH as the logical extension of HFC networks. Cable operators for years have been pushing fiber closer and closer to the home, to enjoy the benefits of greater quality and reliability, and lower maintenance costs. FTTH represents the end game, where fiber has been pushed down to a node size of one home. When fiber is pushed this far, some interesting changes to the way the fiber is used are possible. In FTTH systems:

-One fiber carries downstream and upstream signals, minimizing splicing/connection costs.

-Data is carried on separate wavelengths from RF, resulting in incredible data bandwidths without having to sacrifice any video spectrum. Since data is carried on separate wavelengths from RF, RF spectrum is freed up for more video. There is no tradeoff between data bandwidth and the bandwidth available for video. The entire RF bandwidth from 54 to 1,000 MHz is available for video.

-Reliability is enhanced due to the complete lack of coax in the plant. There are no corrosion issues, no mechanical pull-out issues, no cracked shields, no sheath currents, etc.

-While we are not going to advise you on legal matters, we note that the maximum RF signal level occurs at the side of the home, and is typically less than 20 dBmV. Thus, we would not expect composite leakage index requirements to exist.

-There are no amplifiers to balance: the response you get at the headend is the response you get at the home. Always.

-As shown below, the manner in which upstream signals are handled results in no upstream noise funneling.

-Since the plant is all-dielectric, there is no ingress into the plant.

-Typically there are no actives in the field, and no power connections. Reliability is increased and maintenance is reduced.

-Service disconnect is an integral part of many FTTH systems, removing the need for truck rolls when a subscriber disconnects or connects.

-Expensive CMTSs are not needed in most cases. Data connections are usually gigabit Ethernet to your headend switch.

-Systems come with integral element management – it is not an extra-cost add-on.

-With the exception of the set top box, all equipment is normally located outside the home, where the operator has access. The outside equipment is normally powered from the home (with battery backup for lifeline voice), minimizing the operator's electric bill.

-The FTTH network is architected to carry IPTV should the need arise. IPTV and broadcast video may be carried at the same time.

TYPICAL FTTH ARCHITECTURE

Figure 1 illustrates a typical FTTH physical architecture. The video headend is just as it is for HFC. The voice facility is not changed from HFC – FTTH networks can support the same protocols specified by CableLabs. The switch(s) used to interconnect data in the headend are the same: Gigabit Ethernet links are usually used to connect to the FTTH equipment. No CMTS is needed for the FTTH portion. A new unit, called an Optical Line Terminal (OLT) is used as the data interface with the FTTH plant. Logically, you can think of it taking the place of the CMTS, though the analogy is not precise. A typical OLT is pictured, and serves up to 2300

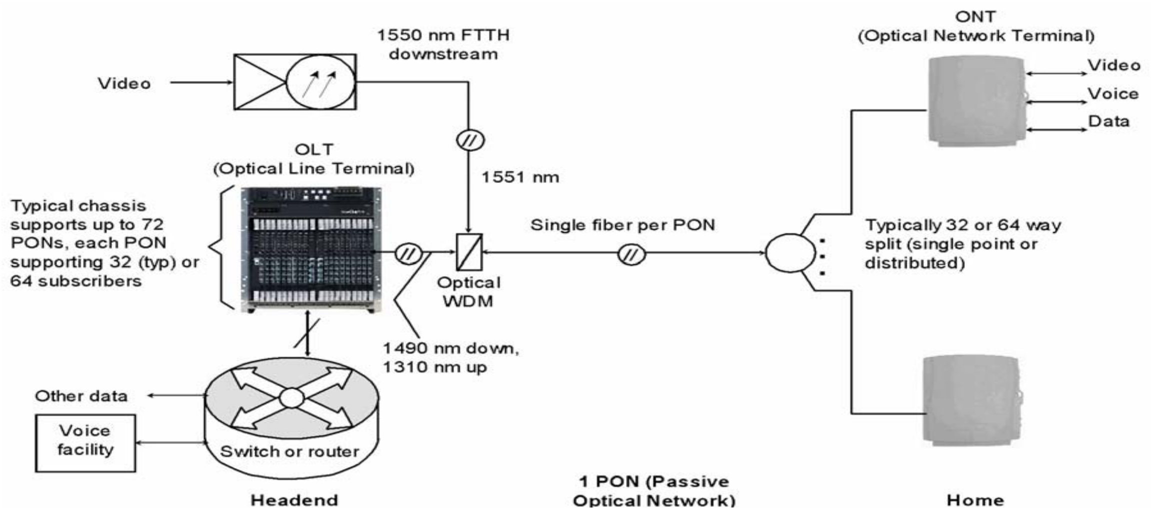

Figure 1. Typical FTTH Architecture

subscribers in a typical configuration, in under 1/3 of a standard rack. That gives you up to 6,900 subscribers served per rack.

The video headend drives an externally modulated 1550 nm optical transmitter, whose output is split and amplified (not shown) as necessary to supply signals to all subscribers. Only one transmitter is normally needed. The output of the 1550 nm transmitter is wave division multiplexed (WDM'ed) with the data carriers handled by the OLT. Standard wavelengths used in FTTH systems are downstream data on 1490 nm, upstream data on 1310 nm, and video on 1550 nm (any suitable standard ITU wavelength).

Normally the network to the home is all passive, consisting only of single mode fiber optic cable of the type cable systems normally use, and passive splitting. Distributed splitting (taps) can be used, but it is more common to use concentrated splitting, where all splitting is done in one or two locations. The network between the headend and the home is called a passive optical network, or PON. While it is technically feasible to serve 64 subscribers per PON, serving 32 subscribers per PON is more common. The cost differential, while not zero, is not great.

The termination at the home is called an optical network termination, or ONT. A number of different ONTs are available, but the workhorse configuration is a box that is mounted on the side of the home. It has an RF output for video, one or more data ports (10/100Base-T), and one or more voice ports (RJ-11 with terminal block). RF return support for set top upstream communications is available from some vendors. All ports are controlled through the element management system (EMS), and may be remotely turned on and off. The ONT is usually powered from a power supply mounted in the home. Configurations are available that allow mounting the power supply outside of the home, and taking power from a special ring installed on the power meter. Power can be taken either before or after the meter. If lifeline voice service is provided, a battery is used to provide a minimum of 8 hours standby/2 hour talk time. The battery condition may be monitored through the EMS.

Other configurations of ONTs may be available. For example, a video-only ONT may be available for customers who take basic video only. For business applications, there may be small, indoor-only ONTs that provide data ports only. Some ONTs provide only one data port and one voice port. Other ONTs provide multiple ports. Finally, ONTs designed for multiple dwelling units (MDUs) may be available, with ports to serve several apartments from one ONT. All ports are controlled through the EMS.

THE ONT RF PORTION

Figure 2 illustrates the ONT with some optional features included. The single fiber from the PON enters the ONT at an optical wave division multiplexer (WDM). The top port of the WDM passes the 1550 nm broadcast signal to a broadcast RF receiver not unlike the receiver portion of an HFC node. The output level is usually set to allow several TVs to be connected. Levels of +12-18 dBmV are common. Recall that the ONT is mounted on the house, so this level exists at the side of the home, not at the pole. AGC is often used to compensate for optical level variation. The AGC may sense the RF signals level, but in this application it is more satisfactory to sense the optical level and correct the RF level.

If RF return to support set tops is used, the RF diplexer separates the upstream signal, digitizes it, and sends it to the headend, where a special device is used to reconstruct the RF to supply it to the set top control system. There are some variations in which the signal is demodulated at the ONT and the demodulated packet is transmitted to the control system. No data is transmitted except when there is a transmission from a set top in the home. Typically the threshold for determining when data is present is set toward the high end of the range of which the set top is capable (accounting for passive splitting/combining in the house), to minimize the effect of any noise in the home. When a set top transmits, usually one or a very few data packets are sent through the data portion of the FTTH system. You can see that this method of transmitting the upstream RF precludes noise funneling in the upstream direction. If a home has a noise problem it would be easy to identify based on the IP address of the transmission.

DATA PORTION

The bottom port of the WDM (Figure 2) passes the 1490 nm downstream data signal to an optical transceiver, and accepts from the transceiver the 1310 nm upstream optical signal. Data modulation is done at baseband (on-off keying) of the optical transmitter. The data rate at the transceiver is 1 Gb/s or higher, spread over only 32 subscribers. Compare this to DOCSIS, which on a per-RF-channel provides about 37 Mb/s downstream and usually about 8 Mb/s upstream, spread over however many subscribers, maybe 100 or so, if there is a typical application.[i] The upstream data rate is 1 Gb/s, so you can offer outstanding upstream bandwidth as well as downstream. This works especially well for gaming and peer to-peer applications. Following the data transceiver is the digital processing section. The front-end is a protocol-specific chip that manages data transmission according to either the EPON or GPON standard. The digital processing back-end provides one or more 10/100BaseT connections for data, and also includes media conversion to support standard analog phone lines.

In Greenfield applications many homes are now being built with category 5 cable so that you can connect the cable directly to the ONT. If desired, a standard cable modem gateway is connected to provide a firewall and

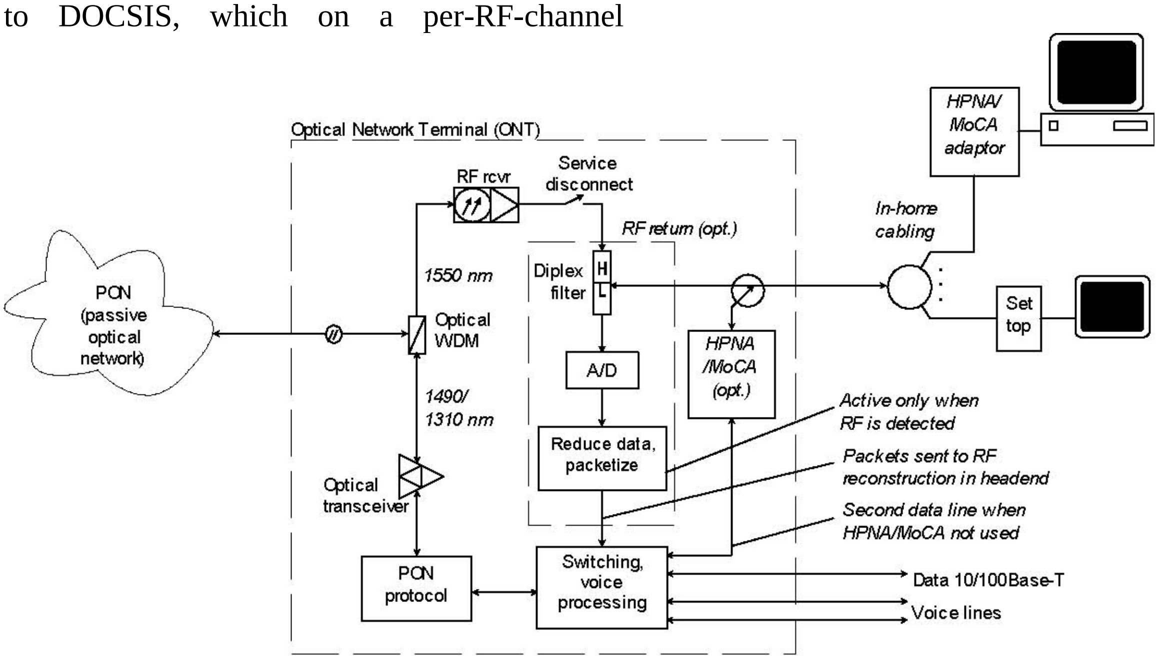

Figure 2. Optical Network Terminal (ONT)

DHCP services for the home. For existing construction, there are several options. Many operators are installing cat5 cabling, but some are opting for one of the standards available for putting data over coax. These standards are HPNA over coax, and MoCA. More on those options later.

MORE ON THE HEADEND

Figure 3 illustrates the headend in more detail. The headend shown is feeding both HFC plant (toward the center right) and FTTH at the bottom. For illustrative purposes, we have shown different VOD zones for HFC and FTTH, but of course this will vary depending on local needs. At the top is the headend switching/routing facility connected to the voice facility and other data services. It is connected to the CMTS for the purpose of data transmission on the cable plant, including voice.

Following standard practice, the downstream signals to the HFC plant and the upstream signals from that plant are transported to and from the node on separate fibers. lower frequency channel amplitude by about 4 dB at channel 2, decreasing the boost at higher frequencies, to the point of little boost above about 200 MHz. The reason for this boost is that fiber optic cable exhibits a nonlinearity called Stimulated Raman Scattering (SRS) that causes the downstream data, carried at 1490 nm (in accord with all modern standards), to crosstalk into the video channel, reducing carrier-to-noise ratio (C/N).

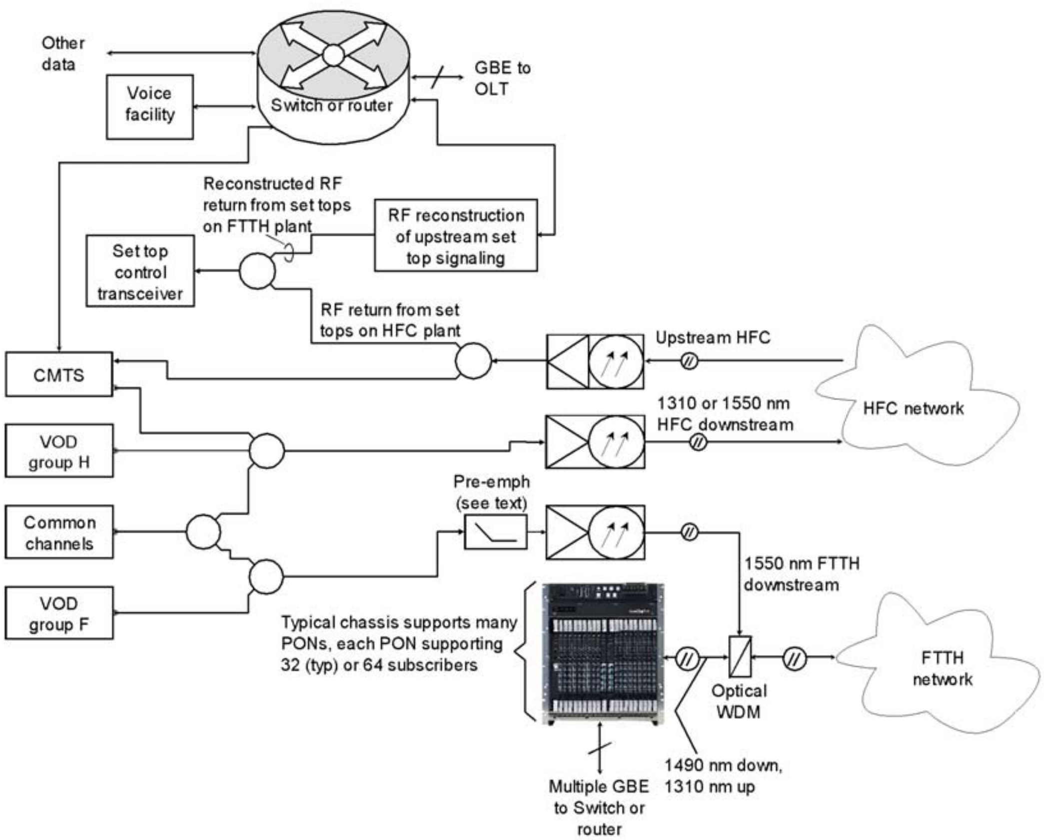

Figure 3. Headend serving both HFC and FTTH Networks

The effect is frequency-dependent, affecting lower frequencies the most. By boosting the low-frequency channels, the C/N can be maintained equal to or better than that delivered by short HFC amplifier cascades.

DATA FEED IN THE FTTH PLANT

The CMTS does not act as the data interface for the FTTH network, because data is carried as on-off modulation of the data transceiver at different wavelengths than that used for video. Thus, data doesn't take spectrum away from video. The interface taking the place of the CMTS is called an Optical Line Terminal (OLT). It may or may not include front-end data concentration (switching). It interfaces to the headend switch, usually using either optical or electrical Gigabit Ethernet (GBE) connections.

RF RETURN IN THE FTTH PLANT

In HFC plant, we handle RF return by providing an upstream path between 5 and about 42 MHZ, using diplex filters at the input and output of each amplifier and at the coax side of a node. We normally use a second fiber to return RF signals to the headend from an upstream RF optical transmitter in the node. FTTH doesn't have an RF return path for signals needing it. Some have proposed adding a modulated laser at each home to accommodate RF return, but this is less than satisfactory from cost and maintenance standpoints.

The normal applications for the upstream plant are upstream data from DOCSIS modems, RF return from set tops, and perhaps status monitoring. In some instances there will be contribution video from the field being returned to the headend to be turned around. In the FTTH plant, we don't need the upstream for DOCSIS (except for DSG – more on that later), and status monitoring is replaced with a complete element management system (EMS) that uses the upstream data on 1310 nm for upstream transmission. That leaves the RF return from set tops that we need to handle.

Figure 2 illustrates how RF return is handled at the ONT, and figure 3 shows RF return handled at the headend. Referring to Figure 2, RF upstream signals from set tops are separated in the diplex filter in the ONT. The RF return signal is digitized in the analog-to-digital converter (A/D). Processing consists of doing some fast data compression and putting the resulting digitized data into an IP packet. The packet includes the IP address of the reconstruction hardware at the headend. This packet is transmitted to the headend along with all other data. Note that the only time bandwidth is consumed for RF upstream transmission is when a packet is actually available for transmission. This only happens when there has been a burst of RF from the set top converter.

Figure 3 includes the RF reconstruction. Upstream data from the FTTH plant appears at the GBE connections at the ONT, which are connected to the headend switch or router. The headend switch routes the RF return packets to a special-purpose headend product that reconstructs the RF signal. The reconstructed RF return signal is combined with RF upstream signals from the HFC plant if desired, and the combined signals are supplied to the receiver of the set top control system. Since the destination for the RF return signals is determined by the IP address at the ONT, the RF reconstruction can be located anywhere in the plant. It is only necessary to assign an IP address to the reconstruction unit at the headend. Then part of the provisioning of each ONT is to tell it the IP address of the RF return packets. They will arrive properly at the reconstruction unit.

The RF return system as shown can handle any of the standards in widespread use today, including SCTE 55-1, SCTE 552, and DSG (DOCSIS Set Top Gateway). Somewhat different provisions must be made for each, due to the properties of the different standards. Consult with the manufacturer of your ONTs for specifics.

Because of the way RF return works in FTTH plant, there is no noise funneling. Referring again to Figure 2, the only time there is a transmission from the RF return section is when an upstream transmission is detected. The threshold for detection is set as high as possible, consistent with the need to make sure all set tops can reach that threshold within their specified maximum output level, taking into account in-home splitting and cable loss. The packet can only be transmitted when nothing else in that PON is being transmitted, and though the RF reconstruction hardware in the headend (Figure 3) services many PONs, only one signal can be passed to it at a time. Thus, the system inherently offers protection against noise funneling. In the unlikely event that you have one home that is generating enough noise to make the RF return circuitry think a signal is present, then that noise cannot affect reception from any other home. Furthermore, the offending home is easy to locate: you simply sniff upstream packets and note the source IP address the illegal packets are coming from. Also note that for SCTE 55-1 systems using contention signaling, the system can actually improve efficiency by queuing multiple transmissions.

PON Vs. NODE

The OLT shown is typical in that it includes a number of optical interfaces, each serving an individual set of subscribers. That set is referred to as a PON, or passive optical network. A PON in this context may be considered as analogous to a node in HFC plant. In FTTH, a PON is effectively a node serving typically 32 subscribers per node. The node analogy breaks down though, when we consider what is in the field. In a node, the node (conversion between optical and electrical) is in the plant, and is followed by a short cascade of amplifiers. In the PON, the 32 (typical) subscriber PON consists of an all-passive network, with the conversion to electrical being done on the side of the consumers' homes. All that is in the field is optical fiber and passive splitters, until we get to the home.

Note that each PON has a WDM after it, which combines the broadcast video at 1550 nm with the data at 1490 nm (downstream) and 1310 nm (upstream). Since each PON has a WDM, it is obviously possible to further divide the RF signals to get more frequency reuse in the FTTH plant, just as you do in the HFC plant. However, if you wish to take advantage of it (your option), you have additional spectrum available in the FTTH plant that you don‘t have in the HFC plant. You are not loosing spectrum for data and voice, since they are carried on separate wavelengths. And you probably have more spectrum available. The RF FTTH spectrum extends to at least 870 MHz, and 1,000 MHz really works (it is often not specified that way for detailed technical reasons, but it works). So you may avoid as much frequency reuse as youi need in some HFC situations.

CURRENT VIDEO PRACTICE

Entities deploying PONs today have a number of philosophies regarding how to deploy video. While some are deploying IPTV exclusively, we find that most (including Verizon) are deploying broadcast video, while reserving the option to deploy IPTV in the future. The reasons for the continuing popularity of broadcast video, especially in competitive situations, are several. Broadcast video is more mature, as the cable TV industry knows well. There are many more features available on broadcast set tops than there are on IPTV set tops, and the user is accustomed to the broadcast experience. Furthermore, IPTV does necessitate certain in-home wiring (or use of the devices discussed in the next section) not needed for broadcast video. Finally, the ability to supply analog-only services without a set top where that is the only service desired, is a subscriber convenience and an operator cost savings.

A likely future scenario is to provide for a broadcast basic service (analog-only or analog and digital) on broadcast, while offering video-on-demand (VOD) and similar services on IP. This gives you the best of both worlds: broadcast where it is most efficient, and IPTV where it is most efficient. While we are not aware of any operators who have implemented this scenario yet, we do know of operators who are expecting to implement it in the next few years.

IN-HOME NETWORKING

Figure 4 illustrates some in-home networking options that are available for use with FTTH and, with suitable modification, with HFC networks. To the left are shown the ONT RF and data connections. Since most homes in North America are wired for coax but not data, there has been a lot of work on putting data on the coax network in the home. The cable industry has been following this work closely. Two standards have emerged, and the selection between them may be coming down to whether or not cable TV set tops are being used. Measured throughput for both standards is on the order of 100 Mb/s. Both standards support data delivery to all computers in the home over coax, networking of the computers, and delivery of IPTV if and when desired.

HPNA 3.0/3.1 can be used where RF return from set tops is not needed, such as where IPTV is being employed for premium services. Originally HPNA was an acronym for Home Phone Networking Alliance, but the organization changed its name to the HPNA Alliance.[ii] This standard was developed for use on in-home phone networks, but it was quickly realized that the same standard would work well over coax. The frequency band occupied is 4-21 MHz, so it overlaps spectrum often used for RF return. Equipment supporting HPNA is readily available from a number of vendors.

The other standard, MoCA,[iii] occupies spectrum above 870 MHz, so it is compatible with RF return. Use of that higher spectrum raises concern about it's viability in older home wiring, but the MoCA association reports good throughput in nearly all homes tested.

Both standards are used in essentially the same way. A unit at the ONT, usually designated as the master, transmits data presented to it on one of the 10/100Base-T connections at the ONT. An adaptor (slave or client) at each computer converts the RF signal back to a 10/100 connection. These adaptors are often called dongles.

The two data-over-coax standards can carry IPTV data to set tops and can also be used for data delivery and in-home networking. Figure 4 shows client-to-client data flow. The standards rely on limited isolation between splitter ports, plus reflections, to achieve client-to-client data communications. This usually works well, as the standards have adequate dynamic range to work over a wide range of attenuation. If a problem were to arise, you can artificially worsen the return loss in the band of interest by installing a filter with a stop band at the device operating range, at the RF output of the ONT.

The use of HPNA or MoCA for in-home networking as well as for delivery of IPTV (if both are being done) will demand that quality of service (QoS) be applied. Both standards have the ability to do basic QoS functions, at least as far as prioritizing one type of traffic over another based on 802.3 quality markings.

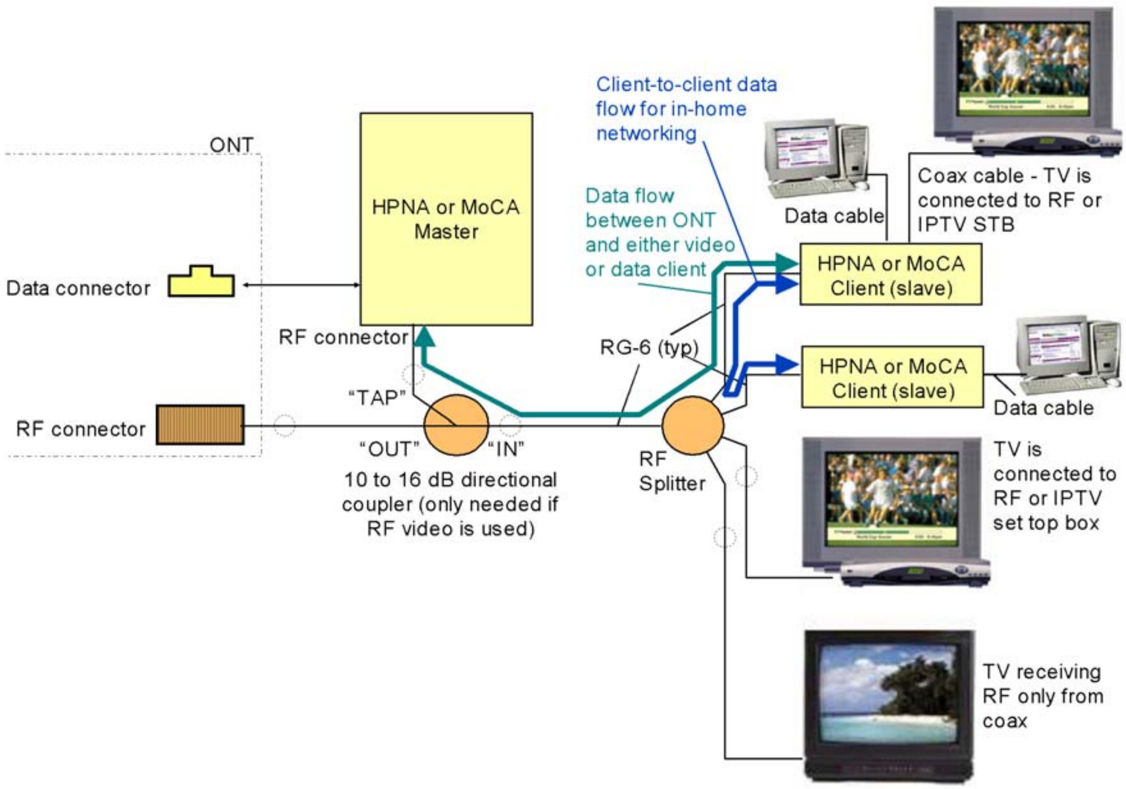

Figure 4. In-Home Networking

DIGITAL TURN-AROUND

Digital turn-around, where you use the upstream data path to send video back to the headend to turn it around and send it to subscribers, is easy in FTTH. This is being done today, where systems are using their facilities to carry local sports. They convert the video to IPTV at the venue, give the packets the IP address of the turn-around device at the headend (or any other point in the network), add quality of service (QoS) parameters, and the turn-around happens. No worries about ingress, no issues of finding spectrum for the upstream video, no plant qualification, no headend re-cabling. Anywhere you have an ONT in the plant is an injection point for entertainment-quality video you can turn around to your subscribers.

VOICE COMPATIBILITY

Voice compatibility between FTTH and HFC is easy, and there are systems using the same soft switch for both today. Many FTTH systems support MGCP/NCS protocol, and they can support SIP. The CableLabs specified NCS is a profile of MGCP (some people say it the other way around), so it is common to support both signaling standards. SIP is starting to gain a lot of traction in the industry, both in HFC networks and in FTTH networks.

A difference between the two networks is the way QoS is implemented. DOCSIS uses a special QoS paradigm in which a communications path is set up at the beginning of a call and torn down at the end of the call. The soft switch (or other voice facility) is responsible for initiating set-up and tear-down of the circuit. FTTH systems, on the other hand, use IETF- and Ethernet-standardized prioritization. The advantage is that there is no need to set up and tear down the connection. Voice packets are identified and are transported with high priority. Soft switches don't have any problems distinguishing between calls placed on FTTH and on HFC, and there are people today who are operating mixed systems, using the same switch for both HFC and FTTH.

CONCLUSION

It is very easy to add FTTH to an HFC network. This is advisable where you have greenfield opportunities close to HFC plant. Many land developers are demanding FTTH in their new subdivisions, because they have learned that FTTH adds value to the homes they build. Cable TV operators are in a unique position to service this business, and at the same time, equip themselves for a future in which they will need FTTH in order to compete.

END NOTES

[i] DOCSIS 3.0 provides more bandwidth by bonding channels, but this takes channels that cannot then be used for video.
[ii] http://www.homepna.org/
[iii] http://www.mocalliance.org/