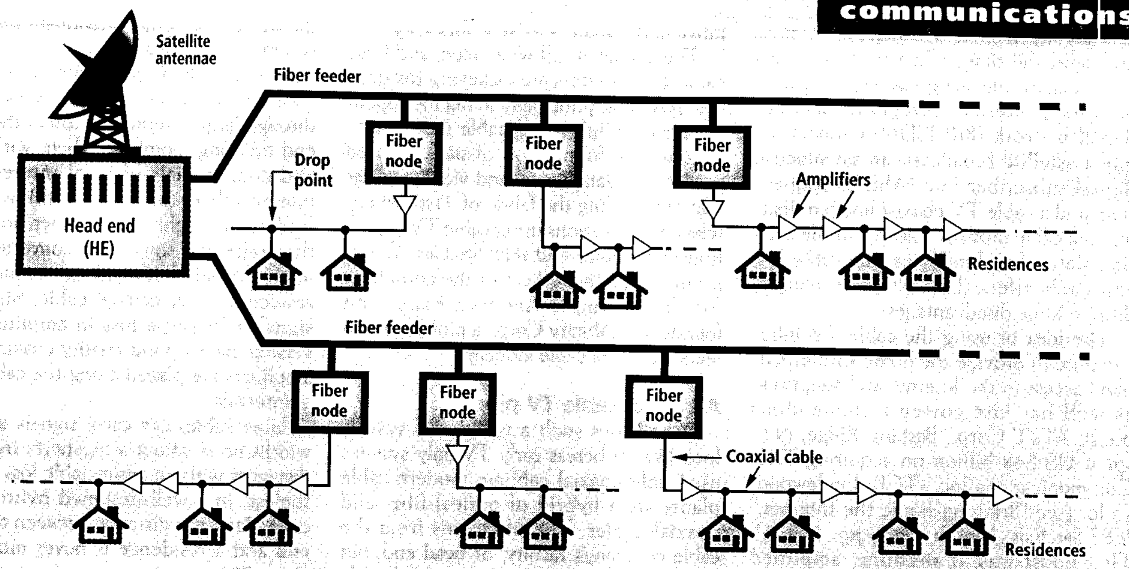


[1] A modern hybrid fiber-coax system uses optical fibers to connect the head end with neighborhood nodes from which coaxial cable runs to individual customers. This typical analog system has unidirectional amplifiers to boost the signal in the coax portion of the cable plant.

Cable it's not just for TV

CABLE SYSTEMS CAN DELIVER DATA AT 30 MB/S WHILE ALSO CARRYING TELEPHONE AND TV TRAFFIC

AMITAVA DUTTA-ROY
Contributing Editor

Just about every telecommuter, investor needful of up-to-the-minute stock quotes, and casual World Wide Web surfer must wish they had a faster on-ramp to the great information highway known as the Internet. Most people rely on a dial-up modem, which is not only frustratingly slow, but (unless they have extra phone lines) forces them to break their data connection every time they want to make a regular phone call.

Fortunately, relief is in sight. Its form: an emerging trend toward providing fast Internet access—along with multiple telephone lines, television programs, and other services—over a single coaxial cable. Cable TV operators are restyling themselves as multiple-system operators (MSOs) and are already offering bundled services at attractive prices. Some of their first offerings may not include telephony, but it will surely come in the not-too-distant future.

Web sites are growing more corpulent with animations, slide shows, and video and audio clips, not just in the name of entertainment but often to convey succinctly to visitors useful information from the owner firms. What could be better, after all, than giving a live product demo to a prospective customer while he or she is on-line? Printed brochures are no match—provided, of course, that the whole Web-browsing experience is not an exercise in frustration.

THIS IS THE SECOND IN A SERIES OF ARTICLES about providing individuals with broadband access to the Internet and other communications services—the so-called last-mile problem. The first article, an overview of the issues called "Bringing home the Internet," appeared in the March issue of *IEEE Spectrum*. This installment concentrates on a single access technology—cable modems. Future articles will cover digital subscriber lines and wireless techniques. —*M.J.R.*

0018-9235/99/$10.00©1999 IEEE

How much speed is adequate? Table 1 compares the times taken to download a 10-megabyte file using dial-up modems, a basic-rate interface integrated-services digital network (BRI ISDN) connection, direct satellite broadcast, an asymmetric digital subscriber line (ASDL) connection, and a cable TV coaxial line terminating in a cable modem. Clearly, in the existing state of technologies, the cable TV approach offers the best performance, despite some disadvantages.

The idea of using the cable TV infrastructure to provide the home with broadband access to the Internet and telephony as well has just gotten a tremendous boost. AT&T Corp., Basking Ridge, N.J., spent US $48 billion on acquiring Tele-Communications Inc. (TCI), Englewood, Colo. [see "Bringing home the Internet," *IEEE Spectrum*, March 1999, pp. 32–38]. That boost was, if anything, amplified when the AT&T–TCI combination announced that it would team up with Time Warner Communications, also in the metropolitan Denver, Colo. area, in offering bundled services in some of the last-named's territories, including the most lucrative in the country—New York City.

The market is still wide open, and large cable TV operators are jockeying for strategic positions, principally in big metropolitan areas. "High-speed cable modem has become the foundation of packet-based services for data, voice, and video services that are building the fabric of 21st-century telecommunications using cable TV pipes," Rouzbeh Yassini told *IEEE Spectrum*. Yassini is chief executive officer of the consulting firm Yas Corp., in Andover, Mass., and founder of LANcity Corp., a pioneer in the manufacture of cable modems.

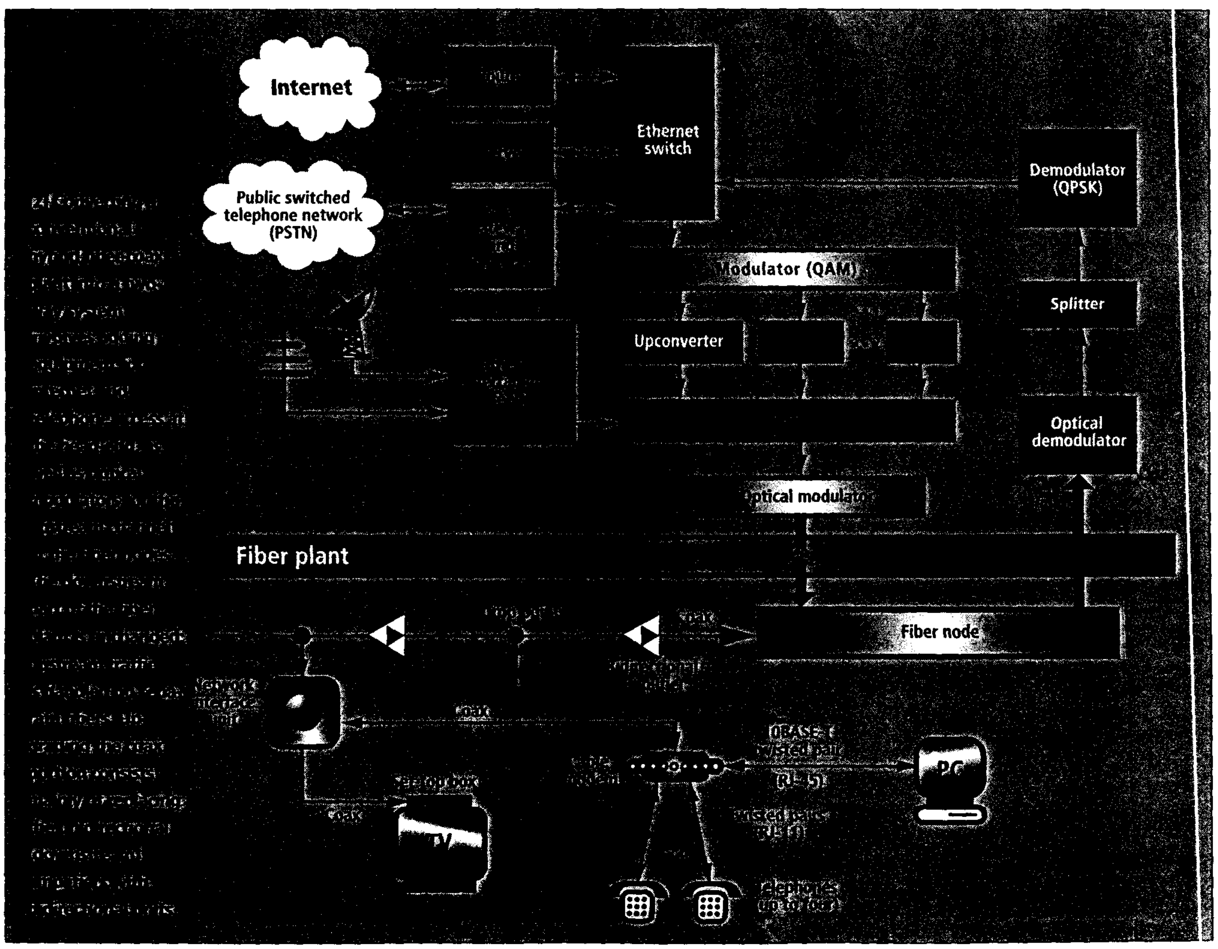
A typical cable TV plant

What does such a wonderful system look like? Whereas early TV-only systems used only coaxial cabling, modern cable plants are a hybrid of optical-fiber and coaxial cables. The fiber runs from the cable company's facility, or head end, out to neighborhood nodes, and coaxial cable carries the signal the rest of the way, to individual residences [Fig. 1]. Today, this tree-like hybrid fiber-coax (HFC) topology is a sensible compromise between cost and bandwidth. In the future, fiber may go all the way to the home, providing even faster communication channels.

A modern HFC plant captures program channels from geostationary satellites through large antennas on top of the head-end building, combines them with news and commercials of local interest, and transmits them (in analog form) over fiber feeders to neighborhood fiber nodes. At the nodes, the signals are converted back into electronic form and sent to individual residences over coaxial cable. Since the signals undergo a loss in amplitude traversing even a good-quality coaxial cable, amplifiers are placed along the cable path at intervals.

Fiber cables can carry signals of bandwidths up to about a gigahertz over long distances without appreciable loss. Nevertheless, in a well-designed hybrid fiber-coax plant, the distance between the head end and a residence is never more than about 80 km.

In North America, analog TV broadcast channels conform to the 1953 standards established by the National Television Standards Committee (NTSC) of the Electronic Industries Association (EIA).



These specify interlaced scans of 525 horizontal lines at a rate of 30 frames per second. For broadcasting NTSC TV signals, each channel requires a bandwidth of 6 MHz. Normally the frequency range of 54–550 MHz is used for analog TV broadcasts over coaxial cables.

Bidirectional information flow

Today's cable plants suit one-way communication, from the head end outward, and so are perfectly adapted to broadcast television. But for Internet access or telephony, traffic must flow in both directions. So a range of frequencies between 5 and 42 MHz is allocated for upstream signals, both analog and digital. Although upstream (from the subscriber) and downstream (to the subscriber) traffic rides on separate fiber strands, they share the same coaxial cables. This is cost-effective, but it raises questions about security.

The first task of a cable TV operator that wishes to offer interactive services is to upgrade its cable plant to handle bidirectional information flow. Return amplifiers and diplexers (band-splitting filters) must be added, controllers installed at the head end, and special boxes installed at the subscribers' premises to separate upstream from downstream traffic. This migration may cost somewhere between $200 and $600 per household passed. (A household is said to be "passed" by a cable system if it is a potential customer of the system—if the cable, literally, passes by the house—regardless of whether the household is actually a customer.)

Enter the Internet

Any discussion of access to the Internet must emphasize that for most residential uses, other than video or desktop conferencing, the exchange of data is asymmetrical. The request an Internet user sends to look up a Web site or search for some information consists of very few packets but may trigger a deluge of data in the other direction. This deluge is an inherent characteristic of Web surfing, and the inability of conventional modems to handle it is one of the main problems that cable modems aim to solve.

But how fast is fast? How fast must a modem be to keep a customer happy? And what is the statistical nature of the data? According to research done at AT&T Laboratories, in Florham Park, N.J., a typical broadband Internet surfer looking at text and still pictures (no streaming audio or video) can read data at only 40 kb/s, averaged over a 3-minute window, and needs an average uplink speed of just 4 kb/s, mostly acknowledgments for the downstream flows, over the same 3-minute window. The downstream data

Speeds of Internet access methods

Access method	Maximum speed	Download time[a]
Dial-up modem (28.8 kb/s)	28.8 kb/s	46 minutes
Dial-up modem (33.6 kb/s)	33.6 kb/s	40 minutes
Dial-up modem (56.6 kb/s)	45 kb/s	30 minutes
ISDN basic rate interface	64 kb/s (128 kb/s with two lines)	21 minutes (10 minutes)
Satellite (DirecPC)	400 kb/s	3.3 minutes
Local multipoint data service	500 kb/s	2.7 minutes
ADSL modem	1.5–9.0 Mb/s	8.9–53 seconds
Cable mode	10–30 Mb/s	2.7–8.0 seconds

Source: Brian Underdahl & Edward Willett, *Internet Bible*, IDG Books 1998

ADSL = asymmetrical digital subscriber line   ISDN = integrated-services digital network

[a] The theoretical minimum for a 10-MB file.

tends to be highly bursty—in other words, it consists of brief periods of high-speed data transfer separated by fairly long periods of inactivity.

From these facts, and knowing that only 30–50 percent of subscribers are active during even the busiest hours, AT&T has concluded that it can easily support 420 customers with a single 6-MHz TV channel. Settling on a standard analog TV channel allows a provider to use some of the same low-cost equipment as is used for analog cable TV transmission.

For fast CATV access to the Internet, the head end is connected by a high-speed link of at least DS-3 (45-Mb/s) speed to an Internet service provider [Fig. 2]. Data received from the service provider is passed through a Fast Ethernet (or Gigabit Ethernet) switch to a downstream modulator, which puts the data on an intermediate-frequency subcarrier using quadrature amplitude modulation (QAM), in which both amplitude and phase are varied to represent information. In most cases, 64 QAM (64 combinations of amplitude and phase) is applied; hence, each combination, or symbol, carries 6 bits of information ($2^6 = 64$). An RF carrier with 6 MHz of bandwidth can therefore carry up to 30 Mb/s of data, after allowing for power roll-off on both sides. (Newer head-end gear and modems can utilize 256 QAM modulation, raising the data rate of a 6-MHz channel to 40 Mb/s.)

The 6-MHz subcarrier is then upconverted and placed on a predesignated RF carrier. That carrier is combined with the RF feeds from TV program channels, and the combination is fed to a laser that converts the complex electrical pulse stream into an optical stream. Next, the optical signal is sent out over the optical-fiber plant to the outlying fiber nodes, each of which serves 500–2000 residences.

At each fiber node, the optical signal is converted back into electrical form (usually by a p-i-n diode) and distributed to the drop points of the coaxial cable plant. From each drop point, a coaxial cable brings the signals to a weatherproof splitter box, or network interface unit, placed outside every residence. A band-splitting diplex filter inside the unit separates the upstream from the downstream signals. The unit further separates incoming signals having different destinations: Internet data for the cable modem, voice telephony, and TV programs.

The cable modem packs the Internet data in the form of 10BASE-T frames, which are fed over an RJ-45 connection to the Ethernet network interface card (NIC) in a computer. The phone connections at the cable modem shown in Fig. 2 are for Internet protocol (IP) telephony, which has yet to come to residences in a big way. For the present, the analog telephony signals are derived directly from the network interface unit and may be accessed using RJ-11 jacks. The TV signals are carried by a coaxial cable to the set-top box, where they are unscrambled and fed to the TV set or videocassette recorder.

Upstream data—a request for a Web site, say—exits the PC through the NIC to the cable modem, where it is converted into a quaternary phase-shift keyed (QPSK) modulated RF signal. (This modulation technique permits 2 bits per symbol because each symbol is one of four phases, and is best suited for relatively low bit-rate transmission in an electrically noisy environment.) The RF signal passes through the diplex filter and is sent onward to the fiber node through the cable plant at a designated frequency band in the 5–42-MHz spectrum. The fiber node then converts the electrical signal into optical form and returns it to the head end.

At the head end, the optical signal is converted back into electrical form, whereupon the Internet data passes through the Fast Ethernet switch over the high-speed digital line to the Internet service provider. With these schemes, downstream data can be transmitted mostly at 10–30 Mb/s and upstream data at 768 kb/s to 10 Mb/s.

Voice signals are generally passed on to a telephone company's Class 5 switch. Most cable TV operators currently offer only analog circuit-switched telephony. Cox Cable Communications Corp., Phoenix, Ariz., probably the sixth-largest cable TV operator in the country, serves 3.8 million customers in the South and Southwest. Of this number, 1.8 percent—the highest percentage for any cable operator in the United States—are also clients for fast Internet access. In addition, Cox is a strong competitor of the local telephone company US West in the circuit-switched analog telephony business. In many areas Cox offers 12 phone lines to a single residence or multiple-dwelling unit (MDU) over one coaxial cable.

Some multiple-system operators, however, are planning to implement their own IP telephony platforms. For example, Princeton, N.J.–based RCN will route IP telephone signals to its own internal gateway. If the called party is both a customer of the company and subscribes to IP telephony, the call will be routed to that person. Otherwise, it will be routed through RCN's gateway to the called party's local phone company and duly completed.

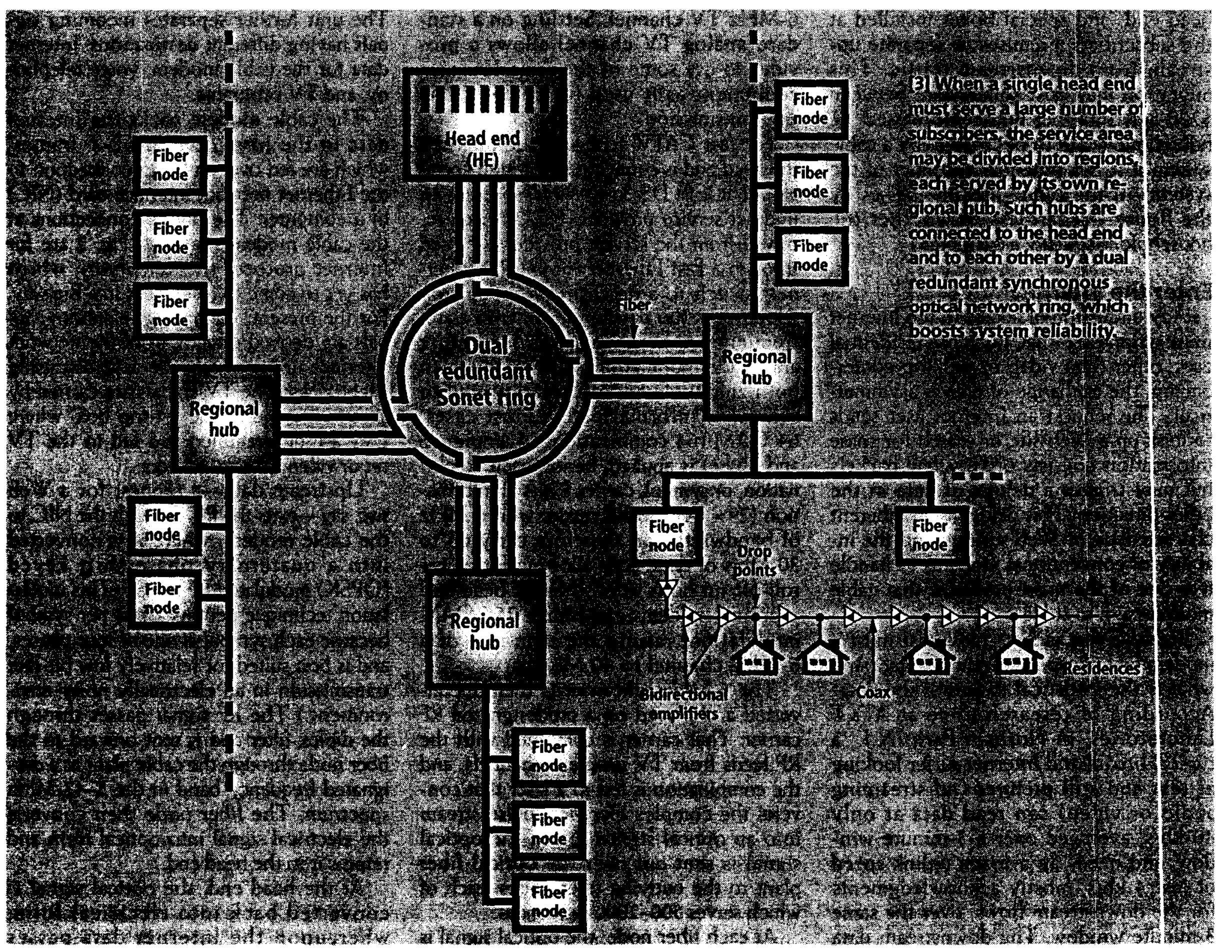
"Both the telcos and the gateways maintain routing tables," Richard Rioboli, senior manager for strategic development at RCN, told *Spectrum*. In fact, the Data Over Cable Service Interface Specifications—Docsis 1.1—to which the industry is migrating will have provision for IP telephony, pointed out Richard Prodan, senior vice president and chief technical officer at CableLabs, an association of leading North American cable TV operators located in Louisville, Colo.

However, Prodan added that "apart from the basic IP technology, there are many traditional business issues associated with public telephone service such as billing, call forwarding, call waiting, directory services (411), and emergency calls (911), which customers expect, that must be sorted out before IP telephony becomes ubiquitous in the world of cable modems." Perhaps importantly, Docsis and CableLabs' PacketCable specifications allow at most four independent IP voice channels through a single cable modem, in contrast with the 12 offered by Cox's system.

In some areas, local regulations may bar the multiple-system operators from offering the upstream path through cable modems. Instead, it may be through a dial-up modem and the public switched telephone network.

Always on

Because the connection between a cable modem and the Internet is packet-switched (as opposed to circuit-switched), the link is always active. As soon as the computer is turned on, it begins a new session with the Internet, and the Internet service provider dynamically assigns it an IP number, which remains valid until the session is terminated. A large provider with thousands of clients may assign local IP addresses to clients using its proxy server to interface with the outside world. That is, outsiders will see the proxy server's address, instead of the local address, and



[3] When a single head end must serve a large number of subscribers, the service area may be divided into regions, each served by its own regional hub. Such hubs are connected to the head end and to each other by a dual redundant synchronous optical network ring, which boosts system reliability.

all communication between a user and the outside world will take place through the proxy server.

The telephone service provided by the cable operators is also "always on" in that it is not interrupted by power outages. Should utility power fail, backup batteries at the cable system's nodes would keep the phones working even when other services go down. This feature is akin to the lifeline service provided by phone companies.

In some parts of the country, the demand for bandwidth appears insatiable. Especially in big metropolitan areas like New York City, one head end may be connected to several regional hubs by OC-48 (2.5-Gb/s) and OC-192 (10-Gb/s) synchronous optical network rings [Fig. 3]. The regional hubs feed the local nodes.

Once the Docsis standard is well entrenched in the industry, its quality-of-service (QoS) parameters will make it fairly simple to set up virtual private networks. Such networks will allow companies to configure seemingly private networks, although they are actually implemented over the shared cable plant run by the multiple-system operator. Properly implemented, a virtual private network combines the low cost of a shared network with an enhanced level of security, albeit not as high as that of a truly private network with its own dedicated infrastructure.

In some networks, Docsis may even make it possible to set up bidirectional symmetrical data flows for real-time videoconferencing and other time-sensitive applications.

Where standards stand

For some years now, multiple-system operators have tempted their clients with Internet and cable TV service. This they did with a splitter box and a cable modem of proprietary design that matched with the head-end terminal equipment. The devices cost a lot and had only a single source. Hence there arose a strong desire for a set of specifications that would be widely acceptable to the industry.

In November 1994, the IEEE 802 Local and Metropolitan Area Network Standards Committee decided to charter a working group to create standards for data transport over traditional cable TV networks. In keeping with the IEEE's international and neutral character, Working Group 802.14 was required to consider the needs of other international bodies, such as the Digital Video Broadcasting Group (DVB) and the Digital Audio and Video Council (Davic), both based in Geneva, and strong in Europe. The standards also called for compliance with the specifications for video compression algorithms used in the transmission of videos as developed by the Moving Pictures Expert Group-2 (MPEG-2). This was a tall order, and proceeded less quickly than some hoped.

To develop a set of workable specifications as quickly as possible, a coalition of CATV operators, known as Multimedia Cable Network System Partners (MCNS Holdings LP), was formed in 1995. The organization issued the first release of Docsis in December 1996.

Some modem manufacturers have been shipping these devices. In the estimate of Michael Schwartz, CableLabs' senior vice president for communications, roughly 20 000 cable modems made to the Docsis 1.0 specs have been shipped without any formal certification. The first two cable modems to be certified by this association as Docsis 1.0-compliant came from Toshiba America Information Systems, Irvine, Calif., and Thomson Consumer Electronics Inc., Indianapolis, Ind. The first head-end gear to be similarly qualified by CableLabs is made by Cisco Systems Inc., of San Jose, Calif.

There is no royalty fee for manufacturing cable modem equipment to the Docsis specifications as long as no part of them is utilized in fabricating equipment for purposes other than those of the cable modem industry. Version 1.1 is expected to be formalized soon.

Based on the Internet Protocol (IP), Docsis can deliver constant bit-rate services such as voice and video over hybrid fiber-coax plants. "The evolution of Docsis continues to make its future versions [an] ubiquitous, robust, more symmetric communications mechanism over any HFC plant, even in the lower [frequency] and dirty [that is, noisy] area of the upstream spectrum," *Spectrum* was told by Thomas Quigley, director of the residential broadband strategic business unit at Broadcom Corp., Irvine, Calif. Broadcom manufactures silicon chips used in cable modems and cable modem terminal systems (CMTSs). Broadcom and Terayon Communications Systems, Santa Clara, Calif., are working together on a proposal for a future release of Docsis.

Security may be a serious issue in a system that uses a shared medium. The Docsis standards have accordingly built in what is known as the baseline privacy specification, which relies on the use of both the 40- and 56-bit versions of the data encryption standard (DES). (There is a U.S. embargo on the export of 56-bit encryption.) Michael St. John, network architect at At Home Corp., Redwood City, Calif., told *Spectrum* that so far there has been no complaint over security from the company's customers who number in the tens of thousands. At Home is a large Internet services provider, partner, and portal provider to many heavyweight cable TV operators in the country.

Independently of the work by the IEEE 802.14 and Docsis committees, Geneva's Davic published its specifications in December 1995. These were subsequently adopted by DVB as standards in Europe. All the same, Davic has kept on working at enhancing its specifications.

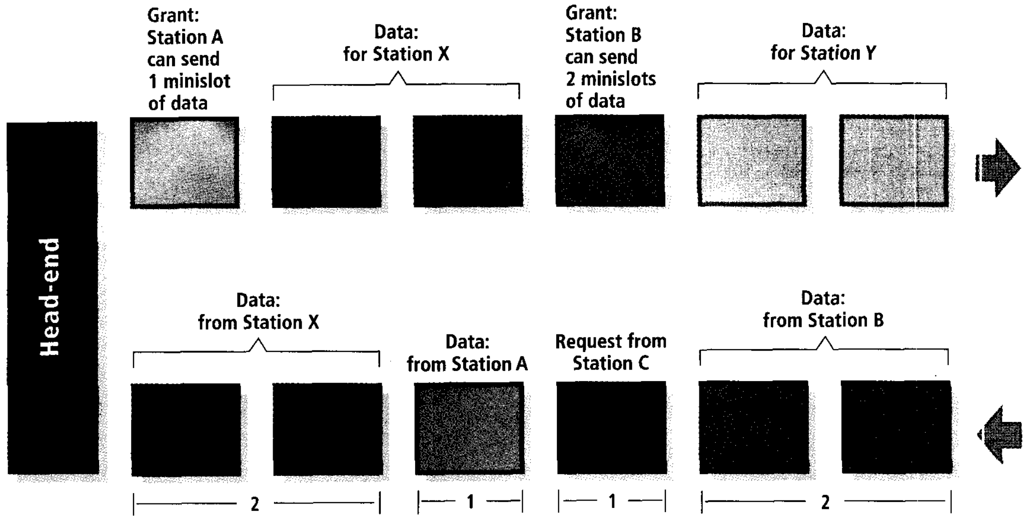
Mark Laubach, vice president and chief technical officer of Com21 Inc., a manufacturer of cable modems and other equipment in Milpitas, Calif., who sits on many standards committees and tracks the work of them all, observed that in the summer of 1998, about half a dozen companies started to manufacture equipment to Davic's specifications. Both IEEE 802.14 and Davic focus on MPEG-2 framing using asynchronous transfer mode (ATM) as the transport protocol. However, since their implementation is different, equipment built to those specifications is not interoperable. Laubach further told *Spectrum*, "The IEEE 802.14 draft is about a year from achieving formal standard status, significantly trailing the availability of either Davic or Docsis specifications, each of which is viewed as standard for the international community."

To date, no companies are known by Roger Durand, chair of the IEEE 802.14a committee, to be working on an 802.14 media access control (MAC) layer. But he said the 802.14a High Performance Physical layer (HI PHY) working group will closely coordinate its efforts with the CableLabs/Docsis 1.2 Advanced PHY work, with the goal of producing a single set of specifications acceptable to both Docsis and the IEEE.

"The proposed standard will dynamically adapt, through feedback, to the existing conditions of the cable plant to maximize the upstream bandwidth near to the Shannon limit," said Durand, who is also principal systems architect at Cabletron Systems, Rochester, N.H. "In many cases this will result in utilizing portions of the cable plant previously thought not usable due to signal degradation [and doubling or more] the upstream throughput while simultaneously enhancing byte error rate reliability."

Further efforts toward developing a set of sound specifications have been initiated by CableLabs. One, the PacketCable initiative, is "aimed at identifying, qualifying, and supporting Internet-based voice and video products over cable systems." Another is OpenCable, a project aimed at obtaining a fresh generation of set-top boxes that are interoperable. These devices will enable a new range of interactive services to be provided to cable customers.

Docsis specifications are recognized by the telecommunications sector of the



[4] To prevent collisions among upstream data packets, a grant system is used in which requests to transmit are sent only in response to polling messages from the head end and permission to transmit the data itself is controlled by a head-end scheduler.

International Telecommunication Union, a Geneva-based unit of the United Nations. The specifications will be formalized under J112.X, where X will denote the region. Different countries have different standards of TV broadcast. In the United States and Canada, it is NTSC.

Data packets

Of concern in sending digitized voice over a packetized system is that delay and delay variations (jitter) be kept within fairly tight limits. Small packets are desirable because they keep the delay down but undesirable because they increase overhead. Long packets have lower overhead, but take longer to fill. In a multi-use hybrid fiber-coax system, a packet size of an IEEE 802.3/Ethernet frame (1518 bytes, maximum) would represent a compromise among many requirements.

What mechanism should be adopted for the media access control (MAC) layer? Downstream data present no problem, being broadcast to all subscribers alike. But upstream data travel from all subscribers to just one head end, risking collisions between packets. Conventional carrier-sense multiple-access with collision detection (CSMA/CD), as used in Ethernet, is not applicable to hybrid fiber-coax systems because cable modems do not transmit and receive in the same frequency band—a station cannot sense collisions between its upstream packets and packets sent from other stations.

Only the head end receives packets from all stations and can sense a collision. But being far from the scene of any collision, it could not request a retransmission for perhaps a millisecond, which is much too long for many time-sensitive services and applications. Conventional polling methods are also unsuitable because of the delays they impose.

For this reason, a time-division multiple access (TDMA) method has been chosen to coordinate the upstream hybrid fiber-coax transmissions. In implementing this, the head end regularly broadcasts a message to see if any stations connected to it wish to begin a new session. Any station that so wishes undergoes an initialization procedure that synchronizes its clock with that of the head end and determines how long it takes for a signal to traverse the path connecting them.

After this initialization procedure, the station sends a small (6-byte) packet to the head end requesting permission to send a specific number of packets [Fig.4]. Upon receiving the request, a scheduler in the head end assigns the station a time window whose duration is specified in increments known as mini-slots—each of which is 2^k times 6.25 μs ($0 \le k \le 7$, depending on expected usage pattern, upstream frequency range, and desired quality of service).

The head-end scheduler also specifies the mini-slots in which a newcomer can place its request packet. Since the station knows its time offset with respect to the head end (from the initialization procedure) and since request packets are very short, collisions between request packets are not a problem.

The permission given by the head end to a station after receiving a request is a small packet of data, called a grant, which is sent by the head end along with other downstream traffic. Upon receiving a grant, a station transmits its upstream data in the mini-slots granted, during which interval no other modem may transmit data and no collisions of data packets can therefore occur. (Variable-length data packets are broken down into permitted lengths of user data packets, each of which consists of up to 1500 bytes preceded by a 6-byte header.)

Another scheme for coordinating upstream data transmission, pioneered by Terayon, is known as synchronous code-division multiple-access (S-CDMA) and is sometimes used in a very noisy cable plant. With S-CDMA, the packets transmitted by the client stations are multiplied by mutually orthogonal digital codes, so that the packets may be transmitted simultaneously over the same frequency band, with each receiver perceiving the unintended signal as random background noise. The mutual interference among simultaneous signals is thereby reduced.

This scheme theoretically is more efficient than a TDMA method and can support more clients per node, especially in noisy environments. Of course, as the number of simultaneous transmissions increases, a point will be reached at which the background noise will become too high for reliable communication.

Since cable subscribers share the transmission media, there is a concern that if the number of subscribers per node goes up, at some point the performance of the entire system may go down. However, Norman Schryer, director of broadband services research at AT&T Laboratories, noted that since (as planned by his company) the size of an upgraded node is 500 homes passed, and since one 6-MHz channel can support 420 customers, then one TV channel will suffice if 84 percent of the potential customers opt for broadband Internet surfing. For larger percentages and new services, such as streaming media, the multiple-systems operator can either devote extra 6-MHz channels to broadband data or else it can split each fiber node into four nodes, each passing 125 homes, in effect pushing fiber deeper *into* its plant. Either approach would restore the quality of service.

Troublesome noise

Electrical noise in the upstream direction can give both end-users and the multiple-systems operator a big headache. Noise can seep into the system from many sources, including home appliances. The use of cheap cabling or a poorly designed splitter can make the problem worse. In a hybrid fiber-coax configuration, each drop cable and neighborhood feeder cable acts as spokes of a sprawling antenna, while the head end acts as a giant receiver and accumulates all their noise. The collected noise degrades all spokes, thus worsening the situation.

There are various ways to minimize the ingress of spurious noise. The first is to prospect the service area thoroughly for potential sources of noise and as far as possible lay out the cable plant to minimize their effects. The second is to utilize as far as possible the cleanest part of the 5–42 MHz band, the portion that is between 21 MHz and 27 MHz. The third is to reduce the number of households served by each head end or regional hub. Admittedly, reducing the number of hubs in a given area will raise system costs. However, in the long run, the investment is worthwhile for an operator committed to good customer service.

Regular monitoring can systematically pinpoint problem nodes and paths, which can then be isolated for inspection and repair. It is possible to "ping" a specific modem by sending a test packet of data to it and discovering its state. ("Ping" is the acronym for Packet InterNet Groper.) No wonder the monitoring and management of hybrid fiber-coax lines and cable modems has spawned an industry by itself. Monitoring equipment is available from several companies, such as Tollgrade Communications Inc., Cheswick, Pa., and Wavetek Corp., San Diego, Calif.

The cable modem and terminal equipment manufacturer Com21 has taken an interesting approach to tackling the noise in the upstream, or return, paths. The key is the company's eight-port card, known as the return path multiplexer (RPM). Located at the fiber node, the eight-port card multiplexes eight return paths so that the ComCONTROLLER, at the head end, can so schedule grants that at any given instant it receives data from only one of those eight upstream links. The seven other return paths are blocked so long as one is open.

Thus, at no time can the noise from eight return paths accumulate at the head end or hub, obviating the expense of deploying the extra hubs or head ends otherwise necessary to reduce the number of subscribers and the noise per hub. "Com21 has seen a strong demand for enhanced technologies for signal-to-noise robustness, ingress noise blocking, virtual private networks, and tiered and differentiated quality of service (QoS) for integrated voice and data services over broadband cable systems," John Pickens, the company's director for technology development, told *Spectrum*. And he added, "The QoS features of the MAC layer of the 1.1 version of Docsis and the PHY layer of its future versions will support both higher peak bit-rates in extremely clean plants and low peak rates in dirty plants."

The bottom line counts

A lot is being said and written about provision of bundled services through coaxial cables. But how much is hype and how much has a good chance of being realized?

The first cable modems to be deployed commercially were made mostly by Motorola, Zenith Network System, and LANcity. Now the situation is noticeably different. It is believed that in the United States alone more than 23 companies are seriously active in this field. Some are only a few years old and others are industry leaders. Cisco Systems, the leading router maker, now also offers a cable modem. 3Com Corp., Santa Clara, Calif., has both cable modem and asymmetric digital subscriber-line (ADSL) offerings. Cabletron Systems, a major packet-switching and xDSL player, has announced both a Docsis cable modem and a software network management platform called Spectrum.

Motorola Inc., Schaumburg, Ill., has redesigned its CyberSURFR modem to conform with Docsis specifications. Arris Interactive, Suwanee, Ga., which may shortly be acquired by Canada's Nortel, ships its Cornerstone products for the cable modem industry.

The rapidity of the progress being made in cable modems may seem to imply that every important problem has been solved, but many remain. Some customers complain about low speed, which may be caused by noise. And costs are always an issue, although Prodan of CableLabs thinks they are bound to drop as the innards of cable modems are manufactured to standard specifications. "We may soon see the entire cable modem on a single chip," he said.

And, of course, there is one additional aspect to accessing the Internet—the selection of the Internet service provider (ISP). By now, many surfers have developed preferences for or aversions to particular providers—America On-Line (AOL) and CompuServe, to name just two. However, cable companies do not appear to be willing to open their networks to outside service providers, and unlike telephone companies, they are not required to do so.

When AT&T–TCI starts offering its services, it plans to offer Internet access through only one ISP: At Home Corp., Redwood City, Calif. A customer who wants to use AOL or CompuServe will have to pay extra for the privilege. How the market will react to these and other realities is anybody's guess. ◆

To probe further

"Bringing Home the Internet," *IEEE Spectrum*, March 1999, pp. 32–38, the first article of this series, gave an overview of the market, principal regulatory issues, and technical highlights of asymmetric digital subscriber lines, cable modems, and wireless and satellite broadcasts.

A general introduction to various technologies that bring broadband to the home is given by George Abe in his *Residential Broadband* (Cisco Systems and Macmillan Technical Publishing, Indianapolis, Ind., 1997). The treatment is qualitative and considerable work has since been done by the standards committees, changing the residential broadband scene.

Albert Azzam's *High-Speed Cable Modems*, (McGraw-Hill, New York, 1997) contains a great deal of practical information. However, the author is secretary of the standards committee and orients his book toward the IEEE 802.14 standards. Furthermore, much technical information, such as different vendors' proposals on protocols, has been made obsolete by the formulation of Docsis standards.

Four highly recommended World Wide Web sites—www.cablelabs.com, www.cablemodem.com, www.packetcable.com, as well as www.opencable.com—give relevant and up-to-date information on MNCS, Docsis specifications, Interoperability tests, and Frequently Asked Questions in general on cable modem technology. There is also information on the participation of the Internet Engineering Task Force IP Over Cable Data Network (ipcdn).

For information on the work done by the IEEE 802.14 standard committee, check out www.walkingdog.com/catv/index.html. The Web page also explains the amusing origin of the title "Walking Dog."

Also worth checking out are www.cabledatacomnews.com, a newsletter on data on cable technology that carries latest news, and www.catv.org, which not only has news of developments in cable technology but also lists educational courses on the topic.

Spectrum editor: Michael J. Riezenman