Payoff

Hybrid fiber/coaxial (HFC) cable networks can deliver interactive services such as telephony and high-speed data services. HFC networks use fiber transmitters, fiber nodes, RF amplifiers, and taps to distribute signals to subscribers and set-top boxes (or cable modems) to return signals to the cable company. This article explains HFC network management system requirements.

Introduction

Telecommunications reform, the Internet, and high-speed data services have revolutionized the definition of communication services. Services rich in multimedia content have the highest demand and require the highest bandwidth to live up to customer expectations. Hybrid fiber/coaxial (HFC) networks currently offer the best network alternative to deliver these services, but traditionally have never been managed like their telco counterparts. This article examines the requirements for managing the hybrid fiber/coaxial cable network, its relationship to the services being offered, and ideas for and challenges of managing the network.

Overview of HFC Networks

When cable TV came about in the 1940s, the intent was to provide TV signals to those who could not receive them from the standard antenna. As more people signed up for cable service, the cable operators simply extended the cable to reach the new customers.

Unfortunately, as they extended the cable, the signal also became weaker, because signal loss is directly proportional to the length of the cable. To overcome the losses, cable operators inserted amplifiers in the transmission network, thus allowing the cable operator to now provide service to more customers. Unfortunately, once again, the amplifiers also added noise and distortions to the original signals; thus there is a theoretical limit to the number of customers the cable operators could service.

Throughout the 1980s, amplifier manufacturers improved not only the noise and distortion characteristics, but also the frequency range. It was now possible to extend the transmission networks farther and offer more channels. Exhibit 1 shows a typical example of what came to be known as the “tree and branch architecture.”

Tree and Branch Architecture

Advances in fiber optic technology made it possible to use laser transmitters, receivers, and fiber optic cable to distribute the cable TV signal to neighborhoods, and then use the existing RF network to distribute the signals to the subscribers. Thus was born the hybrid fiber/coaxial cable network.

The HFC network allowed the cable operator to reduce the number of RF amplifiers needed, which increased the quality of the signal provided and overall network reliability. With the RF network reduced to just a few amplifiers, it was also now easier to support higher frequencies (i.e., more channels). Most current HFC designs support up to 750 MHz of bandwidth, which roughly translates to 110 channels. Exhibit 2 shows an example of a HFC network.
HFC Network Architecture

Requirements For Managing HFC Networks

Since the early days of cable TV, the intent has mostly been to deliver analog television signals to subscribers. Higher frequencies meant that cable operators could offer more channels, thus the cable network explosion during the 1980s and 1990s.

With the newly available bandwidth, several cable operators discovered that they could offer other services that generated additional revenue. Digital Music Express, a CD-like audio service, allowed the cable operator to offer 30 digital radio channels. Pay-per-view allowed the cable operator to offer newly released movies and sports events to subscribers by programming (authorizing) the set-top box for subscribers that ordered the additional service.

Achieving Interactivity

Until this point, most cable networks only worked in one direction, called the downstream path. Basically, the cable signals are broadcast to all set-top boxes, and the set-top controls what the customer is authorized to use.

Some cable plants also have, or are being designed for, a return path, or an upstream path (see Exhibit 3). This design is what makes the HFC network interactive—the ability to pass data either way—and is setting the stage for many types of services, ranging from telephony to high-speed data services, energy management, and Internet access.

HFC Network with Impairments

Most return paths are designed to work in the 5 MHz to 40 MHz frequency range (mostly because that spectrum is not being used for other channels). The return path, however, offers some serious challenges for reliable operation of two-way services. Examples of common problems encountered (for both upstream and return path) with a HFC network are also shown in Exhibit 3.

Distortion.

With any active components, distortion is unavoidable. In the case of HFC network, the main cause of distortion comes from multiple carriers (i.e., frequencies) in amplifiers. If the combined signal strength is too strong, the amplifier will go into compression and generate distortion products. These will cause the existing carrier levels to be distorted by multiples and combinations of other carriers.

Carrier Levels.

As previously stated, if the carrier levels are too high, they will cause the amplifiers to generate distortion products. If they are too low, then the carrier-to-noise ratio will be too low (i.e., not enough signal strength at the receiving end).

The frequency response of the amplifiers can also cause variation of the carrier levels, thus the lower frequencies may be fine and the higher frequencies will have a low (bad) carrier-to-noise ratio.
**Corroded Connectors.**

HFC networks are constructed either above ground (on telephone poles) or underground. In both environments, the connectors (between the cable and the amplifiers) will corrode or degrade with time, either from water seeping into the connection or from other types of wear—everything from animals chewing on the connectors to varying tension on the cable. This type of destruction can either let other signals in (known as “ingress”) or distort the signals passing through it, most noticeably the 60 Hz power supply used to power the amplifiers. This distortion causes 60 Hz and other multiples (usually 120 Hz) distortion across all frequencies.

**Ingress.**

Although the cable network is a closed network, there are still external signals that can get into, and interfere with, upstream traffic. Ham radio has components at 7, 14, and 21 MHz; shortwave radio has components at 6, 10, 12 and 15 MHz; arc welders produce broadband noise that can last for long time periods (minutes); lightning produces broadband noise that can last for several seconds. Home wiring (as when consumers decide to wire up their entertainment system) is responsible for common causes of noise imposed on the return path.

**Noise Funneling.**

The return path also experiences a phenomenon referred to as noise funneling, where the collective noise of all the return path amplifiers collects, or funnels, back into the fiber node. This phenomenon can be difficult to troubleshoot, because it will be difficult to determine which amplifier is causing the significant noise problem.

**“Digital” Requires Monitoring**

Until this time, cable operators had no method equivalent to methods used by the telcos to monitor their network. Cable companies usually relied on subscribers to call in when there was a problem—either no cable signal at all (an outage), snowy images (low levels or carrier/noise problems), or multiple pictures (crossmod, microreflections, or other distortion problems).

With analog TV signals, a wide variety of problems could exist, yet the picture was still visible, thus there was no real need to put in elaborate monitoring systems. With the advent of new, digital-based services, however, there is no graceful fading of the services—they either work or they don't. Digital modulation is more resistant to network problems, but it eventually will reach a point where it won't work.

To ensure delivery of quality services, it becomes necessary to manage both the HFC network and the services that run on top of it.

**Services Running On the HFC Network**

To illustrate the relationship between the HFC network and the services that run on top of it, a few examples are given of the services delivered over HFC and how they might correlate to problems with the network.
Analog Video Service

As mentioned previously, there are many types of problems that can occur in the HFC network and still allow viewing of analog video. These problems could include signal levels that decrease as a function of frequency or distortion products that superimpose several channels onto one. These problems are well known and characterized, and most HFC networks are optimized to minimize their effects.

Digital Services

These are the new services that will take advantage of the broadband capabilities of the HFC network. What is unknown is how the HFC impairments will affect the digital services.

Recent studies have looked at several different HFC networks to test their ability to support digital services. The tests (done by Cable Television Laboratories, Inc.) used a RF T1 modem to determine the performance factors from five different cable plants. Measurements were compared against International Telecommunications Union-Telecommunications Standards Sector (ITU-TSS) G.821 performance objectives.

What these studies concluded was that the return path is a hostile environment. One cable plant defect can make the entire reverse spectrum unusable.

The field testing emphasized the critical importance of conducting a comprehensive and thorough plant hardening effort and maintaining precise gain alignment. The most troublesome conditions were caused by impulse noise, usually observed with cold temperatures, high wind conditions, increased precipitation (including thunderstorms), and combinations of all of these weather variables.

Under these conditions, the integrity of the transmission path (both downstream and the return path) was affected, resulting in increased error seconds, severely error seconds, and poor availability. This does not rule out the ability of the HFC network to deliver the services; it merely indicates that a well-characterized HFC network, along with a comprehensive network management system, is required to offer the new services that meets subscriber expectations.

Ideas For Managing the HFC Network

One method for managing communications networks such as HFC is the Telecommunications Management Network model.

Telecommunications Management Network (TMN) Model

Briefly, the TMN model breaks the operation process into five distinct layers:

- Business management.
- Service management.
- Network management.
- Element management.
- Network elements.
Each of these layers is connected, and each affects the ability to offer services to subscribers. For each layer, the management systems must incorporate the following five functions:

- Fault management.
- Configuration management.
- Performance management.
- Security management.
- Accounting management.

Communications between the layers are handled by a standard protocol—CMIP (Common Management Information Protocol).

The TMN model offers a structured approach to meet the new requirements of HFC management discussed in the previous section. Specifically for the HFC network, the following items should be addressed:

- Monitor status of HFC network (fault management).
- Monitor status of head end equipment (fault management).
- Manage head end equipment (configuration, performance, security, and accounting management functions).
- Monitor Quality Of Service into the head end.

**Example: High-Speed Data Services over HFC**

To illustrate the management approach, an example of high-speed data services over a HFC network is illustrated in Exhibit 4. The data service is very similar to a standard network service found in many corporations, where PCs have access to each other and a main server complex.

**HFC Network with High Speed Data Service**

In this example, the real difference is in the network medium and the signal conversion system (which converts Ethernet traffic into RF packets). Instead of 10-BaseT, FDDI or a T1 line, the distribution network is HFC.

In the traditional data network, there would be routers, bridges, and hubs to segment the traffic over the network. These devices have some monitoring capability to indicate the traffic going through them and the number of packets that were resent. These devices also are part of the management system and have their own management application that can control the type and amount of traffic flowing through them. Typically, this is through the use of Management Information Base and Simple Network Management Protocol (SNMP). Thus, when a problem occurs with a device, it can be used to troubleshoot the data network problems.
**HFC Equipment**

In the HFC environment, the network uses fiber transmitters, fiber nodes, RF amplifiers and taps to distribute the signals to the subscribers and set-top boxes, or cable modems, to return the signals to the head end.

No similar management strategy currently exists for the HFC environment. Most HFC equipment currently does not have monitoring capability built in.

**Status Monitoring Systems.**

Many of the HFC devices support an external transponder, or telemetry equipment, that is managed by a status monitoring system. The communication between the status monitoring system and the transponders is through a proprietary protocol. The communication path is through the HFC network to the transponders and through the return path, or telephone line, for the return communication.

The status monitoring system plays an important role in establishing similar capabilities for the HFC network. In the example shown in Exhibit 4, transponders could be placed in the fiber node, trunk or bridge amplifiers, and line extenders. With these transponders, the status monitoring system would be able to indicate the status of those devices in near real time.

The types of parameters the transponders can measure include AGC levels for the amplifiers, RF levels of various carriers, temperature inside the amplifier or node housing, and laser power level. These parameters allow the monitoring system to predict the current health of the HFC network.

Some specialized monitoring modules, called end-of-line monitors, can perform more detailed measurements on the RF carriers. These parameters are tuned more for analog video (i.e., carrier/noise ratio, depth of modulation, carrier level variation over time) than they are for digital services, but still can be used as a diagnostic tool when problems in digital services occur.

Exhibit 5 shows an example of bringing the status monitoring information into a standard network management system, such as Hewlett-Packard's OpenView platform. This example shows a fiber node and the associated RF devices to service a 500-home area. Color is used to indicate the status of the managed objects—red for critical, yellow for major or minor, green for normal, and blue for unmanaged.

**Status Monitoring System Represented In Network Management System**

Note that although the status monitoring system typically has a proprietary protocol to communicate with the transponders (shown as managed objects in Exhibit 5), they can still be represented in a standard management environment, either through proxy agents or through a mediation device (discussed in more detail later).

**Standard Management Capabilities.**

Most of the components used for the high-speed data service currently support standard management capabilities. The server complex and Asynchronous Transfer Mode switches typically have SNMP capabilities. Home PCs can support some sort of a SNMP agent, allowing them to also be managed as part of the service.
The signal conversion systems and cable modems are relatively new and may not support SNMP capability for the first revisions. Thus, the high-speed digital service could be managed similar to a corporate application, with management products like Hewlett-Packard’s Network Node Manager or Operations Center.

**Monitoring Non-standard Services.**

For those services (or pieces of services) that do not offer standard management capability, it is still necessary to at least monitor the fault status. Most equipment used in the head end will either have some sort of alarm capability or be controlled by a PC application that will have alarm capability, typically through a RS-232 serial port. These types of devices could still be incorporated as part of a management system through the use of a mediation device.

*Exhibit 6* shows the fault manager platform (FMP) from Hewlett-Packard. It incorporates a mediation device as the first interface to the network management system.

**Fault Management Platform**

This mediation device is used to map RS-232, SNMP, and CMIP devices into a standard X.733 alarm messaging format. Also built into the mediation device is event correlation, which allows the management system to correlate related alarms (e.g., HFC outages and critical alarms in services) before forwarding onto the network management system. This would, for example, allow only one alarm to be forwarded when hundreds of alarms may be logged into the mediation device.

At the network management layer (shown as alarm management service and utility tools in *Exhibit 6*), another layer of event correlation takes place. This layer correlates alarms from other head ends or from other types of managed object classes (i.e., head end equipment) to develop root-cause analysis. This is the event correlation that would allow the user, for example, to correlate alarms from the high-speed data service with alarms from the HFC network.

**Manager/Agent Application for Controlling HFC Equipment**

Up to this point, this chapter has discussed monitoring the status of equipment in a HFC network. The other aspect of a management system is to control the equipment—that is, some sort of manager/agent application.

Most head end equipment currently either has no management application or has a PC-based application that was designed to be a standalone application. In order for the network management system to control the devices, there needs to be some way to program the devices, either directly or through an agent application.

If the head end devices have some sort of PC application for control, it may be possible to login from a remote terminal on the network management station and control the devices that way. That would allow for centralized control, but does not meet the requirements of the TMN model.

For those devices that do not have a manager/agent application, or some sort of management information base (MIB), they cannot be automatically managed by the network management system. Equipment vendors will have to develop a manager/agent application for their devices.
Conclusion
Management for hybrid fiber/coaxial networks is in its infancy stage. A majority of the equipment vendors are in the process of developing a network management strategy for their devices and services, which will include the development of a manager and agent application.

SNMP versus CMIP
Currently, most vendors are leaning toward the use of SNMP to control their devices. Because of the widespread acceptance of SNMP in the computer network and systems management, there are hundreds of development tools that make the development task much easier than CMIP. CMIP does have some performance capabilities that far exceed SNMP, and some equipment used with a HFC network (e.g., telephone switches, SONET gear) may use CMIP instead of SNMP.

For the short-term (i.e., over the next five years), the management protocols used will probably include SNMP, TL-1, CMIP, and other, non-standard forms. Thus the network management system used will have to be flexible, one that can handle many protocols yet provide a common, standards-based operating environment.

With the network management system, it will be possible to present the management information for all network elements and services in one consistent graphical user interface and provide for centralized management. With the integrated information, it will be possible to proactively monitor the HFC network, and eventually predict when the HFC network will need maintenance or when it will start to affect the digital services, thus allowing for a reliable, high-speed communications network for many types of services.

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