

Chips and high-speed cable modems enable two-way communications

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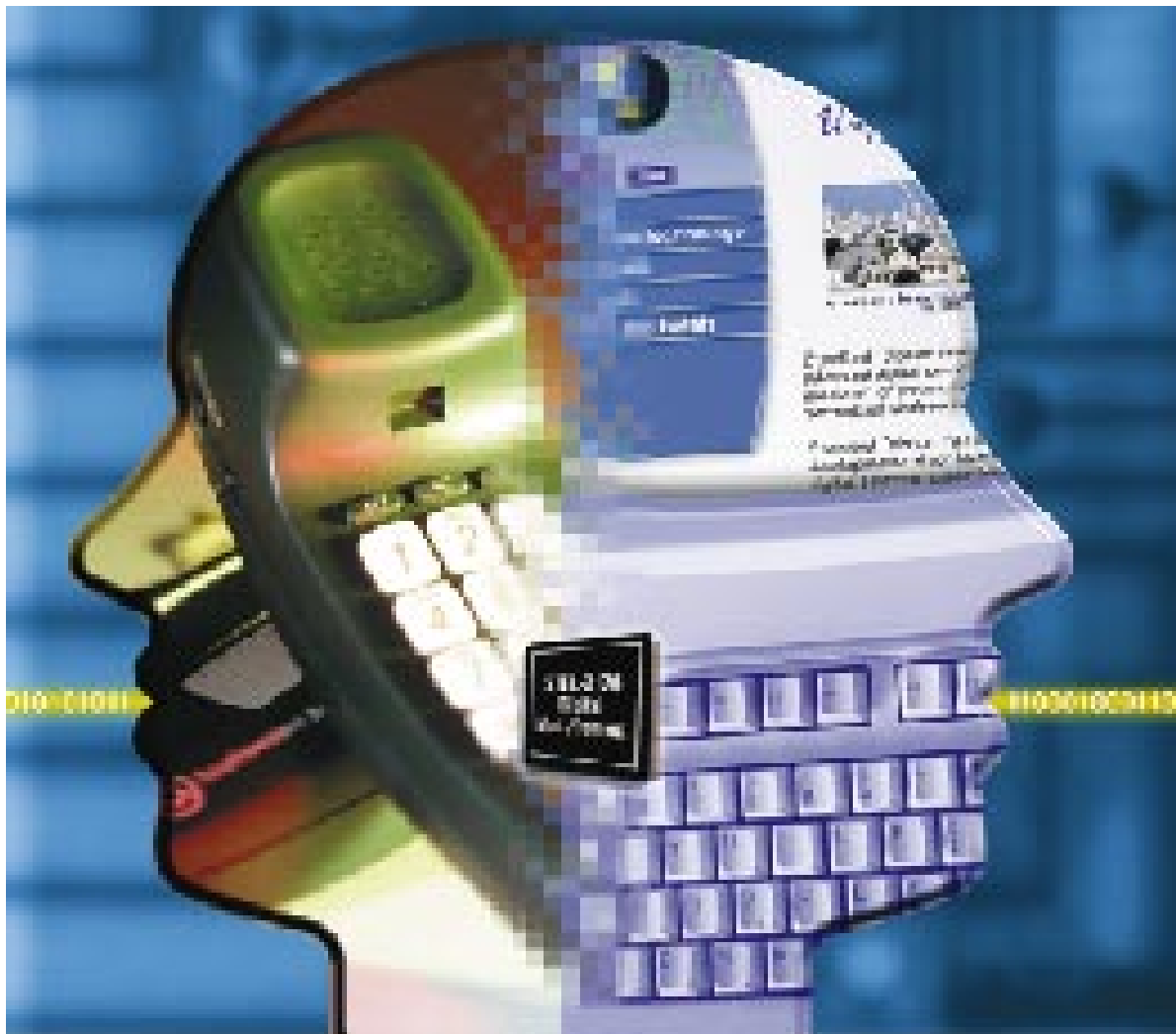


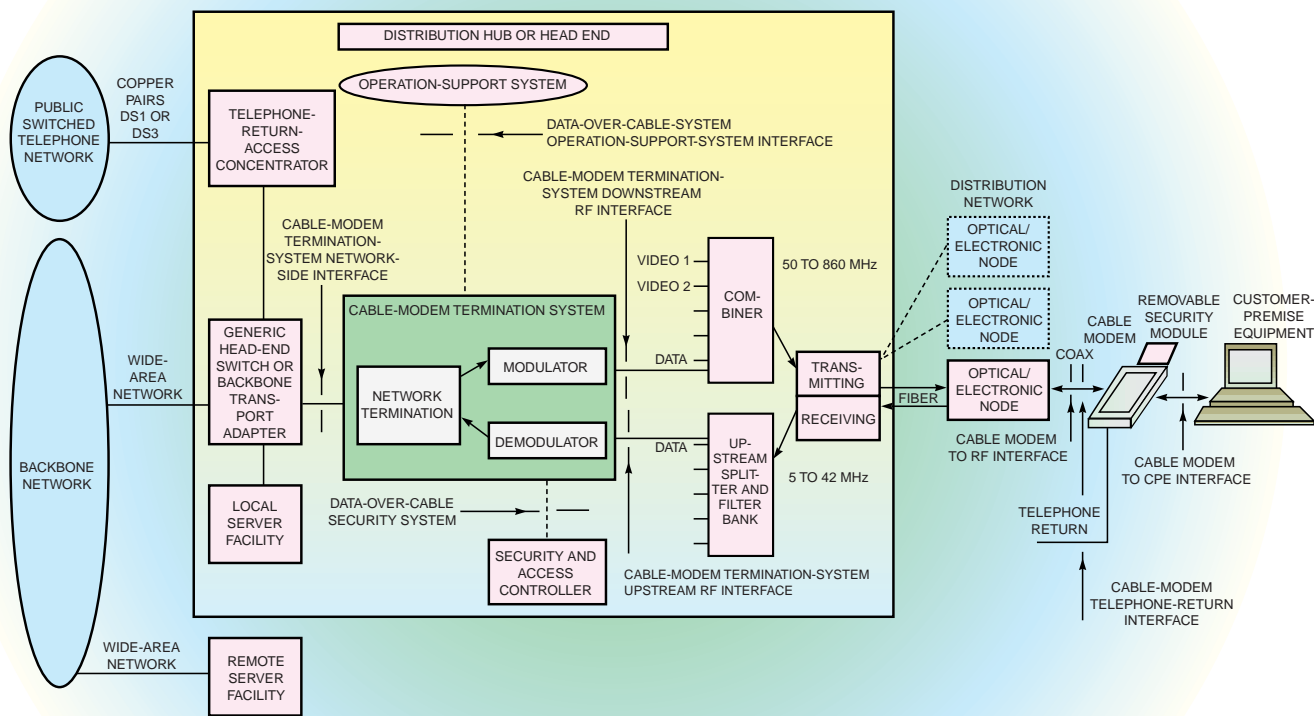
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New cable-modem specifications standardize high-speed, two-way communications. Now, you can use highly integrated chips to customize consumer-friendly modems for retail shelves.

Thanks to emerging standards, chip vendors' products can now accommodate high-speed cable modems for two-way data communications. These products overcome the barriers of using outdated cable-TV technology that once targeted only video broadcast. Today's data communications on cable-TV networks require upstream signaling and increased capacity for possible multitudes of data subscribers. A big step toward overcoming these problems occurred with the emergence of the Data Over Cable Service Interface Specification (DOCSIS).

Realizing a need for a specification to handle today's high-speed, two-way communications, a group of leading cable-TV operators formed the Multimedia Cable Network Systems (MCNS), which in turn introduced DOCSIS, specifying modem interfaces and protocols. The completed first revision of

FIGURE 1



This data-over-cable reference architecture is the basis for services and interfaces specified by MCNS DOCSIS.

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DOCSIS meets the RF-interface, multicasting, network-management, and mobility needs of today's applications. In turn, chip vendors can integrate DOCSIS-compliant circuits into low-cost and efficient chips. Modem designers, in turn, can use these chips to customize interoperable modems without sweating the complexity of two-way RF communications.

Even though designers must produce standard modems, many opportunities are available to differentiate modems. The features that make these modems popular with consumers are ease of installation and ease of use. Features beneficial to multiple-systems operators—cable-TV companies that operate multiple systems in different geographic areas—are network management and multicasting.

Multicasting of premium programming, such as live concerts and stock tickers, is attractive because the operator saves bandwidth by sending out a single copy of the program to a multicast group address and allowing subscribers to join the multicast group. The Internet Group Management Protocol (IGMP) from the Internet Engineering Task Force (IETF) governs these multicast schemes. These schemes work well for controlled intranets, such as cable networks, as long as the hardware and software for content servers, routers, cable modems, and user PCs support IGMP.

Mobility is also important for both multiple-systems operators and consumers; consumers should be able to take their modems to any cable operator's domain and plug and play into the network. The National Cable Television Association estimates that 47% of US cable networks will be capable of two-way communications by year's end. This fact means that about 47% of the 60 million cable subscribers will be eligible for megabit-per-second Internet access at the going rate—about \$40/month.

You can use DOCSIS-compliant modems in cable systems worldwide because of international standards recognition by the ITU (International Telecommunications Union). DOCSIS reached widespread acceptance relatively quickly. Its acceptance grew out

@ a glance

- The Data Over Cable Service Interface Specification (DOCSIS) specifies two-way cable modems for an all-coax or a hybrid-fiber-coax (HFC) network: the cable-modem termination system (CMTS) at the head end and the cable modem at the subscriber end.
- The downstream band of an HFC network can support as much as 40 Mbps per 6-MHz carrier. There can be as many as 115 carriers to divide between video and data.
- The upstream band of an HFC network supports as much as 10 Mbps on carrier frequencies of variable width in the subsplit (5 to 42 or 65 MHz, depending on the standard). These carriers have frequency agility to avoid narrowband-noise problems.
- DOCSIS provides efficient and transparent bidirectional transfers of Internet Protocol packets between the head-end and subscriber locations. Data privacy and forward error correction protect data integrity.
- Standards-compliant chips for cable modems use mixed-signal techniques to provide the bandwidth and reliability to serve broadband requirements. Modem designers can focus on customer features to make their products stand out on retail shelves.

of MCNS' impatience with the IEEE-802.14 data-over-cable work group. MCNS perceived a limited market window for data over cable. It had to move quickly because asynchronous-digital-subscriber-line (ADSL) technology for Internet access through telephone lines might slam the window shut by dominating broadband access connections ([Reference 1](#)). Thinking the 802.14 work group's dependence on asynchronous transfer mode (ATM) might delay the standard, MCNS and CableLabs quickly developed a data-over-cable standard based on existing technology. They focused on transparently transmitting Internet Protocol (IP) packets between the head-end and subscriber locations. Once DOCSIS was completed, the Society of Cable Telecommunications Engineers adopted it and promoted it as an update to ITU-T J.83 for data over cable. It appears that the ITU will approve DOCSIS as an international standard this year.

At the heart of DOCSIS is an architecture with modems for the head and subscriber ends of a hybrid-fiber-coax (HFC) or all-coax network. The architecture describes interfaces and communications protocols for a scalable, bidirectional network ([Figure 1](#)). The family of standards that describes these modems is available at CableLabs Web site, www.cablemodem.com. Besides modems, the DOCSIS family includes operation- and business-support specifications for security, configuration, performance, fault, and accounting

management. An optional telephony return-path specification provides for networks in which the cable plant has difficulty supporting upstream radio communications.

Developing the DOCSIS standard employed mainstream technology, such as Ethernet, MPEG (Moving Pictures Experts Group), and the US Data Encryption Standard (DES), whenever possible to quickly complete the standard. For example, DOCSIS uses 10-Mbit Ethernet for connecting the subscriber modem to the end-user computer because this technology was mature, cheap, and available. In keeping with this modus operandi, future enhancements for USB computer connections will be available this year. Also on the enhancement list is the availability of IEEE 1394 for modem-to-set-top-box connections.

DOCSIS describes the cable modem at the subscriber location and the cable-modem termination system (CMTS) at the head end or distribution hub. DOCSIS also specifies the RF interface between the two modems, describes the interface between the customer-premise equipment (CPE) and the cable modem, and describes the interface between the Internet network and the CMTS. Both modems contain cable-system-specific media-access control (MAC) for managing the RF link. The MAC specification for the cable modem targets the lowest cost for subscriber modems, and the CMTS includes the complex circuitry to manage sending

and receiving multiple-megabit-per-second data streams. DOCSIS leaves defining the remainder of the modem specification to equipment designers who can customize their modems by making trade-offs between features and cost.

Enormous bandwidth

Cable networks boast enormous bandwidth because of well-designed cable plants and modems. By optimizing cable modems for the HFC topology,

DOCSIS takes advantage of this bandwidth (see [sidebar “Hybrid-fiber coax and upstream-modulation impairments”](#)).

The HFC network broadcasts downstream to all nodes. The upstream sub-split, which allows bidirectional traffic on one cable by dividing the frequency spectrum, requires end nodes to negotiate bandwidth reservations: Upstream signals use 5 to 42 MHz, or 65 MHz for the Digital Audio Visual Council

(DAVIC), and downstream broadcasts use from 50 MHz to the upper frequency limit—typically 300 to 860 MHz, depending on the system. Each subscriber modem acquires only the portion of the downstream broadcast addressed to it. These downstream transmissions achieve 27 Mbps on each 6-MHz video channel when using 64 quadrature amplitude modulation (QAM). QAM packs multiple bits into one symbol period; thus, 64 QAM refers

HYBRID-FIBER-COAX AND UPSTREAM-MODULATION IMPAIRMENTS

Hybrid-fiber coax (HFC) describes a distribution cabling system in which fiber trunks feed neighborhood fiber nodes, and coax cable then connects the neighborhood node to each subscriber location ([Figure A](#)). Typically, the maximum separation between the head end and the end-user node is 10 to 15 miles; the maximum separation is 100 miles. Most new and rebuilt cable-TV constructions use this topology.

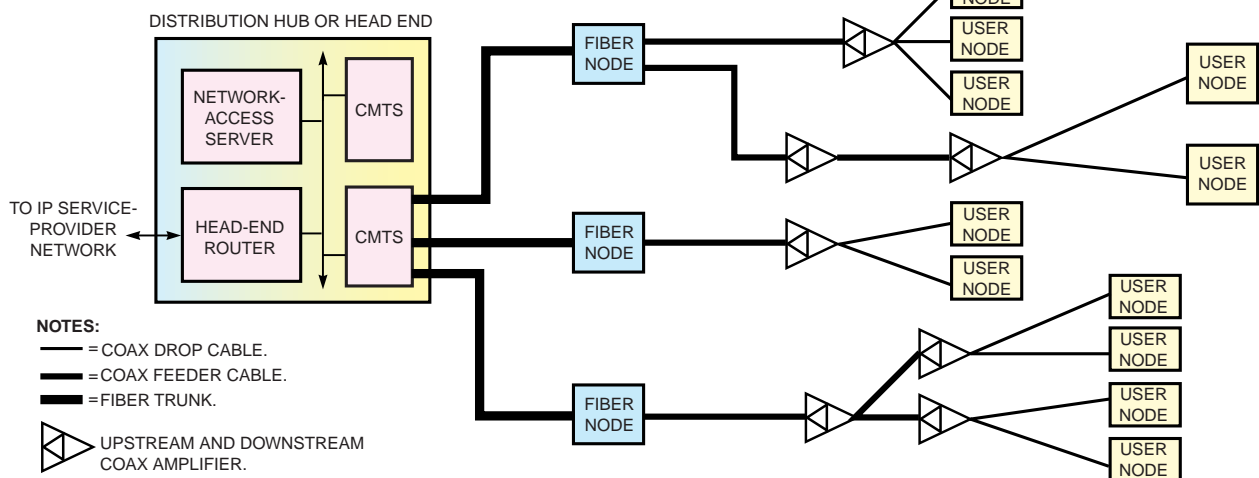
In all cable networks, noise “funneling” is one of the major problems that inhibit upstream data communication. In tree-and-branch architectures, the return noise is an accumulation of the noise from all the upstream amplifiers, plus incoming noise, impulse noise, and other impairments. Funneling noise occurs when all these noise sources combine into one return path to the cable-modem termination system (CMTS). Only the most robust modulation schemes, such as quadrature-phase-shift keying (QPSK) and 16 quadrature-amplitude modulation (QAM), can cope with this noise profile.

HFC systems reduce noise funneling by dividing the large distribution area into many neighborhood service areas. A single fiber attach-

es each service-area node to the system’s signal-processing center, where the network-access server and head-end router reside. This topology reduces the number of return-path amplifiers feeding one CMTS. The electrical-to-fiber conversion node multiplexes all upstream signals into the fiber optics for transport to the processing center.

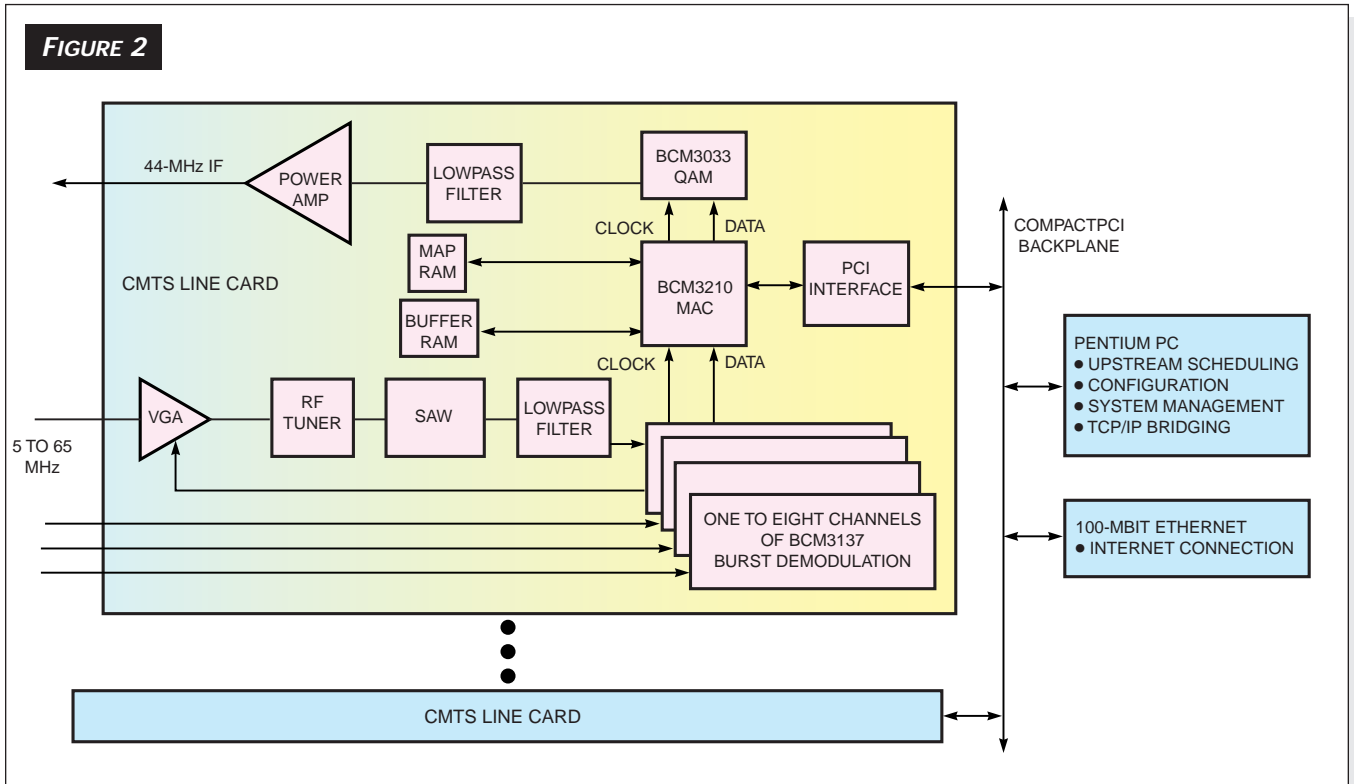
The Multimedia Cable Network Systems (MCNS) Data Over Cable Service Interface Specification (DOCSIS) goes a step further in eliminating upstream-noise problems. It provides five symbol rates, two modulation formats, carrier-frequency agility, pulse shaping, and selectable output power levels. Carrier-frequency agility allows the cable operator to move the upstream carrier to avoid narrowband incoming noise. This noise is not random but is caused by International Radio Regulations-compliant signals, such as broadcast, amateur, and citizens’ band (CB) radios. Flexible symbol rates, formats, and power levels enable operators to use the upstream spectrum to maximum efficiency.

FIGURE A



The maximum number of user nodes to each fiber node is 500 to 3000, depending on the equipment supplier. The system can cascade four to 10 coax amplifiers, depending on the vendor equipment.

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Broadcom's cable-modem-termination-system line-card reference design is for use in head end equipment with a Compact-PCI backplane. A Pentium PC card processes MCNS protocols for managing the downstream and upstream cable network.

to the 64 signals per symbol. More than 115 video channels can exist in a 750-MHz cable system, and you can calculate the aggregate bandwidth. Also, the data rate can increase to 40 Mbps on each channel if the head end, subscriber mo-dems, and cable plant can support 256 QAM. (For a more in-depth discussion of the potential bandwidth of cable systems, check out www.cablelabs.com/ModemPerf.pdf.)

Along with the enormous downstream bandwidth comes a significant upstream bandwidth in the HFC network. DOCSIS uses frequency-division multiple access to divide the 5- to 42-MHz upstream frequency band into 200-kHz- to 3.2-MHz-wide carriers. Different carrier widths accommodate different data-rate requirements (Table 1). Each of these carrier channels also has TDMA slots, or minislots, so multiple cable modems can simultaneously use one channel. A cable modem that wants to transmit upstream nego-

tiates with the CMTS for minislots in the cable modem's assigned frequency carrier.

This HFC cable-system bandwidth lets operators start with a few downstream channels assigned to data and then allocate more video channels for data as cable-modem subscribers and traffic increase. Cable operators plan to expand data capacity without losing video channels by using another borrowed technology, MPEG. DOCSIS incorporates the MPEG-2 transport technology used in digital-TV standards

to pack as many as six video streams into the 6-MHz analog NTSC channel. Each 6-MHz channel uses MPEG-2 to multiplex compressed digital video and even data streams into the same channel.

Negotiating upstream paths

The HFC system has plenty of shared bandwidth in both directions. Cable modems can easily snoop—listen to all traffic in—the broadcast for data addressed to them. The difficult technical question is: How do potentially thousands of cable modems avoid transmitting over each other in the upstream direction? DOCSIS derived a solution for sharing the upstream bandwidth among thousands of nodes. The DOCSIS upstream transmissions use a hybrid MAC developed for cable TV's shared network.

The hybrid MAC benefits from carrier-sense-multiple-access/collision-detection (CSMA/CD) and Token Ring MACs. CSMA/CD is the Ethernet media-access proto-

TABLE 1—UPSTREAM SYMBOL AND DATA RATES

Burst symbol rate (M symbols/sec)	Maximum channel width (MHz)	Burst QPSK bit rate (Mbps)
0.16	0.2	0.32
0.32	0.4	0.64
0.64	0.8	1.28
1.28	1.6	2.56
2.56	3.2	5.12

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col that allows nodes on a shared network to negotiate for transmission. CSMA/CD's best feature is the zero latency that results when a transmitting node senses the network is idle and just starts to transmit. However, when nodes sense that the network is in use, they wait before trying to transmit again. If two nodes collide—because both sense an idle interval and begin to transmit simultaneously—they back off and retransmit after a random time interval. This scheme causes latency, efficiency, and fairness to suffer when many nodes want to transmit. Token Ring works best when many nodes want to transmit. The Token Ring protocol passes a transmit token around the ring, which gives each node a fair chance at transmission. The node with the token transmits in the next time slot, thereby allowing fair and efficient access to a congested network. However, when the network is idle, efficiency suffers, because a node must wait until the token comes back around before the node can transmit.

The hybrid MAC uses the best of both negotiation schemes. Each node that wants to transmit upstream can transmit in reserved minislots when network congestion occurs or can use a collision and back-off scheme when the network is uncongested. DOCSIS also provides for the end node to reserve minislot groups for block file transfers.

To keep data streams orderly, the hybrid-MAC protocol uses a service ID (SID). The SID identifies a cable modem to the CMTS for upstream bandwidth allocation and enables the CMTS to guarantee bandwidth and delay parameters so multimedia streams can have quality of service. To identify data streams, the CMTS assigns one unique SID or more to a cable modem during registration. Each SID corresponds to a class of service—latency and throughput—requested by the cable modem. The most basic cable modem uses one SID for best-effort IP service. More complex modems use SIDs to support multiple “data flows.” Protocols such as the ReSerVation Protocol (RSVP) introduce

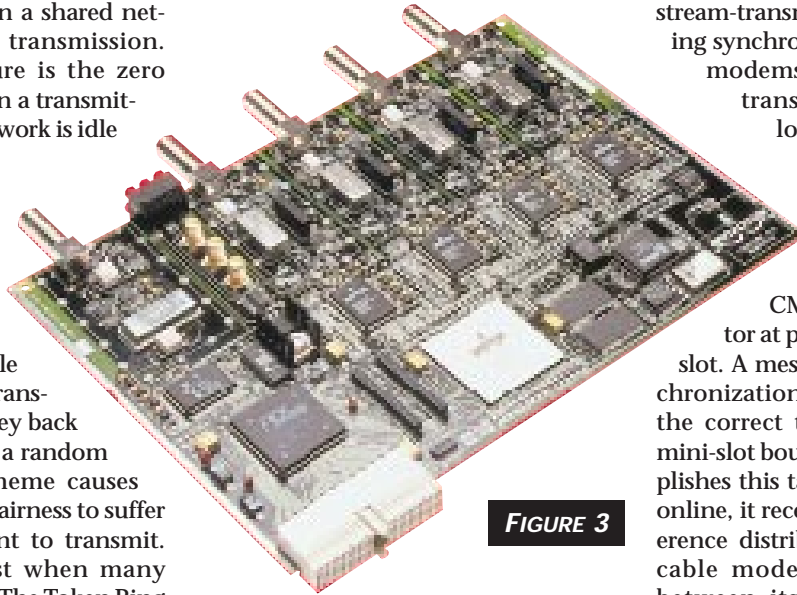


FIGURE 3

Broadcom's CMTS line card depicts the four upstream demodulator inputs that interface to one CMTS MAC. The CompactPCI line card helps accelerate software development.

data flows, which allow IP traffic to meet time-constraint requirements for streaming-video applications, such as videoconferencing and multimedia.

Now, consider the problems associated with the plug-and-play nature of the cable modem. When a cable modem comes online in a network, it must first synchronize with the head end by detecting and interpreting broadcast timing information. Then, the cable modem scans the downstream signals for the upstream channel-map messages that the CMTS periodically broadcasts. The map messages include the upstream negotiation parameters. Using the map, the cable modem begins a message-passing scheme that lets the head end and cable modem find out each other's capability for data rates, IP addresses, and upstream-transmission requirements. Because the upstream-transmission parameters adjust to changing line conditions, such as incoming noise, the head end periodically updates the upstream bandwidth availability map to each subscriber node. Through this procedure, the cable modem knows which frequency channel and which minislots to use for upstream transmission.

Another complex part of the up-

stream-transmission system is the timing synchronization of multiple cable modems participating in TDMA transmissions from disparate locations. The transmitted packets from cable modems can have miles of delay difference to the head end but still must arrive at the CMTS up-stream demodulator at precisely the assigned mini-

slot. A messaging scheme, using synchronization and ranging (acquiring the correct timing offset to align to mini-slot boundaries) messages, accomplishes this task. As the modem comes online, it receives the global timing reference distributed by the CMTS. The cable modem calculates the delay between itself and the CMTS and adjusts its clock accordingly. The cable modem then sends a ranging message to the CMTS with the delay value that makes the cable modem appear to be right next to the CMTS. The cable-modem registration then completes through more message exchanges with the CMTS.

Complex MAC in the CMTS

Most of the complexity involved with configuration, timing, and upstream negotiation resides in the CMTS because of a conscious decision by the DOCSIS architects to keep down the cost of the cable modem. The CMTS is usually a line card in the cable head end equipment. Other components in the head end are MPEG-2 digital-video components, analog-video components, and HFC optical-transport equipment. The CMTS line card includes the downstream QAM and the upstream burst demodulator.

The principal function of the CMTS is forwarding IP packets (Reference 2). The CMTS MAC moves packets between the network-side interface and the RF interfaces and between the upstream RF interface and the downstream interface. MAC forwarding may use the layer-2 bridging, or it may use layer-3 routing protocols from the Open Systems Interconnect network model. The CMTS must also support spanning-tree protocols to reconcile any loop paths that may exist in the

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network. Because cable modems transmit to only the CMTS, the shortest path between nodes in the same upstream trunk forwards packets from the upstream to the downstream RF interface. DOCSIS calls this function the "MAC forwarder function," and it provides connectivity for nodes in the same MAC domain.

The CMTS MAC must control many functions with many algorithm trade-offs. These functions, such as timing synchronization, dynamic host configuration, cable-modem registration, and operational parameter transfers, must comply with the DOCSIS standard, yet there is room for product differentiation in performance and scalability. So

far, only Broadcom offers its version of CMTS MAC in a commercially available chip, the BCM3210. The chip controls head-end functions with four key message types (Table 2, pg 68). Messages sent downstream both to cable-modem MACs and to the CMTS upstream demodulator are the upstream bandwidth-allocation map (MAP) and the upstream channel description. These messages contain information on upstream channel configuration and minislot allocation. The CMTS MAC appends the bandwidth- and ranging-request messages received from the cable modems at the upstream demodulator. The messages need additional information, such as time stamps,

upstream channel identification, ranging information, and power offsets, before forwarding to the processor for system management. In addition to controlling upstream scheduling, the external processor controls the IP packet bridging and the configuration for the MAC forwarding domain.

A CMTS reference design demonstrates its functionality on a line card (Figures 2 and 3). The BCM93210 DOCSIS-compliant CompactPCI line card has four upstream demodulators and a downstream modulator in addition to the MAC device. The card provides 64 and 256 QAM downstream and quadrature phase-shift keying (QPSK) or 16 QAM upstream. The board uses a

REPRESENTATIVE CABLE-MODEM CHIP-SET STANDARDS ORGANIZATIONS AND VENDORS

For more information on products such as those described in this article, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service. When you contact any of the following manufacturers directly, please let them know you read about their products in EDN.

STANDARDS AND TRADE ORGANIZATIONS
CableLabs
Louisville, CO
1-303-661-9100
www.cablelabs.com
www.cablemodem.com
Circle No. 413

Digital Audio Visual Council (DAVIC)
Geneva, Switzerland
www.davic.org
Circle No. 414

Digital Video Broadcasting (DVB)
Geneva, Switzerland
+41 22 717 2719
fax +41 22 717 2727
www.dvb.org
Circle No. 415

IEEE 802.14 Work Group
www.walkingdog.com/catv
Circle No. 416

International Telecommunication Union
Geneva, Switzerland
www.itu.ch
Circle No. 417

Internet Engineering Task Force, Internet Protocol Over Cable Data Networks Work Group
www.ietf.org/html.charters/cable-TV
ipcdn-charter.html
Circle No. 418

Society of Cable Telecommunications Engineers
Exton, PA
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www.scte.org
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www.analog.com
Circle No. 420

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fax 1-714-450-8710
www.broadcom.com
Circle No. 421

Hitachi Semiconductor
Brisbane, CA
1-800-285-1601
fax 1-303-297-0447
www.hitachi.com/semiconductor
Circle No. 422

IBM Microelectronics
Hopewell Junction, NY
www.chips.ibm.com
Circle No. 423

Integrated Device Technology
Santa Clara, CA
1-800-345-7015
www.idt.com
Circle No. 424

Libit
Englewood Cliffs, NJ
1-650-949-2864
www.libit.com
Circle No. 425

LSI Logic
Milpitas, CA
1-800-574-4286
www.lsilogic.com
Circle No. 426

Lucent Technologies
Berkeley Heights, NJ
1-800-372-2447
www.lucent.com
Circle No. 427

Maxim Integrated Products
Sunnyvale, CA
1-800-998-8800
www.maxim-ic.com
Circle No. 428

Motorola
Phoenix, AZ
1-800-521-6274
www.mot.com/sps
Circle No. 429

QNX Software Services
Ottawa, ON, Canada
1-800-676-0566, ext 3000
www.qnx.com
Circle No. 430

Rockwell Semiconductor
Newport Beach, CA
1-800-854-8099
www.rss.rockwell.com
Circle No. 431

SGS-Thomson
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www.st.com
Circle No. 432

Siemens
Cupertino, CA
1-408-777-4500
www.sci.siemens.com
Circle No. 433

Stanford Telecom
Sunnyvale, CA
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fax 1-408-541-9030
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CABLE-MODEM CHIPS

TABLE 2—REPRESENTATIVE CABLE-MODEM CHIPS

Vendor	Part/ price	Function	Modulation; demodulation	Forward error correction	Compatible standards
Analog Devices Circle No. 420	AD9853 \$10.50 (100,000)	Cable-modem digital modulator; integrates high-speed direct digital synthesis, digital 10-bit DAC filters, and DSP digital functions; accepts 20-MHz external clock and internally generates 125-MHz clock	QPSK, 16 QAM	NA	NA
Broadcom Circle No. 421	BCM3210 \$150 (1000)	CMTS MAC; supervises as many as eight upstream and one downstream physical-layer devices; baseline-privacy encryption and decryption; manages upstream hybrid contention/reservation protocol; processes time stamps and system timing; MPEG framing	NA	Annex A and B	MCNS
	BCM3033 \$90 (1000)	CMTS QAMLink universal modulator; variable data rates to 7 Mbaud; 10-bit DAC	4, 16, 32, 64, 128, 256 QAM	Annex A, B, and C	MCNS, DVB/DAVIC, IEEE 802.14
	BCM3137 \$175 (1000)	CMTS QAMLink universal burst demodulator; variable symbol rates from 100 kbaud to 5.12 Mbaud; dual 10-bit ADC plus 6-bit ADC to estimate off-chip analog power; forward-error-correction decoder comprises programmable derandomizer and Reed-Solomon decoder	QPSK, 16 QAM	NA	MCNS, DVB/DAVIC, IEEE 802.14
	BCM3220 \$30 (10,000)	Cable-modem MAC; processes messages; DES encryption/decryption; downstream time-division multiplexing; upstream header and TDMA control; error checking; DOCSIS two-way radio and telephone-return compliant; Motorola 68xxx μ P interface; termination of MPEG-2 convergence	NA	NA	MCNS
	BCM3116 \$30 (10,000)	Cable-modem QAMLink MCNS/DOCSIS receiver; integrated demodulator and forward-error-correction decoder; 10-bit ADC; equalization and echo cancellation	4 to 256 QAM	Annex B	MCNS
	BCM3037 \$20 (10,000)	Cable-modem QAMLink upstream burst modulator; variable symbol rate as high as 6.25 Mbaud; 5 to 65 MHz tunable center frequency; 10-bit DAC; forward-error-correction decoder consists of programmable derandomizer and Reed-Solomon decoder	QPSK, 16 QAM	NA	MCNS
Hitachi Circle No. 422	HD49430F \$13.95 (50,000)	Cable-modem downstream processor with demodulator; all digital AGC; equalizer; interference canceling; symbol timing recovery; carrier recovery with programmable signal-processing parameters	64 QAM, 256 QAM	Annex B	MCNS
	HD49429F \$6.30 (50,000)	Cable-modem upstream processor with programmable encoder, Nyquist filter, and fully digital RF modulator; 10-bit DAC; 1- to 42-MHz carrier range	QPSK, 16 QAM	NA	MCNS
Libit Circle No. 425	LBT 4030 \$32 (10,000)	Cable modulator/demodulator; includes IF conversion (eliminating need for downconverter), DAC, and ADC; variable symbol rates with single crystal reference; blind acquisition of QAM signal within 100 msec; autodetection of modulation format and baud rate	QPSK, 16-QAM, 16, 64, 256 QAM	Annex B	MCNS, Society of Cable Tele- communications Engineers, IEEE 802.14
	LBT 4230 \$20 (50,000) available third quarter	Cable-modem MAC; includes baseline privacy; MAC engine manages two-way-communication protocol; supports multiple address filtering, quality of service, multiple service IDs, and as many as 16 CPE devices	NA	NA	MCNS
Rockwell Circle No. 431	HM2214 \$55 (10,000)	Cable-modem demodulator with integrated ADC, integrated ADC, forward error correction, and deinterleaver; symbol rates as high as 7M symbols/sec; provides fully digital carrier timing, AGC tracking, filtering, adaptive equalization, and Reed-Solomon decoding; MPEG packet and error detection	16 to 256 QAM	Annex A, B, and C	MCNS, DVB/DAVIC
	HM2314 \$55 (10,000)	Cable-modem upstream modulator; carrier programmable from 0 to 65 MHz; provides burst timing; generates sample and symbol clocks from single reference input; performs Reed-Solomon encoding, scrambling, differential encoding, spectral shaping, and pre-equalization	BPSK, QPSK, 16 QAM	NA	MCNS, DAVIC
	HM8416 \$55 (10,000) available July'98	Cable-modem MAC; receives, processes, and transfers downstream MCNS frames; transfers upstream for RF or telephone-return; DES decryption and encryption engine; autolock to headend reference clock; supports DMA transfers; PCI reference design; 160-pin PQFP	NA	NA	MCNS
Stanford Telecom Circle No. 434	Stel-2176 \$30 (100,000)	Cable-modem digital modulator/demodulator ASIC for broadband coax networks; performs spectral shaping and fine tuning across output bandwidth of 65 MHz; high acquisition speed, equalized for as many as 2- μ sec multipath reflections; integrated 10-bit DAC and ADC	QPSK, 16 QAM; 16, 64, 256 QAM	Annex A, B, and C	MCNS, IEEE 802.14, DVB/DAVIC
	Stel-9257 \$450 (5000)	CMTS burst QPSK demodulator; variable data rates of 0.256 to 5.12 Mbps; tunable 5- to 65-MHz RF input; fast acquisition time, short preamble, and short guard time to minimize overhead	QPSK	NA	MCNS, IEEE 802.14, DAVIC
	Stel-1109 \$13 (100,000)	Cable-modem modulator includes DAC; RF output covering 5 to 65 MHz; data rates as high as 10 Mbps in binary phase-shift keying, 20 Mbps in QPSK, and 40 Mbps in 16 QAM	NA	NA	MCNS, IEEE 802.14, Davic

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MAC will include enhancements that fine-tune the quality of service and isochronous features. But, for version 1.0, the cable-modem MAC controls the IP traffic to and from the CPE, forward-error-correction, MPEG-transport, and RF-interface protocols.

All three cable-modem MAC chips help control the RF interface by processing all the messages to and from the head end. These messages concern timing, registration, upstream-communication parameters, upstream negotiations, and data privacy. All these MACs provide for either the RF or the telephony upstream path to the CMTS.

The cable modem processing the downstream data includes the MPEG-transport control and stream demultiplexing. For cable data, the MPEG-2 transport packets encapsulate the variable-length IP packets into their 188-byte format—a 4-byte header and 184-byte payload. The receiving cable modem then demultiplexes the MPEG-2 packets into video streams and data

streams for delivery to the TV display or to a computer.

Besides these required functions, the MAC chips differentiate themselves in the programming interface and in data transfer to the CPE. The Rockwell HM8416 has an I/O register and separate upstream and downstream data FIFOs that are all 32-bit-wide interfaces with additional control and status pins for fast synchronous data transfers (**Figure 4**). The Broadcom BCM3220 has DMA support for two downstream queues and one upstream queue. The Libit LBT4030 positions itself in the business and SOHO category by boasting that it supports 16 CPE devices and multiple SIDs. This CPE side of all MACs will see further differentiation as USB and Ethernet cores become the next step in integrating more functionality into the MAC.

For data privacy, all the devices include a DES engine for encryption and decryption specified by the baseline-privacy function. The DOCSIS

Baseline Privacy Interface (BPI) is a document describing data privacy across the shared RF network. Besides data privacy, cable networks have security concerns with theft of service. BPI does not directly address theft by unauthorized users, but BPI does help prevent such theft, because modems must register to participate in cable service, and this registration deters unknown or unauthorized modems from involvement in this service. Baseline privacy uses the US DES with a 56-bit key. The modems use the cryptographic algorithm from RSA Data Security (www.rsa.com) to transfer the DES key between the CMTS and the cable modem. Another function of the SID for upstream bandwidth allocation is that the SID also identifies security associations for both the upstream and downstream data flows.

Beyond BPI, DOCSIS specifies optional full-security specifications involving plug-in smart cards, or “removable security modules.” The cards use the PC Card (formerly, PCMCIA) inter-

face and provide user authentication.

After examining how complex DOCSIS can be, you can understand why interoperability is a primary concern for all modem designs. To achieve this interoperability, CableLabs has been conducting interoperability testing since late 1997. Chip vendors, modem OEMs, and cable operators are participating in the testing to have their designs blessed. The results have proved that the standard is workable and that performance is as good as expected.

These tests also shake down the specification for ambiguities and inconsistencies. When the testing finds problems with the specification, engineering-change orders go out for review by all participants in the DOCSIS community. When the community agrees on the appropriate changes, CableLabs posts them on its Web site. More than 30 of these change notices have emerged so far. By joining the DOCSIS vendor list, you too can access the Web site.

Future enhancements to the DOCSIS standard will deal with CPE interfaces, isochronous data traffic, and quality-of-service details. The work of the IEEE 802.14 work group dealing with ATM could add the attachments for quality of service and bandwidth on demand that future applications may require. But, as the interoperability testing proves, the standard is ready for cable operators to deploy data-over-cable services to consumers and businesses that need the high bandwidth and services that a cable-TV network offers.

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