J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*

CABLE TELEVISION

Cable TV (*CATV*) as a successful business can be considered an American invention. Even though first commercial cable television installations date back as early as 1936 in Europe (United Kingdom and Germany), they did not create a market at that time.

Right after World War II, the first CATV systems in the United States appeared almost simultaneously in Pennsylvania and Oregon. *Community antenna television* was conceived as a system for delivery by cable of signals broadcast by wireless television stations. The system was primarily targeted to deliver television in rural areas with poor wireless reception. A community antenna provided broadcast television to these neighborhoods via coaxial cables. The abbreviation CATV meant "community antenna television" at this early stage of the system.

For distant places the operator used several microwave links to bring the three major network signals across hundreds of kilometers and then distributed them around the local community by a cable network. If mountains blocked the radio path, a single antenna on the mountaintop fed the cable trunk down into the town. This kind of service was known as *basic cable,* and the customer paid few dollars per month for a high-quality TV signal of three existing channels. Advertisers on those channels were the real promoters of CATV at that time.

The need for signal amplification approximately every kilometer limited the area that could be served. Also, a separate amplifier was needed for each channel, which restricted the number of channels to three or four. In the mid-1960s, improvements in transistors boosted channel numbers progressively. By 1970 there were 2750 operators serving six million homes.

In 1974 satellites (so far used only for government purposes) became commercial. Cable operators started to use satellite transponders to rebroadcast to their facilities' programs from multiple producers, and their large capacity made it possible to offer many channels using up to a total of 300 MHz of bandwidth. Service providers started to produce programming and sell their services to cable as well as to direct broadcast satellite (*DBS*) operators, thus motivating rapid deployment in large metropolitan areas, where cable distribution systems competed with DBS.

Networks specifically designed to be distributed by the cable system appeared in the United States by 1975 with Time Inc.'s Home Box Office (*HBO*); soon others emerged, such as Ted Turner's Superstation (soon renamed WTBS) in 1976, and C-SPAN (live broadcasts of the House of Representatives), ESPN (sports), and Nickelodeon (children's programming), all in 1979. The 24-hour news Cable News Network (*CNN*) followed in 1980.

Though CATV offered a wider range of programming than ordinary broadcasting, the capacity of pure coaxial systems became insufficient, being still small compared to the number of DBS channels. To overcome this lack, with the invention of the linear light source in the 1980s, cable operators started to replace coaxial cable trunks with fiber systems. The benefit was not only in reducing the number of amplifiers (thus increasing available bandwidth) but also in improving the reliability while minimizing maintenance costs. These networks are referred to as CATV *HFC* networks, where CATV no longer means community antenna television but cable television, and HFC stands for hybrid fiber coaxial. New channels were pay-per-view, bringing in new revenues to broadcasters while broadening opportunities to the creative community. This development reached a peak by the mid-1980s and congestion by the early 1990s.

It is worth noting that cable operators must negotiate franchises with municipalities that authorize them to lay cable in the ground, the use of poles, and so on, in exchange for fees to the local government. In this respect CATV is similar to public utilities, since it uses public rights and places to deploy a capital-intensive network. It distributes services from content providers, and subscribers are billed on a monthly basis.

CATV networks have their main market in United States. Their development followed different patterns in other countries. CATV penetration in Southern European countries is still small, but current deployments are full digital and with a large optical trunk plant to target directly not only broadcasting but the broadband market. CATV is full-grown in Central European countries such as in Germany.

Worldwide, CATV networks serve over 200 million residences, while telephony serves more than 500 million. CATV is currently extending its capabilities by migrating from analog narrowband to digital broadband. Indeed, it has recently emerged as a promising access network infrastructure for the delivery of voice, video, and new broadband applications. Current research efforts are focused on the design of protocols for CATV to deliver different levels of quality of service (*QoS*) for diverse user applications.

Catv Network Architecture

The architecture of a CATV network comprises essentially the following three basic operations in traditional cable networks:

(1) Signal Reception Cable programming is obtained from satellite or terrestrial broadcasting at places called *headends,* where signals are also appropriately processed and combined into an analog stream to be broadcast by cable.
(2) Signal Distribution The stream obtained at the headend is distributed to the households via coaxial cable and optical fiber. In order to ensure the quality of signal to households, the signal is amplified (roughly every kilometer) and/or attenuated, depending on the user's proximity to the headend and network nodes. Signals must also be equalized, since higher frequencies undergo higher attenuations.
(3) Signal Delivery Equipment in the home converts cable signals into tunable TV channels. Descramblers decode encrypted programming, and additional equipment allows delivery on demand.

CATV network architecture has evolved drastically since its first implementations. Early CATV networks picked up analog TV signals from satellites or landlines, and each signal was downstreamed through a tree-and-branch topology and one-way delivery services (in contrast to the telephone star topology, which maximizes interconnection). Technical upgrading of CATV networks is infrequent and very capital-intensive, and consequently some geographical areas will overtake others. Nevertheless, their chronological evolution from a technical point of view can be outlined as follows:

- From analog to digital
- From all-coaxial to HFC
- From one-way to two-way

Migration to digital improved the system capacity substantially, since every 6 MHz analog video channel yields 27 Mbit/s of raw throughput with 64-*QAM* modulation and *RS FEC*. Such a data rate can convey up to six digital video channels through MPEG-2 compression with the same quality as analog channels. Migration to

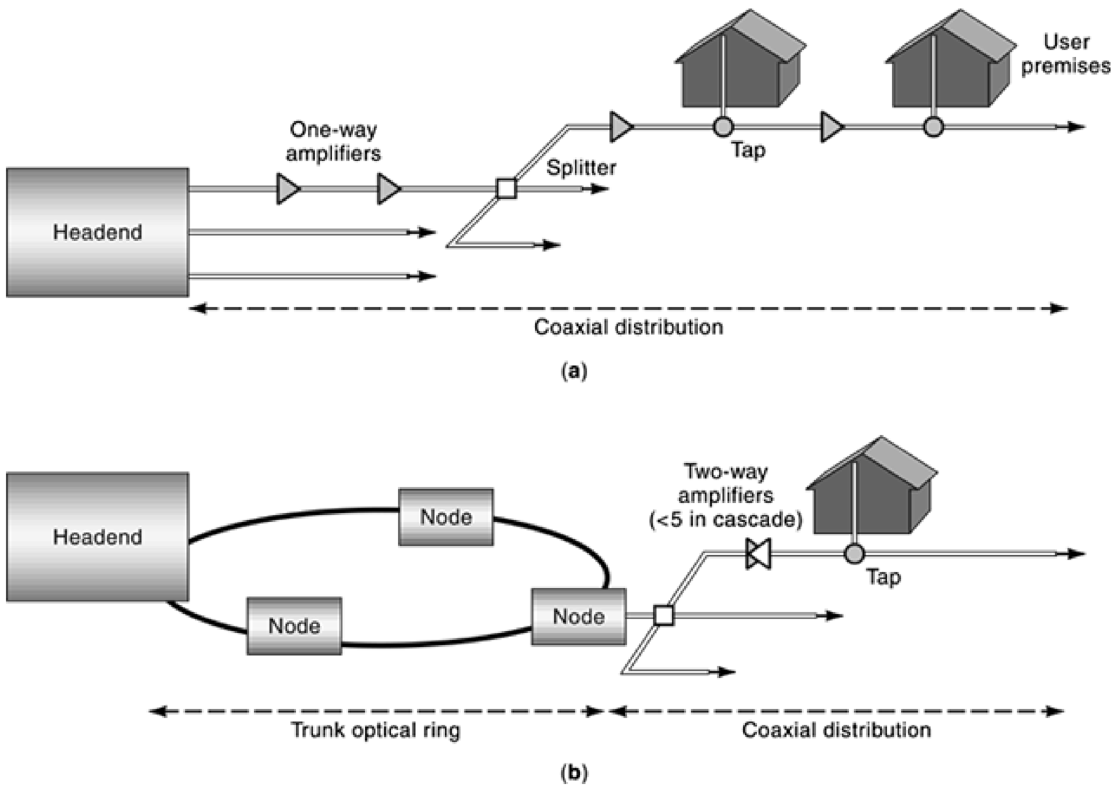

Fig. 1. CATV architectures: (a) tree-and-branch all-coaxial network; (b) hybrid fiber coaxial network with an optical trunk ring.

hybrid coaxial has increased robustness by reducing the number of households in serving areas and increasing the bandwidth (>750 MHz) by decreasing the coaxial cascade depth (1).

Figure 1(a) shows an early tree-and-branch all-coaxial CATV network architecture. Figure 1(b) shows the upgrading to an optical trunk ring (HFC). The dowstream traffic flows from the headend and is directly injected into the trunk fiber (originally coaxial) ring. The optical section is terminated with a *Hub*, or node, which converts optical signals to electrical. Feeder coaxial cable distribution is arranged from the node in a tree-and-branch topology where traffic is split at branching points to up to 2000 houses. Propagation through the cable attenuates the signal by an amount proportional to the square root of frequency, resulting in higher losses for higher frequencies, which is mitigated with amplifiers and equalizers, especially in the UHF bands.

The HFC access network represents the natural evolution of the existing mature tree-and-branch CATV networks for introducing the new digital broadcast or interactive services. An HFC network provides transparent communication channels between the subscribers and the CATV hubs or headends, since no signal processing occurs between the subscriber and the hub, besides optical-to-electrical conversion and eventual frequency translation and amplification. The hub provides the interface between the core network and the HFC distribution network. At this level, communication equipment is used to transmit an analog frequency multiplex comprising both the TV broadcast signals (analog or digital) and the modulated digital interactive ones. Each node generally supplies up to 1000 subscribers (2,3).

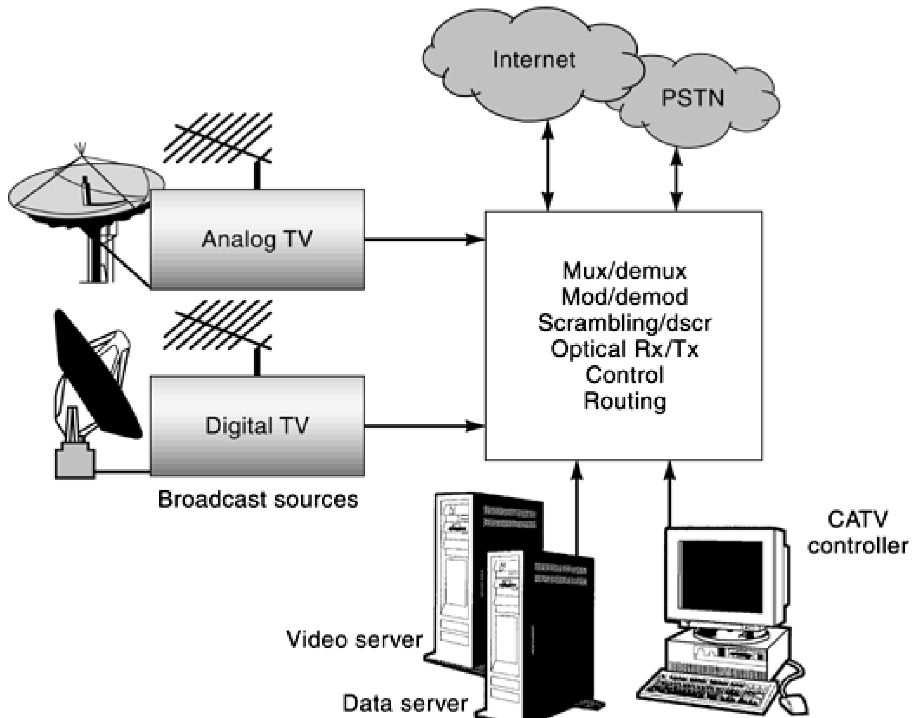

Fig. 2. HFC CATV headend elements and functionalities.

Figure 2 shows a scheme of the headend, comprising a number of possible elements and functionalities of a two-way digital CATV HFC network. Analog or digital broadcast TV is not only the content source of the cable system, which can also supply video and data with local or remote (Internet) servers. Telephone services are also contemplated through connection to the *PSTN*.

Figure 3 shows the elements at user premises. Different modems are necessary for video and data applications, and also an MPEG-2-compliant set-top decoder is needed to transform the digital transport stream for the analog TV set to be able to present the image.

Catv Bandwidth And Capacity

Figure 4 shows an example of CATV bandwidth allocation. This spectrum is an expansion of the standard analog video broadcast spectrum with space reserved for digital video services and an upstream spectrum for interactive services. Current systems allocate a band of 30 MHz to 65 MHz for upstream communication; since the total bandwidth may be up to 860 MHz, the allocation is clearly asymmetric. This arrangement is due to the allocation of analog TV legacy channels from 55 MHz up to 300 MHz to 400 MHz. Bandwidth available for interactive communications lies below 50 MHz and above 550 MHz.

The downstream frequency band is divided in two parts. The wider one is devoted to the broadcast services, among which are analog and digital TV, pay TV, Near Video on Demand (NVOD), FM radio, digital radio, and broadcast data. A small number of these downstream channels will be reserved for the interactive services.

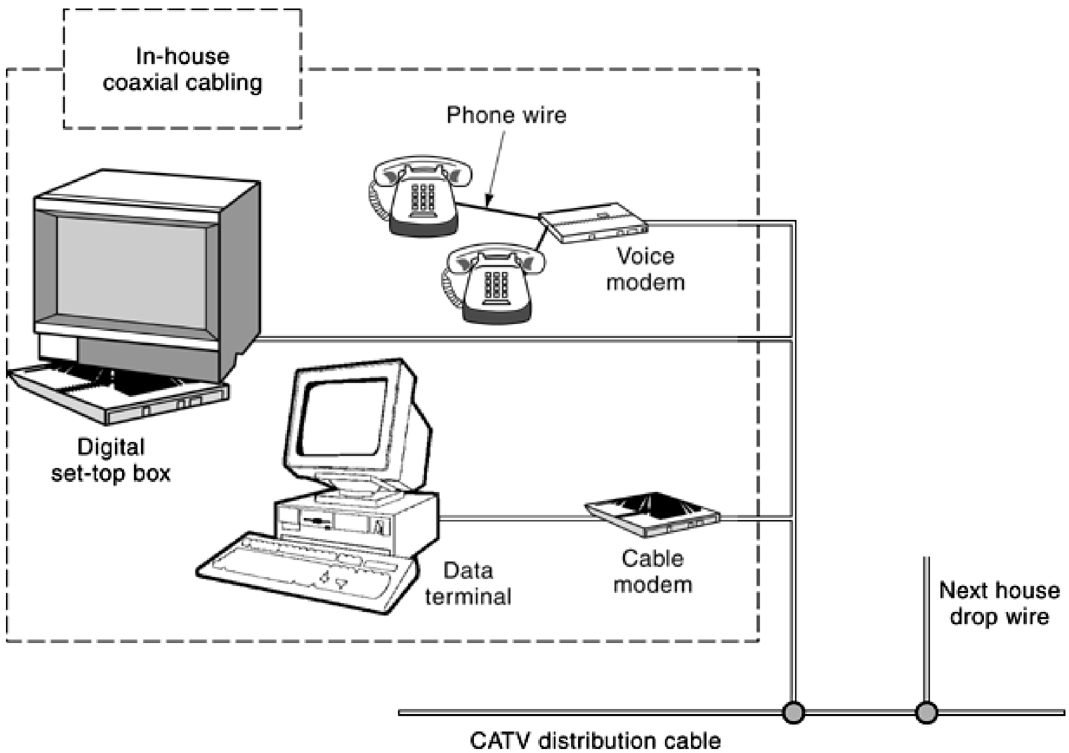

Fig. 3. CATV elements for data and video applications at user premises.

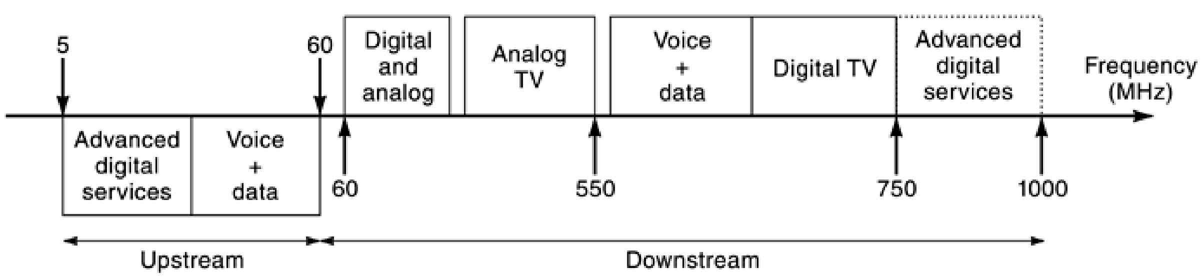

Fig. 4. Example of CATV frequency allocation.

Each channel carries a potential payload of 30 to 40 Mbit/s using a complex multilevel modulation scheme (64-QAM typical).

Assuming downstream channels of 6 MHz with an effective bandwidth of 5.4 MHz and channels from 550 MHz to 750 MHz, the total capacity is approximately of 1 Gbit/s, which should be sufficient at least until high-definition TV (HDTV) arrives. For the upstream capacity let us assume also 6 MHz channels with QPSK modulation, as is being proposed by standardization groups, and a total bandwidth of 30 MHz (more or less as shown in Figure 4). With these assumptions the upstream capacity becomes 10 Mbit/s per channel and 60 Mbit/s in total. Taking into account up to 20% of overhead for upper-layer protocols, the upstream capacity may be reduced to 5% of downstream capacity. This worst-case capacity may be enough, though, since peak hours can be assumed to be below 25% of the day. However, voice applications, for example, need real-time delivery, taking priority over available TCP/IP connections. Bandwidth assignment and bit-rate management by differentiating best-effort traffic from traffic with guaranteed bandwidth are QoS problems to be solved by cable networks. Interested readers may refer to Refs. 4 and 5.

Upstream Transmission

CATV networks were designed for video broadcasting, but cable operators soon realized the usefulness of a return path for movie selection, pay-per-view, billing information, monitoring, and so on. One-way cable networks had an inherent capability for upstream transmission, since raw wire can transport signals in both directions simultaneously. However, amplifiers boost signals only in one direction, blocking the return path. Thus, upgrading to the two-way network architecture must include two-way amplifiers, laser transmitters to the headend, and additional equipment at the user premises. It should be noted that downstream video may be broadcast or on demand, but the reverse path is a shared medium, which means access must be controlled via some medium access (MAC) protocol (6).

An important issue for the reverse path is ingress noise degrading the quality of service. Home electrical devices (hair dryers, vacuum cleaners, etc.) create noise bursts within the 5 MHz to 40 MHz frequency range (within the upstream bandwidth; see Fig. 4), which are propagated back to the network through the amplifiers. Amateur radio and AM radio are also potential sources of interference in the return path. A number of techniques are used to mitigate the interference and noise present in the upstream spectrum:

- Low-pass filtering at the cable drop in the data terminal in the home
- Modulation techniques such as frequency hopping and spread-spectrum cable modems

Standards

The rapid evolution of broadband service has resulted in cable television operators, providers of telephone service, and other service providers seeking to provide voice, data, and video services to their residential and commercial subscribers over existing and new infrastructures. In this context, standardization is needed, mainly to make possible retail distribution of cable network elements in the home for both video and data applications. The standardization of technological features of these elements provides a means to reduce costs by creating a competitive market. Standardization activities cover not only the physical layer (*PHY*), but also the MAC layer, security, and service management. Organizations involved in cable TV standardization are the following (1):

- Digital Audio Visual Council (*DAVIC*)
- Digital Video Broadcasters Project (*DVB*)
- IEEE 802.14
- International Telecommunications Union (*ITU*)
- Multimedia Cable Network System (*MCNS*) Partners Ltd.
- Society of Cable Television Engineers (*SCTE*)
- Society of Motion Picture and Television Engineers (*SMPTE*)
- Video Electronics Standards Association (*VESA*)

Standards from some of these organizations are summarized in the following.

Davic And Dvb. DAVIC was started by Leonardo Charliglione, the Motion Picture Experts Group (MPEG) committee head. It was established in 1994 as a nonprofit association based in Switzerland, and it was constituted with companies involved in all sectors of the audiovisual industry (manufacturing and service), as well as a number of government agencies and research organizations from more than 25 countries. The association was disbanded after 5 years of activity, remaining active only through its Web site (www.davic.org). DAVIC specifications were primarily aimed at promoting the success of interactive digital audiovisual applications and services, and therefore they are based on DVB specifications. Since DAVIC aims at interoperability across applications, it does not specify systems but *components* (tools) that are non-system-specific in that they have to be usable by different industries in different systems and still guarantee interoperability.

The DVB Project is a consortium of companies from more than 30 countries worldwide in the fields of broadcasting, manufacturing, network operation, and regulatory matters. The DVB Project Office is based in Geneva, Switzerland. It aims at establishing common international standards for the migration from analog to digital broadcasting through the design of a global standard for the delivery of digital television (www.dvb.org). Their standards are based on the common MPEG-2 coding. Through the use of MPEG-2 stream packets, DVB is potentially able to deliver TV service [from HDTV to multiple-channel standard-definition TV (PAL/NTSC or SECAM)], broadband multimedia data, and interactive services effortlessly from one medium to another. In particular, DVB signals can move from satellite to cable and from cable to terrestrial. DVB standards are published by the European Telecommunications Standards Institute (*ETSI*). ETSI, the Centre for Electrotechnical Standards (*CENELEC*), and the European Broadcasting Union (*EBU*) have formed a joint technical committee (*JTC*) to handle the DVB family of standards, which can be grouped as follows with regard to transmission standards:

- DVB-C (cable systems)
- DVB-DSNG (digital satellite news-gathering systems)
- DVB-MC [multipoint video distribution systems (MVDSs) below 10 GHz]
- DVB-MS (MVDSs at 10 GHz and above)
- DVB-S (framing structure, channel coding, and modulation for 1–2 GHz satellite services)
- DVB-SFN (megaframe for single-frequency network)
- DVB-SMATV (DVB interaction channel for satellite master antenna TV distribution systems)
- DVB-T (terrestrial systems)

The original specification is DAVIC 1.1, ratified by 1996, covering different generic elements as follows:

- High- and mid-layer Protocols
- DAVIC subsystems (service provider, delivery system, and service consumer)
- System-wide issues (DAVIC functionalities, system reference models and scenarios, reference points, interfaces, and dynamics)

Specifications 1.2 to 1.4 were issued subsequently. The last specification, 1.5, dealt with specific technical issues:

- Jitter concealment tools
- Applicability of DAVIC 1.5 intranet architecture to TV-anywhere and TV-anytime scenarios
- DAVIC cable modem
- DAVIC intranet technical platform specification
- TV anytime and TV anywhere

DVB has submitted to ETSI a complete set of standards defining issues related to the provision of interactive services on cable and LMDS networks:

- ETS 300 802 defines network-independent layers for both media.
- ETS 300 800 defines the network-dependent layers for cable networks.
- ETS 300 429 defines the downstream physical layer for cable networks.

The *DVB RCCL* [return channels for cable and local multipoint distribution systems (LMDSs)] includes the specifications related to network-dependent layers and has been developed in close consultation with DAVIC. The result is the adoption by DAVIC of ETS 300 800 as the only standard for cable modem applications. This is a major step towards common specifications between DVB and DAVIC.

Working in this direction, the DVB/DAVIC Interoperability Consortium provides multivendor interoperability based on the open international standards DVB RCCL (ETSI ETS 300 800) and DAVIC 1.5 for broadband communication (www.dvb-davic.org). The Consortium intends to build a multiservice platform enabling a single system to deliver video, audio, data, and voice to residential devices such as cable modems, set-top boxes, multimedia home platforms, and residential gateways. The consortium of European multisystem operators (MSOs) has recognized it as the preferred technology, so that the DVB-RCCL/DAVIC specification represents a technology that may become a standard for international deployment.

The following vendors have announced their intention to comply with the specification: Alcatel, Cisco, DiviCom, Hughes Network Systems, Nokia Multimedia Network Terminals, Sagem, The Industree, Thomson Broadcast Systems (a subsidiary of Thomson Multimedia), and Thomson Multimedia. It is apparent that while European MSOs have committed to DVB-RCCL/DAVIC, other big providers have already chosen to deploy DOCSIS (data-over-cable service interface specification) technology. DVB-RCC is available as ETSI standard ETS 300 800, "Digital Video Broadcasting (DVB); Interaction Channel for Cable TV Distribution Systems (CATV)." DVB-C is available as ETSI standard ETS 300 429, "Digital Video Broadcasting (DVB); Framing Structure, Channel Coding and Modulation for Cable Systems."

Key physical-layer features of specifications for HFC networks are the following:

- Simple Network Management Protocol (SNMP), network management
- Downstream:
  - "Passband unidirectional PHY on coax" tool (DAVIC 1.3)
  - QAM modulation [called "in-band signaling" (IB)].
  - MPEG and Asynchronous Transfer Mode (ATM), framing
  - Bit rates up to 56 Mbit/s (with 8 MHz carriers and 256-QAM modulation)
- Upstream:
  - "Passband bidirectional PHY on coax" tool (DAVIC 1.3)
  - QPSK modulation [called "out-of-band signaling" (OOB)]
  - ATM framing
  - Bit rate up to 3 Mbit/s
  - Support for a variety of MAC techniques: time-division multiple access (TDMA), contention, and reservation
  - ATM signaling either with UNI (ITU-T Q.2931) or by proxy using DSMCC (digital storage media configuration and control, ISO/IEC 13818-6)

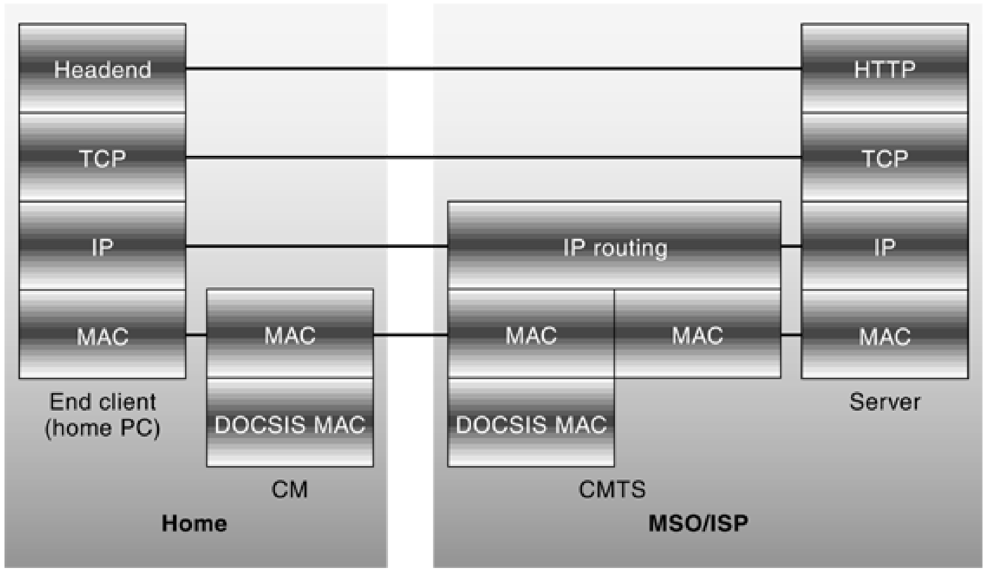

Fig. 5. DOCSIS architecture model. CM: cable modem; CMTS: cable modem termination system.

Docsis And Mcns. MCNS is a consortium of North American entities that came together to develop the specification DOCSIS for transmitting data over a cable network (www.cablemodem.com). DOCSIS 1.0 was proposed in March 1997. In March 1998 the ITU accepted DOCSIS as a cable modem standard (J.112). To deliver DOCSIS over a cable television (CAT) network, one 6 MHz RF channel in the 50 MHz to 750 MHz range is typically allocated for downstream traffic to homes, and another channel in the 5 MHz to 42 MHz band is used to carry upstream signals. Cable modems were described as external devices that connect to a personal computer through a standard 10Base-T (10 Mbit/s Ethernet over CAT3-5 cabling) Ethernet card or USB interface. CableLabs manages a certification process to ensure DOCSIS cable modems manufactured by different vendors comply with the standard and are interoperable.

CableLabs is an organization dedicated to the certification of DOCSIS-based equipment. In April 1999 it issued a second-generation specification called DOCSIS 1.1, which adds key enhancements to the original standard, such as improved QoS and hardware-based packet-fragmentation capabilities, to support IP telephony and other constant-bit-rate services. The next-generation standard is designed to be backward compatible, enabling DOCSIS 1.0 and 1.1 modems to operate in the same spectrum on the same network. A third-generation DOCSIS standard will add an advanced PHY to the core specification to increase the upstream transmission capacity and reliability by using *FA-TDMA* (frequency-agile TDMA) and *S-CDMA* (synchronous code division multiple access).

Vendors supporting the DOCSIS standard are 3Com, Bay Networks, Cisco Systems, General Instruments, Hewlett-Packard, Hybrid Networks, Intel, Motorola, NEC, Panasonic, Scientific Atlanta, Sharp Electronics, Toshiba, US Robotics, and Zenith Electronics.

The DOCSIS architecture model is shown in Figure 5. The PC generates Internet protocol (IP) over Ethernet packets. The cable modem (CM) acts as a bridge and forwards the Ethernet frames to the network. DOCSIS specifies a new MAC layer from the CM to the cable modem termination system (CMTS) in the upstream direction. The Ethernet frame is encapsulated by the CM in a DOCSIS MAC frame and sent to the CMTS. The CMTS (a router or a bridge) de-encapsulates the Ethernet frame and forwards it upstream.

The relationship between a CM and its CMTS is a master-slave relationship. The CMTS controls the bandwidth allocation on the upstream channel. The CMTS sends on the downstream channel bandwidth allocation messages called *upstream bandwidth allocation maps* (referred to as *MAP*s), which define how the time units (mini-slots) on the upstream channel must be used. The cable modem boot process used by the CM influences architecture design, and DOCSIS concludes with an explanation of how the CM boots up.

Key PHY features of specifications for HFC networks are the following:

- Upstream:
  - QPSK or 16-QAM modulation with no interleaving
  - Symbol rates 160, 320, 640, 1280, and 2560 ksymbol/s.
- Downstream:
  - 256- and 64-QAM modulation with variable interleaving
  - MPEG-2 Transport Stream (TS), framing
  - Variable packet length
  - Grant-based bandwith assignment

DOCSIS standards have not yet been accepted in Europe and Asia. The alternative standard DAVIC/DVB for cable modem systems, also called the EuroModem standard, has been formalized, and, as was stated before, a significant number of European cable system operators have embraced it.

IEEE 802.14. The IEEE 802.14 Working Group is a committee of engineers representing the vendor community that has developed a specification for data-over-cable networking. The group was formed in 1994 and intended to develop a specification that would be recognized as an international standard. However, MCNS defined an international specification first. Despite ITU recognition of DOCSIS as an international standard in 1999, the IEEE 802.14 Working Group continued to work on its specification, and MCNS indicated that it would implement IEEE 802.14's advanced PHY specification. Overall the future of the IEEE 802.14 specification is unknown. The group had good intentions and its specification was undoubtedly a better technological alternative than that developed by MCNS. However, timing is critical in developing standards.

At the current time, performance characteristics of the standardized DOCSIS and the DVB/DAVIC CM specifications have not been well assessed. For both specifications an OPNET model has been created by CableLabs and MIL3 for the former, and by EuroCableLabs Centre of Competence for the latter. However, both models support only the features of the upstream channel. Current research aims at the development of a new simulation model for the downstream channels for both the DOCSIS and the DVB/DAVIC protocols using the OPNET simulation package. Its performance should be based on the system throughput versus offered load and the end-to-end delay versus system throughput with respect to:

(1) Number of CMs in the CATV network
(2) Variable offered load
(3) Different scheduling algorithms.

Technical Differences Between Standards

As we described before, DVB/DAVIC and DOCSIS/MCNS are two groups of standards defined by different organizations currently focused on delivering data to set-top boxes and PC cable modems, respectively. Due to market dynamics, while both standards look to deliver data to broadband services, the technical evolution has

Table 1. Comparison of Standards

Characteristic	DOCSIS/MCNS	DVB/DAVIC
Downstream modulation	64 and 256 QAM (MPEG-2 transport)	QPSK for out-of-band channels; 16, 64, and 256 QAM (MPEG-2 transport) for in-band channels
Upstream modulation	QPSK and 16 QAM	QPSK
Access modes	No support of fixed-bit-rate access	Contention, reservation, and fixed-bit-rate access on the same channel
Downstream	256- or 64-QAM	Up to 56 Mbit/s (256-QAM)
Upstream	160, 320, 640, 1280, and 2560 Ksymbol/s	256 to 6.176 Mb/s (200 Hz to 4 MHz bandwidth)
	QPSK or 16-QAM	QPSK
IP datagram encapsulation	Direct Ethernet frames mapping on MCNS packets	ATM framing by using AAL5 or LLC/SNAP
Fragmentation capability	No support of fragmentation mechanism	Variable fragmentation length (multiple ATM packets)

been different, though it is expected that these two courses will probably converge in some way. Table 1 shows the technical differences between the standards. Recently OpenCable has started to design a retail-model set-top box using the DOCSIS standard for data, but also using the DAVIC standard. This box has DAVIC as well as DOCSIS components: DAVIC is chosen as a “core” requirement, and DOCSIS as an extension for the specification.

Applications

Two-way CATV HFC applications should be grouped into two major markets, in part because such applications are driving different (not necessarily divergent in principle) paths in the technology upgrading and standardization:

- Digital video over cable TV networks (although in the transition from analog to digital broadcasting, cable systems will also deliver analog channels)
- Data services over cable TV networks.

In fact the two markets will converge, since multimedia applications relate to both. The road to such a confluence is being paved now through the standardization process, and the success achieved by each of the parts will depend on both cost and technological accomplishments. In either case digital video or data application services are to be delivered both in broadcast and in interactive mode.

Digital Video over Cable TV Networks. First it is interesting to point out differences and key technological and performance aspects of analog versus digital video. Unlike analog video, which degrades in quality, digital video is virtually identical to the parent. There is a major difference between the way computers and television handle video. When a television set displays its analog video signal, it displays the odd lines (the odd field) first and the even lines (the even field) next. Each pair forms a frame, and there are 60 of these fields displayed every second (30 frames every second). This is referred to as *interlaced* video. Instead, the computer displays each line in sequence, from top to bottom. This entire frame is displayed 30 times every second. This is often referred to as *noninterlaced* video.

Analog formats include *NTSC* (National Technical Standards Committee), used in the United States, Mexico, Japan and Canada. Phase alternation line (*PAL*) is used in western Europe, and Sequential Couleur à Mémoire (*SECAM*) is used in France, Russia, and Eastern Europe (Hewlett Packard, p. 4).

Digital formats include Joint Photographic Experts Group (*JPEG*), Motion JPEG (*MJPEG*), MPEG, Advanced Video Interleave (*AVI*) from Microsoft, Indeo from Intel, and CellB for use on Sun SPARCstations. Of these digital formats, only MPEG is an internationally recognized compression standard.

Benefits of digital video are in random access to stored information, the ability to compress the video, and the low cost of reproduction without loss of quality. From a transmission point of view, a number of digital channels can be sent where only one analog channel was allocated. VCR video is in analog format running at 30 frames/s. To achieve the same quality on the desktop, without compromising on frame rate, resolution, color resolution, or image quality, one needs hundreds of gigabytes of disk space. Twenty-five centimeters (10 inches) of videotape is required to record one second of video. Compression is the solution, and there are two types:

- *Intraframe compression* compresses each individual video frame. JPEG and MJPEG use intraframe for compression ratios of 20 : 1 to 40 : 1. The larger the ratio, the poorer the quality.
- *Interframe compression* only looks at the video data that have changed. This also reduces the bandwidth necessary to carry the video stream. MPEG uses interframe compression and can achieve up to 200 : 1 compression rates. Roughly, 9 Mbyte of hard-disk space is required for every minute of MPEG compressed video. CATV and DBS use MPEG-2.

TV broadcasting and video conferencing, which allows a group of users to communicate in real time through the use of live streaming audio and video, are the main applications of digital video.

Data Services over Cable TV Networks. Data services can be divided into narrowband and broadband applications according to the amount of bandwidth required. Telephony is narrowband, and multimedia contents are broadband.

Telephony. We may include voice services within data interactive applications. Telephony can be offered by cable by using IP to deliver voice through the use of a gateway located at the cable headend. Telephony networks can either be private or allow access across the Internet or to and from the PSTN. Videotelephony is a natural successor to telephony, although more complex. There is a tradeoff between quality, bandwidth, and real-time.

PUSH Applications. PUSH technology is the delivery of information from server to client over IP. Webcasting and multicasting (transmission of files or streaming audio and video to preselected multiple users) are PUSH applications.

Virtual Private Networks. Since a cable system acts as a broadband network, operators are capable of establishing virtual private networks (VPNs) as completely closed environments (intranets) allowing users to access the Internet.

Home Monitoring and Security. Cable networks can be used to monitor homes for fires, break-ins, and medical emergencies. The available bandwidth of a cable network, combined with the system's being always on, enables emergency information to be quickly transmitted.

Telemedicine. Medical doctors, patients, hospitals, clinics, and mobile units can use the CATV broadband technology for quick transfer of huge files to provide diagnosis, treatment, consulting, and education.

Immersive Environments. An *immersive environment* is a virtual social environment, managed by a computer program, where the user is represented within the program as an animated character (avatar) visible to all of the users. This is clearly a broadband multimedia application, where sound, data, and video come together, requiring a great amount of bandwidth along with critical constraints on latency.

One goal for a media immersion environment (*MIE*) is for people to interact, communicate, collaborate, and entertain themselves naturally in a shared virtual space while they reside in distant physical locations. The MIE has applications in many domains where physical presence is expensive (e.g., distance learning); impossible (e.g., space exploration), unsafe (e.g., nuclear studies), or inconvenient (e.g., entertainment), or where more than one person must be involved (e.g., remote medicine). The principal function of MIEs is to synthesize multimodal perceptions that do not exist in the current physical environment, thus immersing users in a seamless blend of visual, aural, and (potentially) haptic information.

Alternative Technologies

A CATV HFC is called an *access network*; it may also be referred to as a last-mile solution or (for solutions proposed by telephone companies) a local loop solution. An access network connects customers' premises to the network termination and performs operations interfacing with the transport network, content provider, and home network elements. Figure 6 shows graphically the technological frame for the access network. All technologies share a common element, which is the *network termination* (*NT*), or network interface, in the home. The main functions of these networks are the following:

- Connection to the core transport network by switching, routing, and multiplexing
- Classification of user traffic by QoS
- Security procedures and handling of packet encapsulation
- Registration of hardware and updating of software in the household equipment
- Measurements for billing

A number of alternative cable and wireless competitive technologies are becoming feasible for the access network, so that major CATV providers have had to accelerate standardization of their products.

Competitive wire technologies are the following:

- xDSL (asymmetric, symmetric, high- and very high-bit-rate digital subscriber line)
- FTTx (fiber to the neighborhood, curb, building, etc.)
- *ISDN* (Integrated Service Digital Network).

Competitive wireless technologies are the following:

- MMDS (multichannel multipoint distribution system)
- LMDS (local multipoint distribution system)
- Satellite [deosynchronous earth orbit (GEO) and low earth orbit (LEO)]

In the following a brief description is given of each of these networks.

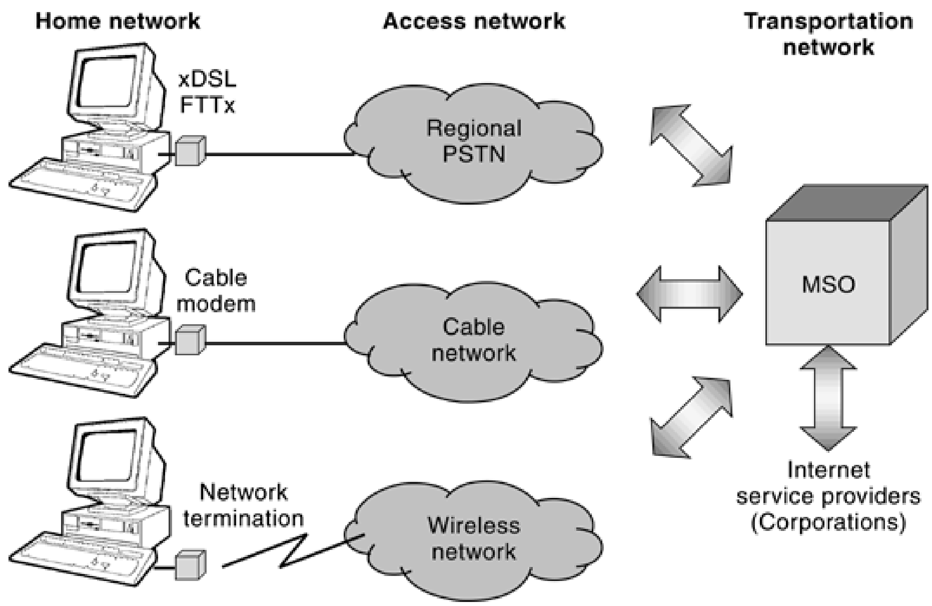

Fig. 6. Alternative technologies for access networks: wired and wireless.

xDSL (Digital Subscriber Line). xDSL refers to a series of networking technologies, comprising ADSL, HSDL, VDSL, and SDSL, that are capable of supporting high data rates over the existing telephone network. The technology bases its competitiveness on the existing extensive infrastructure and heavy capitalization associated with telcos.

Standard telecom modems establish a data stream between two arbitrary points using the entire telecom system—that is, from the sender's local loop, through the telephone switching system (mostly digital switches now), and then to the receiver's local loop. Standard modem connections can span continents, with one end thousands of kilometers from the other end. DSL modems, on the other hand, establish a connection from one end of a copper wire to the other end of that copper wire: the signal does not pass into the telephone switching system. Consequently, DSL modems are not limited to using the voice frequencies passed by the standard telephone system (typically 0 to 4 kHz); DSL modems typically use more than 100 kHz. To reiterate, one end of the DSL link will be at the consumer site, the other end must be at the other end of the copper cable, usually at the local telephone exchange, where data and voice are split. The voice frequencies are wired into a traditional plain ordinary telephone service (POTS) switch and enter the usual telephone switching network. The data frequencies are wired into a corresponding DSL modem, and the resulting high-speed digital data stream coming from (or going to) the consumer is then handled as ordinary data (not analog voice) and may be hooked into any number of networking technologies for further connection to the data's destination. Thus, the data never enter the standard telephone switching system. Typically the data will be routed over a local-area network (LAN) or wide-area network (WAN) connection (10Base-T Ethernet, T1, T3, ATM, frame relay) to a business office.

Over the next five years, xDSL (and particularly ADSL) is considered to be the greatest threat to the cable modem industry.

FTTx (Fiber to the Neighborhood, Curb, Building, Etc.). The growing demand for interactivity and more bandwidth per subscriber is being satisfied by pushing fiber closer to the home and by the availability of the required electro-optic components. FTTx refers to a series of networking technologies that run optical fiber from the central office to a user's neighborhood (FTTN), curb (FTTC), building (FTTB), home (FTTH), etc. Though the optical fiber is relatively inexpensive, optical transmitters and receivers are very costly. However, continued growth of broadband services is fueled by the clear advantages that optical fiber systems offer in cost, reliability, and performance for broadcast networks.

FTTH is not a practical solution for the moment to deliver residential data services. The present idea is to replace long copper lines with fiber optic lines (not only in the telephone network, but also in CATV). The major drawback is the cost of the replacement of the copper-based infrastructure. A critical point is what part of the network will be replaced with fiber optic lines: that is what distinguishes FTTH, FTTB, fiber to the office, FTTN, fiber-to-the-street, FTTC, etc. On the other hand, users of a CATV network again use copper lines, but all the rest of the infrastructure is fiber-optics-based. With the exception of FTTH, all the above approaches use some form of high-speed metallic access technology for service delivery to the customers' premises.

ISDN (Integrated Service Digital Network). ISDN is a service provided by local telephone companies that modifies regular telephone lines so that they can transmit data almost five times as fast as the fastest analog modems currently available. In addition to the significant increase in transmission speed, ISDN also allows the transmission of not only data, but a combination of data, voice, and video simultaneously on one line. ISDN provides higher speeds than POTS by allowing data to be transferred digitally from end to end. In contrast, POTS converts the digital data to analog within the local loop that extends into the home or office, significantly reducing transmission speed. An ISDN line can carry up to 128 kbit/s of data. Converting to an ISDN-compatible configuration for the consumer only requires an additional piece or two of relatively inexpensive hardware. Telecommuting to an office or base requires additional equipment at the base. While ISDN usage costs are slightly higher than those for analog telephone lines, users enjoy more than commensurate benefits.

Though ISDN has a share of the high-speed connectivity market, the technology is limited to 128 kbit/s and thus is in a different class than technologies that can support megabytes per second. In particular, it is very limited for video applications; it can only be used for videoconferencing with 6 to 8 frames per second.

Satellites. There are two basic types of satellite systems being proposed: GEO and LEO.

GEOs orbit in the Clarke belt, approximately 35,000 km (22,000 miles) above the equator. With this orbit, the satellite can stay over the same area of the earth for an indefinite period of time. Each GEO serves one geographic area, and can theoretically cover about 41% of the earth's surface. Companies proposing GEO systems are planning on using between three and fifteen satellites to deliver worldwide service. The primary advantage of GEO systems is that they are a proven technology. Most current communications satellites are GEOs. A GEO system is also far less expensive than an LEO system, and also GEO ground stations can be relatively simple because they need only target a fixed point relative to the earth. The main drawback for GEO systems is called the *latency factor*. In order to obtain information from an Internet server, a signal has to travel 35,000 km to the satellite, then 35,000 km back to the earth. This round trip takes approximately one-quarter second.

LEOs orbit 20 times closer to the earth, between 700 km (450 miles) and 1350 km (700 miles) above the earth's surface. Each LEO is moving relative to the earth, covering a particular area for only a few seconds. Because of this, a network of many satellites is required to cover the world.

Teledesic plans to launch a large number of LEOs that will be capable of offering high-speed Internet access anywhere in the world. Service providers will include Teledesic, Globalstar, OrbComm, and SkyBridge and M-Star (backed by Motorola). M-Star, while a broadband LEO system, is not aimed at the consumer market like Teledesic; it is planned to offer high-bandwidth intercontinental links between network providers rather than end users.

Satellites require a dedicated piece of the spectrum. Currently, the ITU has allocated 2.5 GHz of spectrum for fixed satellite services in the 28 GHz Ka band. There are fourteen satellite applicants vying for pieces of that 2.5 GHz. Requests for single applicants range from 750 MHz to the full 2.5 GHz, with most applicants requesting 1 GHz of spectrum.

The reason the Ka band has not been used in the past is that such high-frequency transmissions are easily blocked. Buildings, trees, and other solid objects can cause a loss of signal. This makes these frequencies unsuitable for use by ground-based systems, because they would require a large number of transmitters to be able to avoid all obstacles. Satellites avoid many of the problems associated with blocking because their signals come from directly overhead. Buildings and trees do not present an impediment to signals coming from overhead satellites.

Power-Line Area Networks (Access via Utility Power Grids). There have been proposals lately for traditional power companies to provide high-speed access via their existing grids. The biggest obstacle to this technology is that data are scrambled when they pass through transformers. This obstacle is slowly being overcome as several companies continue to work towards a solution. Nortel Networks has successfully tested networks in Europe and Asia, where the transformer-to-customer ratio is 1/300. They have successfully bypassed the transformers, but their speed has been limited, being comparable with cable modems and xDSL. Data are transferred through the actual power wiring.

***NIU* (Network Interface Unit).** NIU refers to high-speed connectivity through hybrid fiber-coax or FTTH or FTTC networks using a network interface unit at the customer premises rather than an external or PC-installed cable modem. Systems using NIUs usually support both data and telephony. Since the technology can be utilized by cable operators, it is not actually a competitor to the cable industry but to cable modems.

Multipoint Multichannel Distribution Service, and Local Multipoint Distribution Systems. Multipoint multichannel distribution service (*MMDS*), also referred to as wireless cable, delivers broadband services to subscribers through microwave transmitting and receiving antennas. The channels allocated to MMDS are generally used to provide a multichannel video programming service that is similar to cable television, but, rather than being hard-wired, MMDS uses microwave frequencies.

MMDS is a wireless technology for access networks that operates at frequencies 200 MHz to 2700 MHz. Its range may be 50 km to 60 km, and its main advantage is invulnerability to weather conditions. Operators that offer wireless video service can also offer data services. MMDS operators can offer telco return service and, with the emergence of LMDS (see below), will be capable of supporting bidirectional services.

The local multipoint distribution system (*LMDS*) is a broadband wireless technology used to deliver voice, data, Internet, and video services in the at frequencies of 25 GHz and higher (depending on the license). Spectrum in the millimeter band has been allocated for LMDSs to deliver broadband services in a point-to-point or point-to-multipoint configuration. Due to the propagation characteristics of signals in this frequency range, LMDSs use a cellularlike network architecture (normally the cells are large and a big city can be fully covered with four or five cells). The services provided are fixed (not mobile) and are seriously impaired by adverse weather.

Cable Modem versus Set-Top Box. Numerous companies are working towards high-quality, full-screen, real-time delivery of video programming that can be delivered via a cable modem or broadband Internet connection. As the cable television networks transition from a broadcast-only network to a high-bandwidth two-way network, the importance and functionality of the set-top box increases. Currently, mixed cable modem and set-top box network architectures and services exist. Developments in the set-top box industry have been restrained by the control the cable companies have over their equipment. Currently, a set-top box includes closed, proprietary technology, which prohibits its use on other cable systems' networks. Technology is evolving in both directions, from the cable modem to the set-top box and vice versa. Current technology development can be summarized as follows:

Cable Modem Technology.

- Cable modem from DOCSIS, IEEE 802.14, IETF, DVB, and ATMF
- EuroModem from DVB-RCC and ETS 300800

- EuroDOCSIS from DOCSIS (DOCSIS cable modem with some DVB technical compliance)

Set-Top Box Technology.

- **EuroBox**

  A number of cable operators from across Europe have developed the Eurobox Platform. This concept is based on a common set-top box and a common application program interface *API* and conditional access method. The box specification is used as a reference model by the cable industry and manufacturers. Viaccess has been selected as the conditional access system, and Open TV as the API. The Eurobox Platform has been successfully implemented, for example, in France, Sweden, and Denmark. However, some cable operators, notably in the UK, do not appear to be following this platform in its entirety.

- **OpenCable**

  This initiative from CableLabs includes guidelines for building advanced set-top boxes including feature enrichments to support broadband applications.

- **Multimedia Home Platform**

  MHP includes set-top boxes, integrated TV receivers, in-home digital networks, personal computers, network computers, and so on. The first specification for MHP, covering home access networks (HANs) with an active NT and based on an ATM interface operating at 25 Mbit/s or 51 Mbit/s, was approved by DVB–EBU JTC and published by ETSI as TS 101 224. The MHP API consists of a software specification that will be implemented in set-top boxes, integrated digital TV receivers, and multimedia PCs. The MHP will connect the worlds of broadcast television, Internet computing, and telecommunications through these devices and their associated peripherals.

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INTERNET RESOURCES

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CableLAbs, research organization for US cable operators: http://www.cablelabs.com
CATV CyberLab: http://www.catv.org
DAVIC: http://www.davic.org
DVB/DAVIC Interoperability Consortium: http://www.dvb.org
DVB Web site: http://www.dvb.org
DOCSIS specifications: http://www.cablemodem.com
ECCA Web site: http://www.ecca.be
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