HFC Networks – Status and Perspectives

Oleg Borisov Panagiev[1]

Abstract - **In the Hybrid fiber/coaxial (HFC) network, a number of 500-2000 subscribers in CATV network may cause serious collisions during the request phase. This paper discus status and perspectives HFC networks – structures, spectrum, communication medium and applications. HFC used M-ary quadrature amplitude modulation for the transmission of a compressed digital video signal (MPEG) along with the common amplitude modulation with a partial suppression of the vestigial sideband (AM-VSB).**

Keywords - **Cable television (CATV), HFC, fiber node, MPEG-2**

I. Introduction

Cable television (CATV) networks are engineered primarily to deliver a specific service using specific technologies. The technical analysis of cable therefore focuses on the basic capabilities of the cable medium.

The first systems have been built from two essential components: coaxial cable and broadband amplifiers. The television signals that are delivered over a traditional cable network are not fundamentally different from the signals delivered over the air, but a cable system can often deliver better quality signals and more channels, and there are technological reasons why this is so.

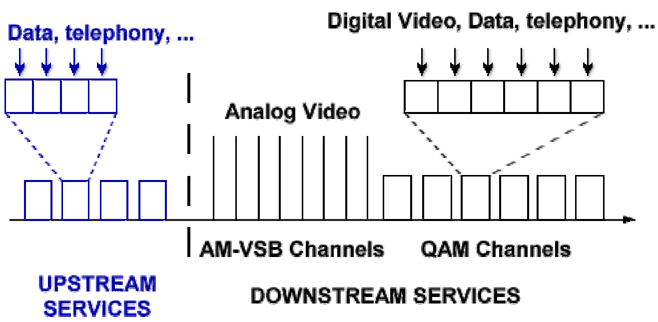

Fig.1. Spectrum HFC

Each TV channel is modulated in a 8 MHz channel between the frequencies of 47 MHz and 860 MHz (the range used varies among cable service providers). A television ‘tunes’ to the desired frequency and demodulates the original TV signal from the carrier wave. This is identical to lower frequency broadcasts like FM radio (frequency spectrum - 87 MHz to 108 MHz - is sandwiched in the range used for TV broadcasts) - Fig.1.

[1]O. B. Panagiev is a system engineer at the Technical University of Sofia, e-mail: olcomol@yahoo.com

When designing the system for cable television with the aim of minimal nonlinear distortions, it is necessary to optimize the number of the transmitted programs (channels) and the number of the amplifiers connected in series from the Head End to any point of CPN. It is know that, with the increase of the number of programs, the level in the exit of every amplifier has to decrease.

Cable systems are not limited to the bandwidth that is designated by the CENELEC for broadcast television; a cable can carry as many channels as the infrastructure will permit, which in modern systems can be a hundred channels or more.

The transmission, or encoding, of analog television signals is done in the same manner as it is for broadcast television, receiving these signals is straightforward.

There are TV that is not built specifically to receive cable will require an external receiver because a wider range of frequencies is used on cable systems, and sometimes because a television receiver cannot properly discriminate between adjacent channels. This external receiver (a *set-top box*) re-transmits a selected channel to one that the television can receive. Modern televisions, however, can often tune cable channels directly.

II. THE CABLE TOPOLOGY

The coaxial cable and broadband amplifier technologies define the essential capabilities of cable networks. But we also need to understand how real cable systems are actually built out of these and other components such as optical fiber, since this introduces both technological and economic constraints on using cable to support other communication applications.

We begin by identifying four basic components of a cable network: the *head end*, the *trunk network*, the *distribution network*, and *drops*. Cable networks are topologically organized as a tree, with the head end at the base of the tree, and the trunk, distribution, and drop parts of the network forming successively smaller branches (Fig.2).

The features for the CATV – coaxial network:
• the network consists mainly of passive components;
• the amplifiers are capable of relaying signals in both directions;
• the network topology is tree-shaped, branching out from the head-end, reflecting the usage of the network (i.e., analog broadcast services);
• the set-top box simply acts as a tuner or channel selector for the TV, but may include some analog access control mechanism for pay-TV channels;
• the network is effectively a shared media system which is contention-free at present (only one transmitter, the head end), but will not be contention-free in the future (with interactive digital services and data services) unless a media access control protocol is used.

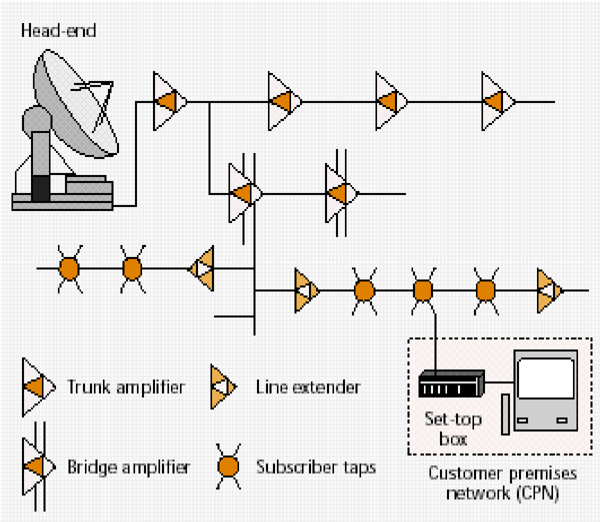

Fig.2. CATV – coaxial network

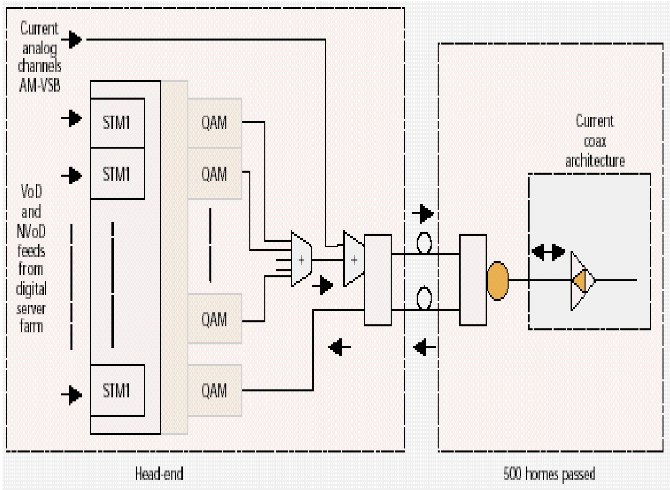

Fig.3. Hybrid fiber/coaxial network.

III. Hybrid Fiber/Coaxial Systems (HFC)

The modern cable systems use both coaxial and fiber optic cables for transmission - *hybrid fiber/coaxial* (HFC) systems.

Optical fiber has several advantages over coaxial cable. Foremost are that fiber has the potential of carrying far more bandwidth, is much more immune to noise, and attenuates signals much less. Furthermore, fiber cable itself is not significantly more expensive than coaxial cable.

The connections and end points of broadband fiber optic networks are far more expensive than they are with coaxial. Optical sources and receivers that send and receive electrical signals on a fiber network cost hundreds or thousands of euros. Making connections on a fiber network requires relatively expensive splicing operations. The result is that while fiber can be more cost-effective for long-haul point-to-point communication, coaxial is less expensive where there are many branches and connections in a network.

Hybrid fiber/coaxial systems (Fig.3) use fiber in just this way. The trunk parts of the network, where there are long distances of cable with few branches, are replaced with fiber, and the distribution network within a neighborhood remains as an ordinary coaxial system.

Fiber trunks have the advantage of eliminating long chains of broadband amplifiers that add noise and the potential for failures on the cable system; over these lengths, fiber requires no amplification. The only amplifiers that remain between the head end and subscribers are those in the distribution network, so that the entire path to a subscriber may have at most four to ten amplifiers. But a hybrid fiber/coaxial system is not typically a digital transmission system; the fiber portions are generally carrying analog signals that are simply re-transmitted onto the coaxial at fiber nodes. Since the fiber itself is inexpensive relative to its supporting infrastructure (sheaths, splices, and transmitters and receivers), adding more strands of fiber does not dramatically drive up the cost of a trunk system. As a result, hybrid fiber/coaxial systems are typically built with individual fibers connecting each coaxial distribution network to the head end.

Because hybrid fiber/coaxial networks are be less expensive to build, can carry more bandwidth, and are more reliable than traditional all-coaxial networks, they are the preferred architecture for building new or upgrading existing cable television networks regardless of future strategies.

For digital transmission there are currently many modulation and coding schemes in use. One of the reasons for the differences in CATV networks around the world is the lack of standardization in the CATV community, especially compared with the telecom sector. Such bodies as are currently addressing the issue of standardization:

- CENELEC (Comité Européen de Normalisation Electrotechnique) and European Telecommunications Standards Institute (ETSI);
- IEEE 802.14 Working Group (WG) and ATM Forum Residential Broadband WG (North America based, but with worldwide participation);
- Digital Video Broadcasting (DVB) and Digital Audio Video Council (DAVIC).

The digital SDH carrier (Fig.3) is being used solely for telephony while the current coaxial/analog architecture is being used for digital data! In many cases this is due to the lack of an integrated carrier such as asynchronous transfer mode (ATM). Since ATM equipment is now widely available, the maturing HFCs can take digital feeds from the head-end directly to the SDH carrier with conversion at the street box. The *server farm* of digital video servers would require careful management to perform such functions as load balancing and fail safety, to provide the best utilization of the resources available and a reliable service. The quadrature amplitude modulation (QAM) functions would probably be realized as a bank of modems that would also require (at the very least) monitoring to preempt any faults or detect the presence of particularly errorprone channels. If ingress (or other noise) is a problem, the management actions here might involve signaling/interaction with other components such as amplitude modulation vestigial sideband (AM-VSB) transceivers in order to select less noisy channels. This means that the AM-VSB transceivers must be capable of being managed dynamically and in real time. This dynamic channel selection may also apply to the cable modem at the customer premises network (CPN), so there is a need for this device to be manageable also.

In the future, the fiber node and street box may support fiber to the curb (FTTC) or fiber to the home (FTTH), so the importance of this device in terms of management will increase. Also, the equipment at these points may become more complex (especially the street box) if ATM is used to deliver to the set-top box or cable modem. In these cases, more sophisticated management facilities will be necessary.

IV. Two-Way Transmission

Our description of CATV systems so far depicts a network that distributes signals only from the head end to subscribers, and cannot transmit signals back to the head end.

For the most part this is accurate, as the engineering of these systems reflects the fact that they are used to carry television service to subscribers and not the other way. But it is possible to carry two-way signals on a cable system, and in fact many cable systems are either built with some two-way capability or designed so that this can be added to the system later on. The coaxial cable medium is not itself directional, and sending signals on it in one direction does not preclude also sending signals in the other direction. This is true generally for any wire line medium; telephone networks in fact carry voice signals in two directions simultaneously over the same circuit, and it is possible to separate these two signals at the ends of the line.

In practice the noise on upstream channels comes mostly from external sources of noise (such as noise generated from radio transmitters, electric motors, computers) that leak into the system through imperfections in the network and home wiring. Such noise is called *ingress*, and it is difficult to characterize exactly because it depends on the nature of particular sources. Different parts of the cable spectrum can have very different upstream noise characteristics simply because the sources of noise change at different frequencies. A hybrid fiber/coaxial architecture can provide some relief to the noise funneling problem. Because neighborhood distribution networks are connected individually to the head end by fiber trunks, the sources of combined upstream noise can be limited to one neighborhood, and can be reduced as neighborhood nodes are made to serve a smaller number of subscribers. If we expect that the total upstream noise rise in proportion to the number of subscribers, then splitting a 5000-subscriber into ten 500-subscriber nodes might improve the upstream signal-to-noise ratio by 10 dB.

V. HFC Application

The applications that we can easily list for cable are for the most part existing applications that would be carried on a new medium. This is conceptually similar to recent efforts use the Internet to carry voice communication (so called Internet telephony) and fax communication. It is also just what cable television systems did in their original role as distributors of broadcast television. But some important communication applications we use today grew out of existing services: fax transmissions now account for a significant amount of telephone traffic, and the tremendously popular World- Wide Web application is only a recent use of much older Internet technology. Voice and fax communication, for example, are two applications that are supported by standard telephone service. Internet service (specifically the IP transport that is provided by the network) supports the applications of electronic mail, remote login. In the case of telephone service, the network technology was engineered around one application but other applications were able to adapt to what the service provided.

Several entertainment applications for cable fall into the category of *playback* applications that involve delivering a data stream, usually for video or audio, over time to a device that plays it to users. Implementations often use data compression schemes, such as the MPEG standards for audio and video that can dramatically reduce the data rate required for transmission.

The Table I below summarize the technical demands that these communication applications would place on CATV systems.

TABLE I

Application:	**Network Traffic:**	**Other Issues:**
Broadcast Video	2×10^6 b/s downstream (compressed) variable but limited rates.	Providers need security mechanisms for pay-per-view applications.
Video-on-Demand	3×10^6 b/s downstream (compressed), variable but limited rate. Small (10^3 b/s) upstream rate.	Providers need security mechanisms for pay-per-view applications.
Advanced Television	10^7 b/s downstream (compressed).	Similar to television applications.
Digital Audio	10^6 b/s downstream.	Playback demands similar to video delivery.
Telephony	6×10^5 b/s two-way (uncompressed) fixed rate.	Packetization delay may be a problem. Users demand privacy. Standards demand very high reliability.
Video Conferencing	10^5 b/s two-way (compressed), highly variable data rates.	Latency is a problem for interactivity. Privacy is important to users.
Computer Networks	10^5 to 10^8 b/s or more, two-way traffic. May be very bursty.	Traffic characteristics and future needs depend on what applications will be used.
Electronic Games	Depends on application.	Interactive multi-player games demand low-latency two-way communication.
Telemetry	10^3 b/s, very bursty.	Security is important to prevent fraudulent use. Reliability may be essential for some applications.

VI. Conclusion

Although cable networks have been engineered primarily to deliver a broadcast television service, modern hybrid fiber/coaxial networks have the potential to provide a powerful communication medium that could support a variety of applications. Because cable networks are built to transmit high-bandwidth signals, they can support aggregate data rates on the order of several gigabits per second. The transmission characteristics on cable are not symmetric—communication upstream is inherently more difficult than downstream—but the largest bias against upstream traffic is simply the small bandwidth allocation that is typically given to upstream communication when cable networks are built. Cable networks share a coaxial transmission medium among multiple users, and while this on one hand gives cable the flexibility to dynamically use resources as needed, it on the other hand requires technical means of allocating resources. Furthermore, the shared medium can create privacy, security, and reliability problems that cable communication systems may need to address. The sorts of applications we envision being supported by cable systems have diverse communication needs, some taking advantage of the high data rates that cable can support, some demanding high reliability from the network, and so on. One vision of how these applications might be supported on cable networks would devote specific services to specific applications, but it is equally conceivable that many of these applications might be integrated into a single service. The Internet, or something like it, may in the future become a common platform for supporting many applications. This may blur our distinction between services and applications, but regardless of this the technical demands of applications must ultimately be satisfied by the underlying network technology.

REFERENCES

[1] O.B. Panagiev, "Some Capabilities of the Optical Technologies in the Cable Television Systems".,IX NSASC "Electronics'2000, Sozopol 20-22 sept. 2000

[2] IEEE Commun. Mag., vol. 35, no. 6, June 1997.

[3] M. Laubach, "Using ATM over Hybrid Fiber-Coax Networks," presented at SPIE Eastern Conf., Philadelphia, PA, Oct. 23, 1995.

[4] IEEE Commun. Mag., vol. 36, no. 3, Mar. 1998.

[5] C. Eldering, H. Nageen, and G.Floyd "CATV Return Path Characterization for Reliable Communications." *IEEE Communications* 33, no. 8 (August 1995): 62-69.

[6] D. Estrin, "Data Communications via Cable Television Networks: Technology and Policy Considerations." Master's thesis, Massachusetts Institute of Technology, 1982.

[7] D. Feldmeier "A CATV-Based High-Speed Packet-Switching Network Design." Master's thesis, Massachusetts Institute of Technology, 1986.

[8] P. Fockens, "The 43 Mbit/s Digital 16-VSB Modem for Cable TV." *Communications Technology*, May 1994.

[9] H. Fowler, and W. Leland "Local Area Network Traffic Characteristics, with Implications for Broadband Network Congestion Management." *IEEE Journal on Selected Areas in Communications* 9, no. 7 (September 1991).

[10] D. Lindstrom, "Sniffing A Cable Modem Network: Possible or Myth?", SANS Institute, 2002

[11] http://www.cablemodem.com

[12] http://rpcp.mit.edu