Cable modems—Broadband highway to the home

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Cable operators are eyeing a huge business opportunity in providing residential customers with high-speed Internet access. The market for cable modems is expected to increase dramatically over the next few years. This increase will be the result of rising user demands for access to the services and capabilities made possible by greater speed, such as high-quality voice, video on demand, and a variety of entertainment services.

The authors describe the technology of using cable plants to bring high-speed Internet access into the home.

Introduction

Surfing the World Wide Web typically offers residential Internet users a click-and-wait experience rather than an interactive extravaganza. Because connection speeds are typically limited to 53 kbit/s or less, frustrated residential online users are demanding higher-speed connections. However, in spite of the slow narrowband speeds currently available through existing dial-up telephone modem connections, residential Internet and online usage continues to grow rapidly.

Local service providers currently offer residential ISDN services that provide connection speeds up to 128 kbit/s. To offer downstream speeds in excess of 1.5 Mbit/s, service providers will have to look to alternative solutions, such as digital subscriber line (DSL) technologies, faster downstream data connections from direct broadcast satellite (DBS), fixed wireless access, and high-speed cable modems.

Broadband coaxial cable passes by more than 105 million homes in North America, and more than 75 million of these subscribe to cable TV. Coaxial cable connections offer nearly universal coverage and a powerful platform for providing high-speed data access to residences and small businesses. However, to support advanced communications services, one-way cable television systems must be upgraded into modern two-way networks. This is a technically complex and capital-intensive proposition.

Cable systems were originally designed to deliver broadcast television signals efficiently to subscribers' homes. To ensure that consumers obtain cable service via the same TV sets with which they receive over-the-air broadcast TV signals, cable operators recreate a portion of the over-the-air radio frequency (RF) spectrum within a sealed coaxial cable line or CATV network designed and used for cable TV distribution. The system must be upgraded with bidirectional amplifiers in the cable-distribution or CATV network before signals can flow in two directions. Most CATV networks are a hybrid of fiber and coaxial cables. Signals are passed through fiberoptic cables from the head-end center to locations near the subscriber. The signals are then transmitted in coaxial cables that run to the subscriber premises. Higher-frequency signals flow toward the subscriber and lower-frequency signals flow toward the broadcasting head-end.

BOX A, TERMS AND ABBREVIATIONS

ADC	Analog-to-digital converter
ARP	Address resolution protocol
ATM	Asynchronous transfer mode
BER	Bit error rate
BPI	Baseline privacy
Cable network	Refers to the cable television plant that would typically be used for data-over-cable services.
CATV	Cable TV
CM	Cable modem
CMCI	Cable modem-to-CPE interface
CMTS	Cable modem termination system
CPE	Customer premises equipment
DBS	Direct broadcast satellite
DHCP	Dynamic host configuration protocol
DOCSIS	Data-over-cable service interface specification
DSL	Digital subscriber line
DSP	Digital signal processor
FEC	Forward error correction
Head-end	Central distribution point for a CATV system
HFC	Hybrid fiber-coaxial
ICMP	Internet control message protocol
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate frequency
IP	Internet protocol
ISDN	Integrated service digital network
ISP	Internet service provider
LAN	Local area network
LLC	Logical link control
MAC	Media access control
MCNS	Multimedia Cable Network System Partners Ltd.
MSO	Multiservice operator
NAT	Network address translation
NSI	Network-side interface
OSI	Open systems interconnection
PC	Personal computer
PDU	Packet data unit
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quadrature phase-shift keying
RF	Radio frequency
RFC	Request for comments
RFI	RF interface
RISC	Reduced instruction set computing
SID	Service ID
SNAP	Subnetwork access protocol
SNMP	Simple network management protocol
SU	Subscriber unit
TFTP	Trivial file transfer protocol
UDP	User datagram protocol
USB	Universal serial bus
VoIP	Voice over IP

Cable plant architecture

Several elements are required to bring high-speed data over cable (Figure 1). A cable plant consists of a hub or ring of hubs. In a typical cable plant, one or more of these hub facilities serve as the collection points. The head-end hub gathers television signals from various sources—primarily satellite TV transponders. The TV signals are picked up, decoded, and down-converted to selected channels. These channels are then combined into a local fiberoptic network for local distribution or placed on a higher-capacity optical network between the regional hubs. One or more of these hubs also serve as the main interface to the Internet and are tied to it via high-speed optical links.

Each hub has a head-end that uses smaller fiber bundles to distribute the television signal to smaller local distribution amplifiers. The fiber is then terminated and the signal is converted back into electrical signals that are sent over coaxial cable into the neighborhood (Figure 2). This scheme of using a mixed fiber and coaxial cable distribution scheme is called a hybrid fiber-coax (HFC) system. The amplifiers in this part of the network must be bidirectional.

In the past, the cable plant typically distributed signals from the head-end system to the customer premises using coaxial cable. Today, however, nearly all operators, including multiservice operators (MSO), have upgraded or are in the process of upgrading their plants to hybrid fiber-coax systems. These systems provide clean, high-quality signals to the neighborhood without replacing all of the cable to the customers' home.

To introduce data into the system, the IP infrastructure must be overlaid on existing systems. Connections to the Internet backbone via concentrators and routers are provided via high-speed optical connections, typically OC-8 and higher-speed connections. These connections are brought into the head-end hub and distributed via routers and optical links to various regional distribution hubs in the MSO network. The IP network is tied into a special adapter called a cable modem termination system (CMTS), which consists of one or more cable modem line cards (CMLC). CMLCs convert the IP data stream into downstream (to the home) and upstream (from the home) RF signals. The downstream signals are sent through an up-converter, which puts them on a specific channel and combines them with the other standard TV signals.

The upstream signals are collected from the subscribers. In a properly designed system, there are several upstream channels for each downstream channel. This is because the upstream data is transmitted at a slower rate than the downstream data. The traffic must be engineered to provide adequate service to users. Voice, streaming video, and gaming services use the greatest amounts of bandwidth. The downstream data rate—approximately 30 to 40 Mbit/s—can be shared by some 500 to 2,000 users. The upstream data rate is approximately 8 Mbit/s per channel. Proxy servers and data cache servers are also employed at the local hub to improve system performance.

Cable service providers in North America and Europe have different transmission requirements for channel width, upstream bandwidth, downstream bandwidth, channel center frequencies, and power limits per channel. After the data-over-cable service interface specification (DOCSIS) had been successfully certified in North America and Europe, cable operators adapted it and most of the specifications set by DOCSIS for Europe. Euro-DOCSIS was formed to address European cable operators, Internet service providers (ISP), and end-user needs (for a

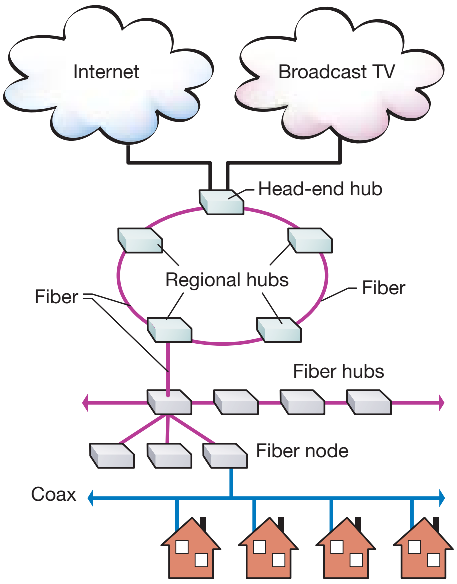


Figure 1
Architecture of the regional hub HFC network.

Figure 2
Architecture of the cable system.

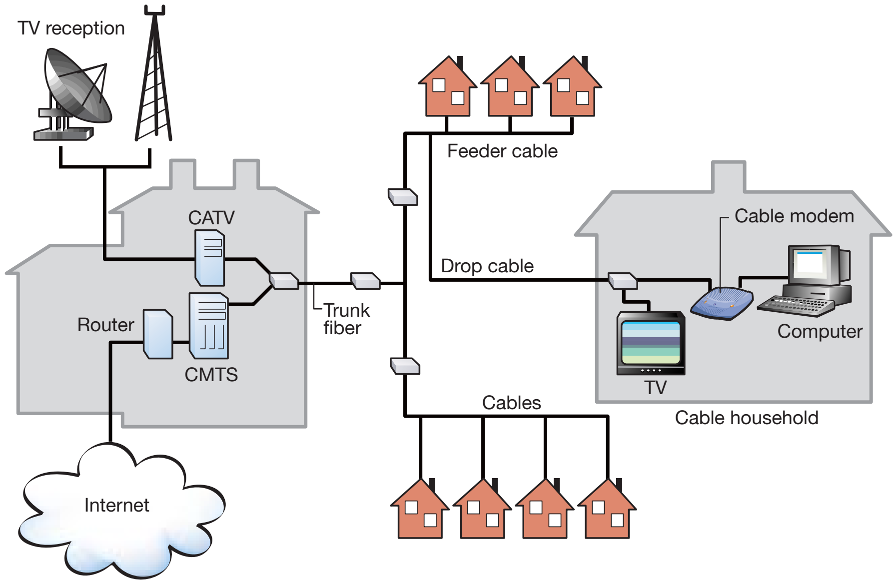


TABLE 1, PROPERTIES OF DOWNSTREAM SIGNALS

Frequency	42 to 850 MHz in North America; 65 to 850 MHz in Europe
Bandwidth	6 MHz in North America; 8 MHz in Europe
Modulation	64 QAM with 6 bits per symbol (normal) 256 QAM with 8 bits per symbol (faster, but more sensitive to noise)

TABLE 2, DATA RATES PER MODULATION SCHEME

	64 QAM	256 QAM
6 MHz	31.2 Mbit/s	41.6 Mbit/s
8 MHz	41.4 Mbit/s	55.2 Mbit/s

comparison of DOCSIS and Euro-DOCSIS, see Tables 1, 2 and 3).

The cable modem termination system

A CATV network consists of six major parts:

- a cable modem termination system;
- a trunk cable;
- a distribution system or feeder in the neighborhood;
- the drop cable to the home and in-house wiring;
- a cable modem, which is connected via coaxial cable and optical fibers; and
- customer premises equipment (CPE).

Figure 3 shows a simple diagram of the data traffic through a data-over-cable system as well as the external interfaces of the key components. The interface between the wide-area network (WAN) and the CMTS is called the network-side interface (NSI); the interface between the CMTS and the cable modem is called the radio frequency interface (RFI); and the interface between the cable modem and customer premises equipment is called the cable modem-to-CPE interface (CMCI). The user connects to the Internet service provider through the WAN interface.

The system shares media for upstream and downstream transmissions. The two most common problems in this architecture are

- the need to control access to shared resources, particularly upstream bandwidth; and
- the injection of ingress noise in the upstream direction.

Traditional coaxial cable systems typically operate with 330 or 450 MHz of capacity, whereas modern hybrid fiber-coax systems have been expanded to 850 MHz. The terms CMTS and head-end are commonly interchanged in contexts that refer to the equipment responsible for communications in the cable network. In reality, the CMTS could be part of the head-end—the equipment from which multiservice operators broadcast television content.

Logically, downstream video programming signals—that is, from the CMTS to the cable modem—begin around 50 MHz, the equivalent of channel 2 for over-the-air television signals. The portion of the spectrum between 5 and 42 MHz is usually reserved for upstream communication—that is, from the cable modem to the CMTS. In North America, each standard television channel occupies 6 MHz of spectrum (in Europe, 7 or 8 MHz). Thus, a traditional cable

TABLE 3, ELECTRICAL INPUT TO CABLE MODEM

Parameter	North American value	European value
Center frequency	91 to 857 MHz ± 30 kHz	112 to 858 MHz ± 30 kHz
Level range (one channel)	-15 dBmV to 15 dBmV	43 to 73 dBµV for 64 QAM 47 to 77 dBµV for 256 QAM
Modulation type	64 QAM and 256 QAM	64 QAM and 256 QAM
Symbol rate (nominal)	5.056941 Msym/sec (64 QAM) and 5.360537 Msym/sec (256 QAM)	6.952 Msym/sec (64 QAM) and 6.952 Msym/sec (256 QAM)
Bandwidth	6 MHz (18% square root raised cosine shaping for 64 QAM and 12% square root raised cosine shaping for 256 QAM)	8 MHz (15% square root raised cosine shaping for 64 QAM and 15% square root raised cosine shaping for 256 QAM)
Total input power (40-900 MHz)/ (80-862 MHz) for Europe	<30 dBmV	< 90 dBµV
Input (load) impedance	75 ohms	75 ohms
Input return loss	> 6 dB (88-880 MHz)	> 6 dB (85-862 MHz)
Connector	F-connector per [IPS-SP-406] (in common with the input)	F-connector per [IPS-SP-406] (in common with the input)

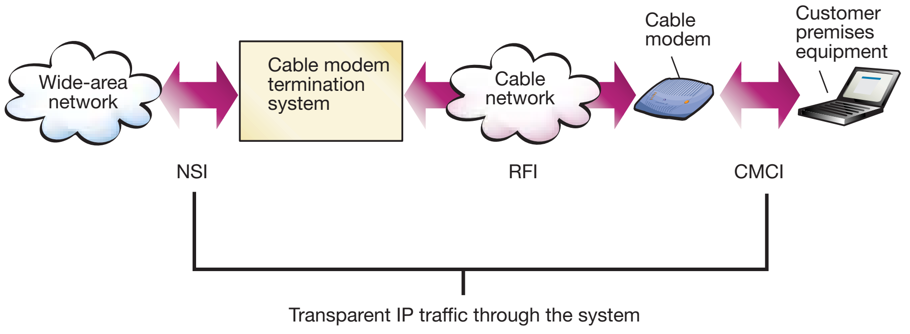


Figure 3
Data traffic through data-over-cable system.

system with 400 MHz of downstream bandwidth can carry the equivalent of 50 to 60 analog TV channels, and a modern hybrid fiber-coax system with 700 MHz of downstream bandwidth has capacity for some 80 to 110 channels.

To deliver data services over a cable network, one television channel (in the 50 to 865 MHz range) is typically allocated for downstream traffic to homes, and one or more channels (in the 5 to 42 MHz band) are used to carry upstream signals. Depending on the availability and the business viability of other channels, the number of cable modem users supported by a head-end can be incremented by commandeering other channels for data and IP transmission. When a channel is used for data, it cannot be used for other conventional, revenue-generating broadcasts, such as commercial TV or pay-per-view services. However, new Inernet-based revenue-generating services can now be offered on that channel.

Figure 4 shows the modulation and demodulation protocols as well as frequency ranges for the CATV system. It also shows the bandwidth and effective bit rates. Figure 5 compares upstream and downstream transmission.

Using 64 quadrature amplitude modulation (QAM) transmission technology, a single downstream 6 MHz television channel can support up to 27 Mbit/s of downstream data throughput from the cable head-end. Speeds can be boosted to 36 Mbit/s using 256 QAM. Depending on the spectrum allocated for service, upstream channels from the home can deliver 0.5 to 10 Mbit/s using 16 QAM or quadrature phase shift key (QPSK) modulation techniques. The upstream and downstream bandwidth is shared by active data subscribers who are connected to a given cable network segment, typically 500 to 2,000 homes on a modern HFC network.

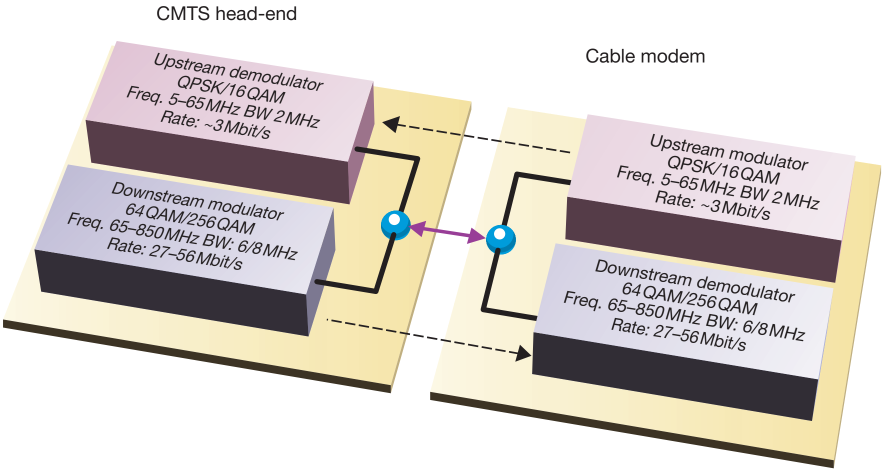
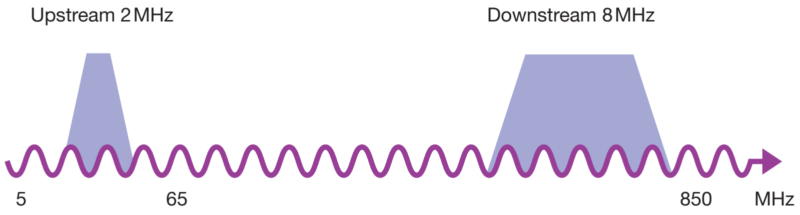


Figure 4
Functional block diagram of the cable modem termination system.

Figure 5
Frequency domains of the upstream and downstream channel positions.



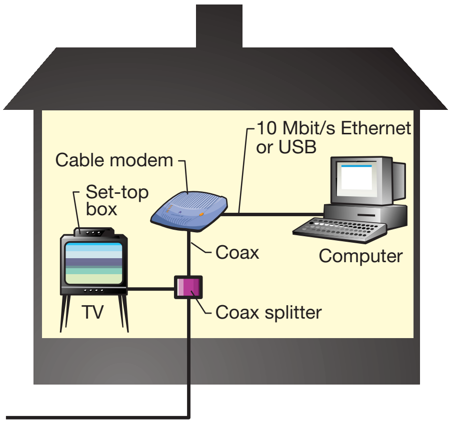


Figure 6
Home environment.

Depending on the network architecture and traffic load, an individual subscriber might experience access speeds from 500 kbit/s to 1.5 Mbit/s or more. Compared to dial-up alternatives, this is blazing performance.

Cable modem details

Description

The cable modem (CM) is a modem in the truest sense of the word—that is, it modulates and demodulates signals. Among its key components are

- a tuner;
- a demodulator;
- an encryption/decryption unit; and
- an upstream modulator.

Cable modems typically send and receive data in two slightly different ways. In the downstream direction, digital data is modulated and then placed on a 6 MHz (North America) or 8 MHz (Europe and PAL system) channel somewhere between 65 and 850 MHz. Upstream transmission is more challenging, since it tends to be very noisy in the 5 to 65 MHz region. Noise or interference is generated by amateur radio operators, citizen band (CB) radios, home appliances, loose connectors and poor cabling. Since cable networks form a tree or branch architecture, noise is aggregated as the signals travel upstream.

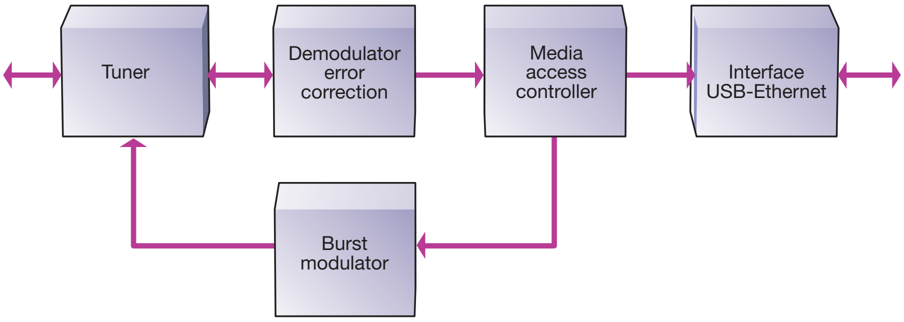
When a cable modem is installed, a power splitter and a high-pass filter might be necessary to isolate the TV set from "strong" signals from the cable modem. The filter also blocks upstream ingress noise in the low frequency band. Figure 6 shows how the signal is split from the main cable to TVs and cable modems in the home.

Figure 7 shows the major components of a cable modem implementation. The tuner, including the diplexer, connects directly to the CATV outlet, which provides upstream and downstream traffic to the rest of the cable modem. The tuner solution, which integrates the diplexer into a dual-conversion tuner and digital signal processor, demodulates 64 and 256 QAM signals. The output is a 44 MHz intermediate frequency (IF) signal that is fed into the analog-to-digital converter (ADC) inputs for demodulation and error correction. The media access controller then extracts data and sends it to the customer premises equipment via a universal serial bus (USB) or Ethernet interface.

The tuner also includes a line amplifier for the transmit function, controlled by the media access controller (MAC), which sends upstream signals at the level negotiated by the cable modem and head-end. According to DOCSIS, Reed-Solomon forward error correction (FEC) is recommended. This adds robustness as well as physical layer overhead, which translates into delay.

The heart of the protocol implementation resides in the MAC. The CMTS has control over the allocation of upstream and downstream bandwidth in a dynamic mix of con-

Figure 7
Cable modem architecture.



tention- and reservation-based transmission opportunities. Each cable modem has a unique 48-bit MAC address that is used for registration and authentication. This is entered in a table with the primary service ID (SID) and IP address, once the IP address is assigned. The CMTS then communicates to the modem with the assigned ID.

Significant processing power is needed for

- converting encoded signals into the format needed by the customer premises equipment; and
- conveying messages from the end-user to the destination point through the CATV system.

All available silicon solutions currently implement digital signal processors (DSP) for demodulating downstream transmissions, which are expected to have low bit error rate (BER). The DSPs handle demodulation, whereas regular processing power is devoted to implementing the key components of the cable modem transmission protocol. Powerful RISC processors enforce protocol functions.

Downstream transmission takes place in one of the 6 or 8 MHz channels between 65 and 850 MHz at 25 to 56 Mbit/s, as determined by the modulation scheme (Table 1). The raw data rate depends on the modulation and bandwidth (Table 2).

A symbol data rate of 6.9 Msym/s is used for 8 MHz bandwidth and 5.2 Msym/s is used for 6 MHz bandwidth. Due to error correction, framing and other overhead, the effective data rate is somewhat slower than the raw data rate. Since downstream data is received by all cable modems, the total bandwidth is shared by all active cable modems on the system. This is similar to Ethernet, except that the wasted bandwidth is much greater in Ethernet.

Operation

Initialization

Cable modem communications are set up through a series of initialization steps. After power-up, the modem scans for a downstream channel with which it can synchronize. The CMTS sends synchronization packets to generate a timing reference. Cable modems are synchronized and ranged so that they know when to begin transmission—in order to hit a specific minislot provided by the head-end. The CMTS controls access to slots by assigning specific “transmit opportunities” to ranges of minislots (a transmit opportunity can be contention- or reservation-based). A reserved slot is a timeslot that is reserved for a particular cable modem—that is, no other cable modem may transmit in that timeslot. The CMTS allocates timeslots through a bandwidth-allocation algorithm. The algorithm is vendor-specific and might differ considerably from vendor to vendor. Reserved slots are generally suited for longer data transmissions. After synchronization is complete, the cable modem receives the upstream parameters it needs to inform the CMTS of its presence on the network. The cable modem receives the upstream allocation information—which it uses to start the ranging process.

Due to the physical distance between the head-end and cable modem, the time delay (in milliseconds) can vary significantly. To compensate for delay, each cable modem employs a ranging protocol that effectively adjusts its internal clock. To do so, a number of consecutive timeslots (normally three) is reserved for each ranging process. The cable modem is instructed to transmit in the second timeslot. The CMTS measures the transmission and instructs the modem to adjust its clock as necessary. The two timeslots before and after create a gap to ensure that the ranging burst does not collide with other traffic.

Ranging is also used to coordinate the transmission power level of all cable modems, so that the upstream bursts arrive at the CMTS at the same level. A balanced transmission power level is essential for maintaining optimum performance of the upstream demodulator in the head-end. The attenuation from the cable modem to the head-end can vary by more than 15 dB.

Contention slots are open for all cable modems to transmit in. If two cable modems transmit in the same timeslot, their packets collide and the data is lost. When this occurs, the lack of positive ACK from the CMTS serves to indicate that the CMTS did not receive any data, and the cable modems retransmit at another, randomly selected time. Contention slots are normally used for very short data transmissions, such as a request for reserved slots, in order to transmit more data.

Ranging registration allows the cable modem to identify itself to the CMTS. It also allows the head-end

- to assign downstream and upstream frequencies;
- to set power levels; and
- to distribute other administration information necessary to manage the network.

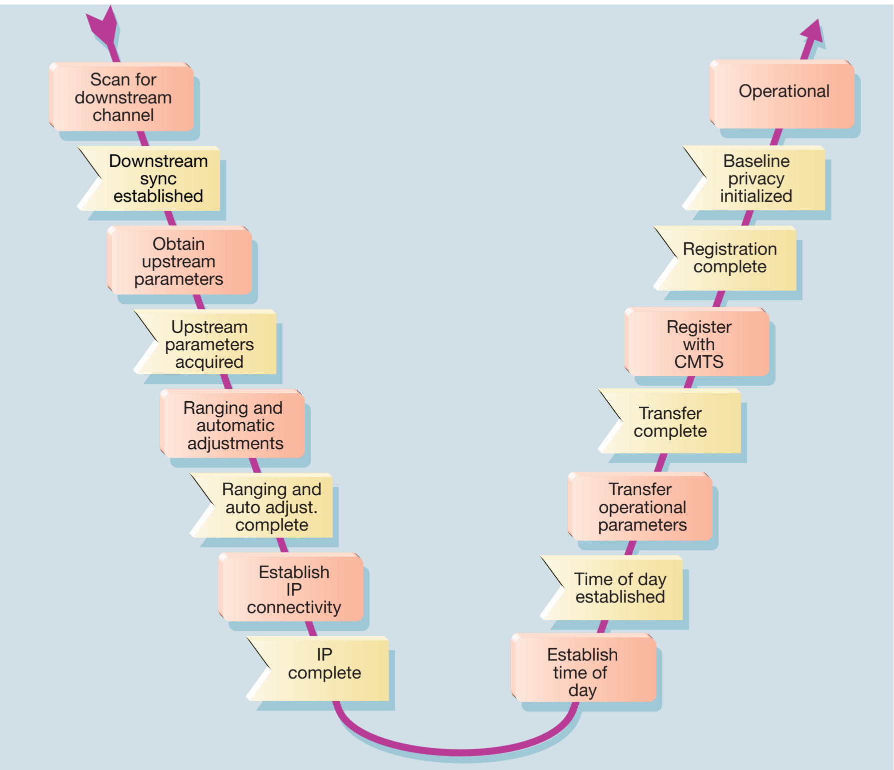


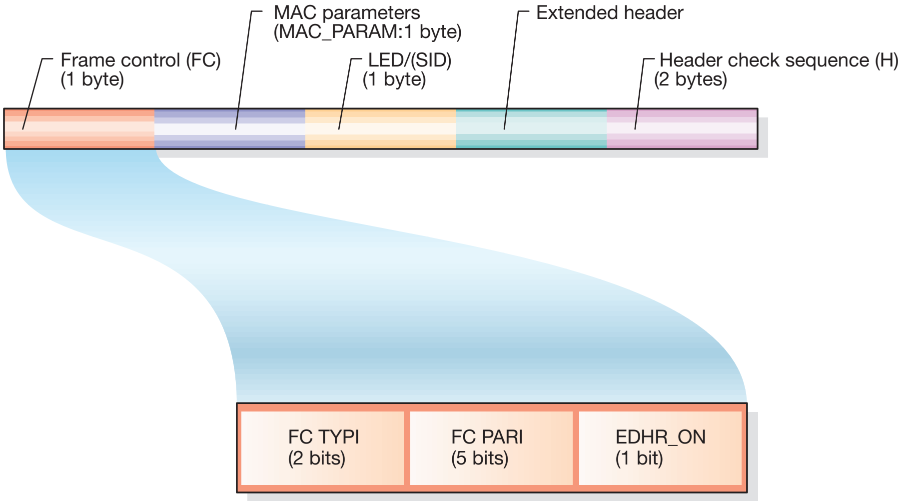
Figure 8
Initialization process.

The time-division multiple access (TDMA) transmissions from cable modems at various distances from the head-end must be coordinated so that all transmissions align with the boundaries of the head-end minislots. Discrepancies between individual modems and the head-end are caused by propagation delays in the CATV plant, the FEC interleaving function (a variable-depth interleaver supports latency-sensitive and latency-insensitive data), and processing time.

The CMTS informs the modem of the propagation delay after it receives the ranging request. Upstream frequency assignments can change at any time. The head-end ensures that the cable modem receives the new frequency assignment before listening for the modem's transmission on the frequency. After ranging is complete, the cable modem must invoke dynamic host configuration protocol (DHCP) mechanisms to obtain an IP address and continue the registration/configuration process (provisioning process).

The DHCP server responds with IP addresses, the name of the configuration file, and server addresses. After establishing a security association, the cable modem must download (via TFTP) a file with configuration parameters from the configuration server. The CMTS then checks that the configuration was obtained from a legitimate configuration server. Finally, the cable modem registers (Figure 8) with the CMTS and be-

Figure 9
Generic frame format.



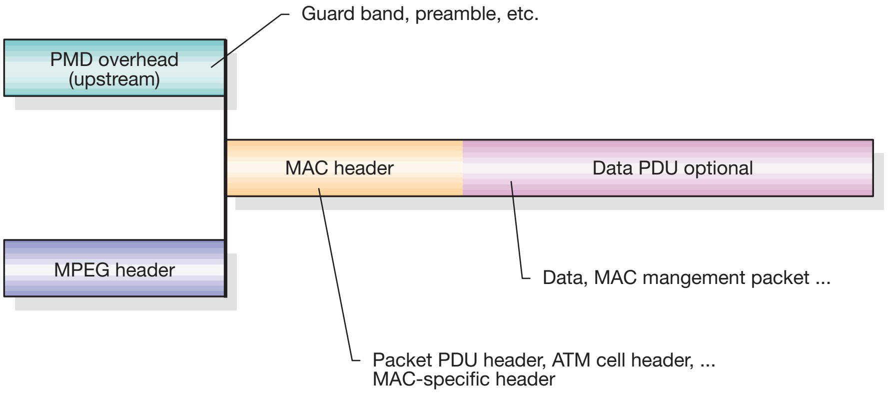


Figure 10
Generic MAC frame format.

comes operational. The CMTS must authorize the cable modem before it can send traffic into the network.

Each cable modem should contain a unique 48-bit MAC address (IEEE 802) that is assigned during the manufacturing process, and security information necessary to authenticate the cable modem.

When the initialization process has been completed, the customer premises equipment can communicate with the outside world through the CATV installation. The communication is bidirectional—downstream and upstream.

Upstream traffic

The term upstream is used to indicate the signal transmitted by the cable modem. Upstream traffic always occurs in bursts, so that many cable modems can transmit in the same frequency. Of the two modulation schemes (QPSK and 16 QAM), 16 QAM (four bits per symbol) is the fastest, but it is also the most sensitive to ingress noise. The upstream direction is characterized by

- a flexible and programmable cable modem under the control of the CMTS;
- frequency agility;
- time-division multiple access;
- QPSK and 16 QAM modulation formats;
- support for fixed-frame and variable-length packet data unit (PDU) formats;
- multiple symbol rates;
- programmable Reed-Solomon block coding; and
- programmable preambles.

When an Ethernet packet arrives at the cable modem from customer premises equipment, it is encapsulated in a MAC packet with a PDU header. The cable modem assesses bandwidth allocation for transmission opportunities and sends the MAC frame when allowed. Transmission opportunities have two basic components: number of minislots, and physical layer characteristics.

At the other end, the CMTS receives the packet, removes the header, and then forwards the packet to another cable modem through the radio frequency interface or to the WAN through the network side interface. Figure 9 shows a generic frame format; Figure 10 shows a generic MAC frame format. There are three types of MAC header: packet PDU MAC header, ATM cell MAC header, and MAC-specific header.

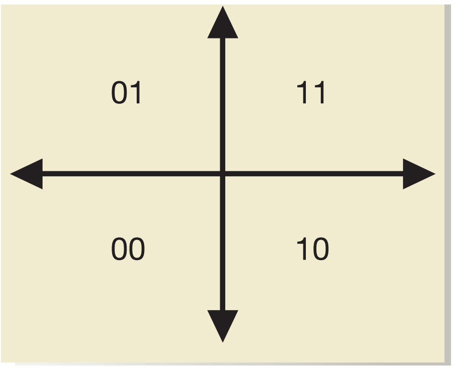


Figure 11
QPSK symbol mapping.

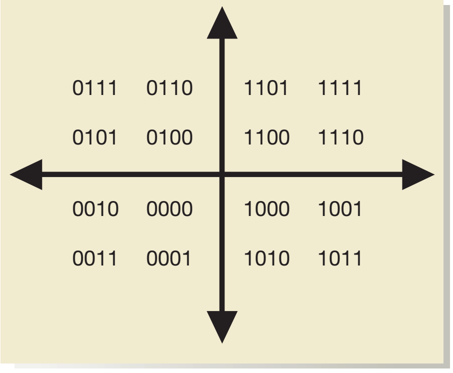


Figure 12
16 QAM symbol mapping.

In the upstream direction, the digital signal is encoded to QPSK or 16 QAM, converted into an analog signal, and sent to the tuner for transmission in the 5 to 65 MHz bandwidth. Figures 11 and 12 show the upstream symbol mappings. Figure 12 represents differential-coded symbol mapping.

Table 4 summarizes the characteristics of the upstream packets generated by the cable modem.

Downstream traffic

The RF signals from the CMTS to the cable modem are encoded in either 64 or 256 QAM. The symbol mappings resemble those shown in Figure 12, but with six-bit encoding for 64 QAM with 16 codes per quadrant, and eight-bit encoding for 256 QAM with 64 codes per quadrant.

There are several stages in the downstream transmission of packets from the CMTS to the cable modem.

When powering up, the cable modem extracts information that regulates when and how it is to communicate with the head-end. The information needed for the initial contact is available in the frames that are broadcast on the network.

During the ranging process, information is transmitted to help the cable modem adjust its timing and upstream transmission levels. After the modem has been registered, the downstream traffic will contain the download data and administrative information that the cable modem requested or information that the CMTS wants to distribute. Every cable modem can listen to the signals broadcast from the CMTS, but only the modem with the correct destination address can access the information contained in the payload section of the packet.

Ordinarily, one downstream channel is paired with multiple upstream channels to achieve the requisite balance in data bandwidth. Each modem transmits bursts in timeslots (reserved, contention or ranging). The cable modem must accept a modulated RF signal (Table 4).

Basic operation of the CMTS

A head-end cable modem termination system communicates with cable modems located in subscribers' homes, to create a virtual local area network (LAN) connection.

TABLE 4, ELECTRICAL OUTPUT FROM THE CABLE MODEM

Parameter	North America	Europe
Frequency	5 to 42 MHz edge to edge	5 to 65 MHz edge to edge
Level range	+8 to 55 dBmV (16 QAM) +8 to +58 dBmV (QPSK)	+68 to 115 dBµV (16 QAM) +68 to +118 dBµV (QPSK)
Modulation type	QPSK and 16 QAM	QPSK and 16 QAM
Symbol rate (nominal)	160, 320, 640, 1,280 and 2,560 ksym/sec	160, 320, 640, 1,280 and 2,560 ksym/sec
Bandwidth	200, 400, 800, 1,600 and 3,200 kHz	200, 400, 800, 1,600 and 3,200 kHz
Output impedance	75 ohms	75 ohms
Output return loss	> 6 dB (5-42 MHz)	> 6 dB (5-65 MHz)
Connector	F-connector per [IPS-SP-406] (in common with the input)	F-connector per [IPS-SP-406] (in common with the input)

Signals from various sources, including broadcast transmissions, satellite-delivered programming, and local television broadcasts, are received and processed in the head-end. Each television signal travels on a different frequency that acts as a self-contained spectrum inside the cable.

Network-layer requirements for the CMTS extend beyond transparency to IP traffic. The CMTS must also support

- variable-length subnet masks;
- classless addressing;
- IP multicast addressing and forwarding;
- Internet group management protocol (IGMP);
- proxy ARP; and
- the filtering of DHCP downstream-bound broadcast packets to protect against BOOTP server spoofing.

The data-over-cable protocol relies heavily on the CMTS for its implementation. Each node on the head-end is capable of supporting between 1 and 2,000 cable modems. The average number of cable modems per node is expected to be around 500. The CMTS is responsible for the initialization, ranging and maintenance of the network formed by the cable modems. The initialization process, which is managed by the CMTS, can be divided into the following phases:

- synchronization—the CMTS sends timing and frequency information to the cable modem, to establish synchronization;
- ranging—the CMTS guides the cable modem through the ranging process;
- IP connectivity—the CMTS establishes IP connectivity;
- time—the CMTS establishes the time of day;
- settings—the CMTS transfers operational parameters; and
- baseline privacy initialization (BPI)—the CMTS initializes baseline privacy if the cable modem can run it.

The CMTS and the cable modem operate as forwarding agents and as hosts. Figure 13 shows the protocol stack used by these components. The data forwarded through the cable modem is *link-layer transparent bridging* and supports multiple network layers.

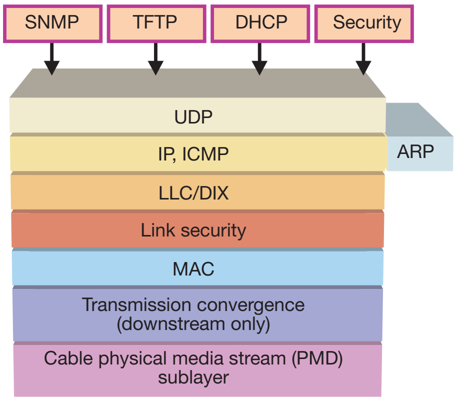


Figure 13
Protocol stack on the RF interface.

The main function of the CMTS is to transmit IP packets transparently between the head-end and end-user. Management functions, such as support for spectrum management and software downloads, are sent as IP packets as demonstrated in Figure 13. Both the CMTS and the cable modem operate as IP and logical link control (LLC) hosts according to the IEEE 802 standard for communication over the cable network. The CMTS must support the transport of IP traffic and must be able to restrict the network layer to a single protocol, such as IP.

Conceptually, the CMTS forwards data packets at two interfaces between the CMTS-RFI and the CMTS-NSI, and between the upstream and downstream channels (Figure 14).

The cable modem access network operates at layers 1 (physical) and 2 (media access control/logical link control) of the open systems interconnection (OSI) reference model. Thus, layer 3 (network) protocols, such as

Figure 14
Data forwarding through the CMTS and cable modem.

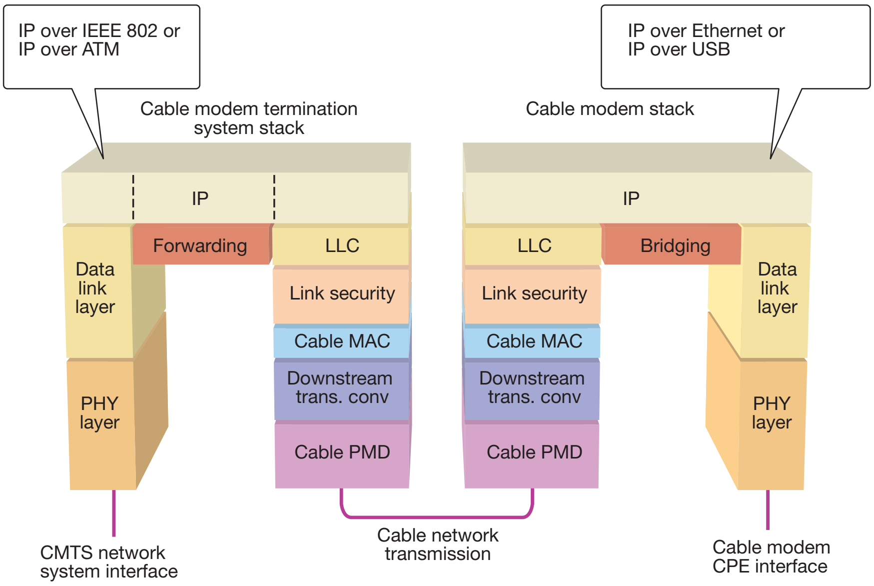


Figure 15
Ericsson currently offers two cable modem products: the PipeRider HM200c and HM201c. The HM200c is DOCSIS 1.0 certified and the HM201c is Euro-DOCSIS certified. The HM200c has received conditional @Home certification. The PipeRiders connect to customer premises equipment via USB and 10 Mbit/s Ethernet interfaces. A PipeLock security button allows the user to isolate the LAN and WAN sides of the cable modem when it is not in use, but keeps the modem attached to the system and available for instant access. In accordance with a specification in the DOCSIS standard, the modem software can be upgraded remotely by the cable operator. The HM200c/HM201c has been certified by regulatory bodies for use in the US, Canada, the EU, Japan, Korea, Australia, and China.

IP traffic, can be seamlessly delivered to end-users over the cable modem platform.

Standardization

In the US, cable operators formed a consortium called CableLabs to accelerate the development of standards within the cable industry. In Europe, tComLabs performs a similar role. Other efforts are currently underway in Europe and North America to standardize voice over IP (VoIP) over cable and home networking.

One of CableLabs' recent standards regulates the sending of data over cable. This effort resulted in the development of the data-over-cable service interface specification (DOCSIS) which was adopted as IEEE 802.14. An appendix to this standard applies to European television standards. The standard was also adopted by tComLabs, a consortium of European operators who coordinated it as Euro-DOCSIS 1.0. (ETSI standard, ES 201 488 V1.1.1). It is based on the 1.1 RFI Version IO6, which is included in tComLabs' appendix to Euro-DOCSIS.

Every cable modem has to go through DOCSIS certification by CableLabs. To date, DOCSIS has gone through seventeen certification waves. Each wave consists of a set of lab tests and documentation to ensure cable modem design compliance with established specifications and standards. Euro-DOCSIS requirements are certified by tComLabs. They are currently in their third wave of compliance testing.

VoIP

Many cable operators are eyeing voice over IP as a major source of revenue and have asked CableLabs to develop a standard, known as PacketCable, which includes voice as well as provisions for other kinds of media. The standard prompted several enhancements to the DOCSIS standard (DOCSIS 1.1), including quality of service (QoS) and additional remote-management features.

TRADEMARKS

PacketCable and DOCSIS are trademarks and/or trade dress of CableLabs or third parties.

Some of the enhancements are

- configuration and registration for cable-modem-based QoS;
- fragmentation of upstream packet data;
- payload header suppression; and
- dynamic establishment of QoS-enabled service flows by the CMTS.

The PacketCable standard stipulates how quality of service should be implemented for different kinds of multimedia flow. The security part of the standard also incorporates provisions for baseline privacy and encryption protocols, for encrypting packet data across the cable network.

The future of cable modems

In the future, cable modems will probably be bundled with other networking features and LAN technologies to facilitate the distribution of broadband IP into the home. At the low end, simple versions of cable modems will be incorporated into personal computers. This evolution into a home gateway is already starting to take place. For convenience and security, the gateway will provide basic software features, such as network address translation (NAT), and function as a DHCP server for local devices, allowing users to set up an extensive home network. Firewalls and content filtering can also be incorporated into the modem to enhance the security of the family computing environment. Operators can simplify the implementation and generate additional revenue by offering these features in the form of a managed service.

Universal plug and play is being investigated to make implementation easy. Other wired and wireless LAN interfaces are being considered, including Bluetooth, HiperLAN/2, HomePNA and powerline networks. Specialty devices, such as set-top boxes and game machines, might also come with built-in cable modems in the future. These devices might even serve as home gateways.

Regardless of the form these devices take, the most interesting and exciting part will be the additional capabilities, services, and entertainment that broadband access will bring into our homes.

Conclusion

A tremendous opportunity exists with broadband over cable. Cable industry standardization is driving exponential growth as evidenced by sales of DOCSIS-standard modems. Cable modems with wireless interfaces will form a foundation step to increased opportunities for mobile Internet services in the home. Soon Internet protocol solutions for various broadband-to-home methods (cable, DSL, fiber) will converge to similar systems. These solutions will not only include infrastructure, but also a suite of additional revenue-producing services for operators.

The full set of services available from Ericsson to cable operators will be a key differentiator among equipment providers. Much of the work for fixed and mobile IP access already developed by Ericsson can be applied to the cable end-to-end solution.

Ericsson has the right mix of capabilities to make broadband over cable a success—cable modems, infrastructure and services. This combination constitutes the bridge that links the worldwide Internet to the home.

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