CHAPTER

3

Television Over the Internet: Technological Challenges

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Technology is a key factor in shaping the future, but there are many technological uncertainties and challenges that will need to be resolved for television over the Internet to become a reality. This chapter discusses these technological challenges.

DELIVERY INFRASTRUCTURE

Television and video are delivered by a variety of means to consumers, as is depicted in Fig. 3.1. Conventional broadcast television is transmitted over the air by radio waves in the VHF and UHF frequency bands. Broadcast television originates at the television studio, and increasingly broadcast television signals at the studio are in a digital format, although conventional VHF/UHF transmission remains mostly analogue.

An additional channel in the UHF band was given to the VHF broadcasters to be used for the broadcasting of digital TV, which could be high-definition TV (HDTV) or the multicasting of a number of digital TV programs at conventional resolution. Consumer response to such digital TV has been very low thus far in the United States.

Television programs are transmitted to earth from communication satellites located in geostationary orbits above the Earth's equator by virtue of a technology called direct broadcast satellite (DBS) television. DirecTV is the dominant DBS provider in the United States. Over 200 television pro-

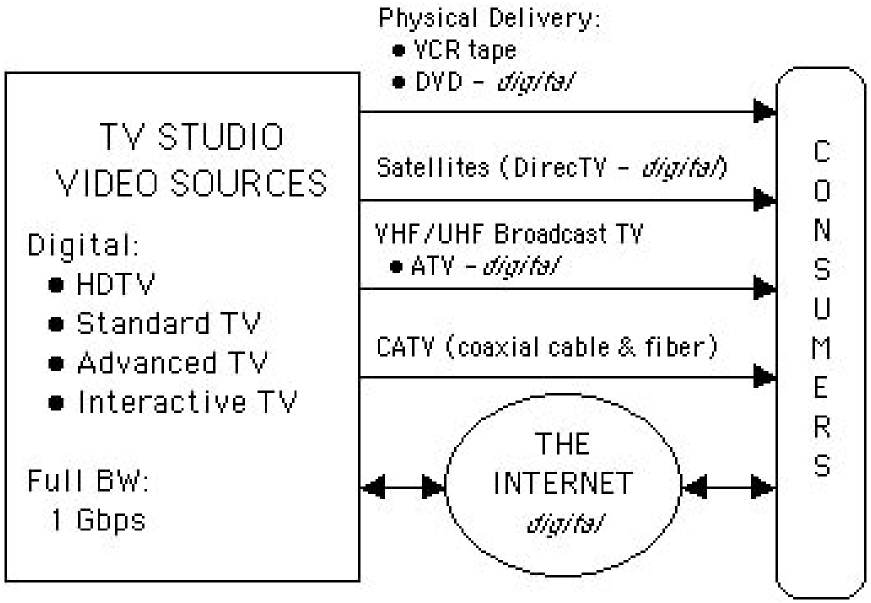

FIG. 3.1. Television signals are delivered to consumers over a wide variety of media and means.

grams are converted to a digital format, compressed to reduce their bit rate, and broadcast to earth over the DirecTV DBS service. Over 15% of households in the United States obtain their television from DBS.

Another 64% of households in the United States obtain their television over the coaxial cable of the local cable television (CATV) service provider, with AT&T currently being the largest CATV provider in the United States. The signals sent over CATV are mostly analogue television at the conventional bandwidth of 6 MHz per TV channel. Given the success of DBS with its digital transmission of television, CATV will increasingly likewise migrate toward digital, thereby being able to offer more channels of programming. It would be nice if the quality of programming content were to match the increase in the number of channels, but it seems that more channels equates to lower program quality because each channel is able to capture a much smaller audience.

DBS, CATV, and VHF/UHF television signals are all broadcast electronically, either as radio waves or as electrical waves over coaxial cable. Recorded video is delivered physically on magnetic tape or on laser discs. Prerecorded video is used for mostly movies and for other programming.

Such video has been physically delivered over tape—the videocassette recorder (VCR). Increasingly, video is being delivered physically in digital form in a compact digital videodisc (DVD).

COMPRESSION

At the TV studio, television cameras are still mostly analogue, but digital technology is becoming increasingly pervasive. Within the studio, digital television signals operate at full digital rates. HDTV digital requires about 1 Gbps (10^9 bps), and digital video recorders are available to record such fast rates. What is not available are media capable of transmitting such fast rates to consumers in their homes. Compression is the interim solution until more bandwidth becomes available.

Television signals consume vast amounts of bandwidth. An analogue broadcast television channel in the United States requires 6 MHz of spectrum space. The analogue video signal itself requires about 4 MHz of analogue bandwidth. Converting this analogue video signal to a digital format for home quality can consume a bit rate of about 84 Mbps. High-definition professional studio quality requires about 1 Gbps. Such tremendous bit rates are very costly to transmit over conventional broadcast and switched systems. The solution is compression.

Video images change slowly from frame to frame. Rather then transmit the entire information in each frame, compression techniques encode and transmit only the changes in information from one frame to the next. This is interframe compression. Within each frame, the information from one scan line to the next is very similar. Compression techniques encode the changes from one scan line to the next and also look for similar blocks of information. This is intraframe compression. Compression algorithms have been developed by the Moving Pictures Expert Group (MPEG) of the International Standards Organization (ISO).

A conventional television signal has an analogue bandwidth of about 4 MHz. When converted to a digital format, this television signal requires a bit rate in the order of roughly 100 Mbps. When compressed, a much lower bit rate in the order of about 4 Mbps suffices. Compression is, however, a compromise with quality, and certain artifacts can appear in the reconstructed television image. Most of these artifacts would not be bothersome to most viewers, however. Compression to lower bit rates as low as only 1 Mbps can be done if the degradation in quality is acceptable.

TECHNOLOGICAL SPECIFICATIONS

There are a number of technological factors that characterize signals. Various factors are shown in Table 3.1 for voice, data, and video signals. The

TABLE 3.1
Technological Factors

	Voice	*Data*	*Video*
Bandwidth:			
• analogue	4 kHz		6MHz
• digital	64kbps	56 kbps to 1 Mbps	84 Mbps
• compressed:			
good quality	8–12 kbps		4 Mbps
lower quality	1.2 kbps		1 Mbps
Directionality	Two-way	Two-way	One-way
	Full duplex	Half duplex	Simplex
Holding time	Minutes	Minutes	Hours
Symmetry	Symmetric	Asymmetric	Asymmetric
Network	Switched	Switched	Broadcast
Timing	Distributed	Distributed	Prime time
Purpose	Communication	Information	Entertainment

factors for these three signals are quite different, which might imply different kinds of networks to deliver each.

Perhaps the most important factor in characterizing a signal is the bandwidth—either analogue Hertz or digital bits per second—required to transmit the signal. In analogue form, telephone quality voice requires 4 kHz; an analogue television channel consumes 6 MHz. Analogue signals can be compressed to reduce their bandwidth. Analogue telephone speech could be reduced by a factor of 10 using vocoder technology.

Digital signals are characterized by their bit rates, but they also occupy analogue bandwidth. All signals, analogue or digital, occupy bandwidth. A telephone signal converted to digital format requires 64 kbps; a television signal requires 84 Mbps. The digital television signal can be compressed to as low as 1–4 Mbps, but a digital speech signal can be compressed to as low as 1.2 kbps. Whether analogue or digital, television requires considerably more bandwidth and bit rates than telephone speech. Data signals fall in between speech and video in terms of bit rate.

Most voice telephone calls are quite short, in the order of a few minutes, although some people visit for hours by phone. Traditional television programs and movies are much longer in duration, usually a half hour or more. Although most data sessions are short, downloading a large file can take a long time. Voice requires a symmetric switched connection with equal transfers of information in each direction. Video is broadcast in one direction. Voice requires a full duplex connection to enable both parties to speak simultaneously. Data directionality can switch in a half duplex manner. Video is usually one-way all the time in a simplex manner, except for interactive, two-way television. Data requires a switched network, but most of the data traffic is asymmetric in one direction.

The audience timing for voice and data communication is distributed during the day, although there are some peak hours of use. Video is usually watched by nearly everyone at the identical prime-time hours. The purpose of voice is communication, the purpose of data is information, and the purpose of video is mostly entertainment. Thus, voice, data, and video are quite different in terms of their technological characterization. This might imply different network architectures and delivery technologies.

NETWORK ARCHITECTURE

Networks can be classified according to their locale. Backbone networks (called long distance networks for voice telephony) cover great distances, such as across continents or under oceans. Local access networks are the means in which access to backbones is obtained. Lastly, there are intrapremises networks that carry signals from one computer to another within a building or office. The technological challenges for Internet television are different for these different networks.

Networks consist of three major areas: transmission, switching, and control. Transmission deals with the various media over which signals travel from the source to the destination. Transmission also deals with how many signals can be combined to share a medium—what is called *multiplexing*. Switching and control treat the various methods for assuring a signal gets to a specific destination.

There are many transmission media: copper wire, optical fiber, coaxial cable, and radio waves. Signals can be multiplexed by assigning each its own unique band of frequencies, or what is known as *frequency-division multiplexing*. Digital signals can be multiplexed by assigning each its own unique place in the time sequence, or what is known as *time-division multiplexing*.

In the analogue world, signals occupy bandwidth measured in Hertz. In the digital world, signals require bit rates measured in bits per second. But even digital signals have waveforms, which occupy frequency space measured in Hertz.

Telephone speech can be converted to a digital format, usually at a bit rate of 64 kbps. Data is already digital and operates over a wide range of speeds, with personal computer modems operating at 56 kbps and high-speed modems at about 1 Mbps. Television can be converted to a digital format in the range of 1 Mbps to 100 Mbps, depending on compression and quality. Thus, speech, data, and video can all operate in a digital format in which a bit's a bit. To many people, this common digital format represents a convergence of signals. But in the old world of analogue, speech, data, and video all occupy analogue bandwidth in which a Hertz is a Hertz. It thus means little philosophically whether signals are analogue or digital, because the format of a signal is really an engineering question depending on the need for noise immunity.

The telephone network uses a form of switching known as *circuit switching*. The Internet uses a form of switching known as *packet switching*. These two approaches to switching are quite different. Circuit switching seems best suited to voice telephony, although it can also be used for data communication. Packet switching seems best suited to data communication, although it can also be used for voice telephony.

With circuit switching, a continuous connection is maintained for the duration of the communication. This connection can be a real circuit formed by a physical electrical connection between the two parties. This connection can also be a virtual circuit created by transferring digital bits in such a manner to give the appearance of a physical connection. With circuit switching, the communication flows effortlessly and continuously, whether or not any real information is communicated. The connection, be it physical or virtual, is always there and available for use.

With packet switching, information is broken into a series of packets, and each packet is sent separately from the source to the destination. Depending on the specific protocol or standard being used, packets can be fixed in length (either very short, consisting of about 1,000 bits, or very long) or variable in length. In addition to the actual information being sent, each packet also contains header information along with information specifying the addresses of the destination and source.

The historical evidence is that the pace of growth in capacity of transmission systems is accelerating. More recent generations of transmission systems have compounded annual growth rates much faster than older systems. Switching is dependent on computer technology, and computer processing power grows by Moore's law at a constant growth rate. Thus, transmission bandwidth is outpacing switching. This could change if a new generation of switching systems, such as optical switching, were developed. In the meantime, one of the rationales for the development of the Internet and packet switching, namely, to save bandwidth, is today much less valid. Packet switching might therefore be replaced by circuit switching, which wastes bandwidth but has simpler switching and little latency. There is always a trade-off between bandwidth and latency. The real issue today is not bandwidth, but switching.

Most switched networks are organized into a star configuration, with switching occurring at the hub of the star. A bus configuration is used mostly for broadcast applications, such as cable television, in which the same signals are sent to everyone. A bus configuration can also be used for switched data, such as the Ethernet protocol, in which the data signals include information to specify the destination.

Most engineers would consider cable television to be a broadcast, nonswitched architecture. However, switching does occur at the set-top cable box where the viewer chooses which channel to watch. In effect, all channels are sent to everyone, and the viewer chooses which one to watch. This is clearly a form of switching.

NETWORK REQUIREMENTS FOR SWITCHED VIDEO

Conventional broadcast VHF/UHF television today remains analogue, but direct broadcast satellite television is already compressed digital. Digital TV is also being broadcast over-the-air by the conventional TV stations utilizing additional UHF channels allocated for that purpose. Nearly all TV studios are heavily digital already. Thus, it is not “digital” that characterizes Internet TV. What characterizes Internet TV from conventional television is the use of a packet-switched network to deliver video, either downloaded or streamed in real time. But a number of technological challenges need to be overcome for this switched video to happen. One is the amount of traffic generated by video.

Claims continue to be made that data traffic exceeds voice traffic. But studies of users show that for switched networks voice traffic greatly exceeds data traffic by a factor of at least ten (Noll, 1991; Noll, 1999). Much of the actual data traffic could be search services and overhead, although the downloading of programs and media is an ever increasing trend. Telephone speech, when converted to a digital format, consumes 64 kbps in each direction. Thus, 10 minutes of two-way speech consumes a total of 76.8 million bits. It would require a tremendous amount of Web surfing to consume this amount of bits, and many people spend an hour or more each day talking on the telephone, wired or wireless. All this changes for video.

Two hours of digital video compressed to an average transfer of 4 Mbps consumes a total of 28.8 billion bits. These 2 hours of compressed video require nearly 400 times the capacity required for 10 minutes of a two-way telephone conversation.

Transmission capacity in backbone networks is probably available for Internet television. A single strand of today's single-mode optical fiber routinely carries a few Gbps. The theoretical maximum capacity of a single light-frequency channel of single-mode fiber is 200 Gbps, which is enough capacity to transmit 50,000 compressed TV programs. As impressive as this may be, if the entire light spectrum were used, then the theoretical capacity increases to 50,000 Gbps (Noll, 1998). This is enough capacity to carry 12.5 million compressed video programs at 4 Mbps each. If audiences are bored by today's 200 channels over DBS, then imagine 12 million channels from which to choose!

Intra-premises wiring in the form of coaxial cable or even twisted-pair of copper wire has considerable capacity to carry video and is not a problem. The access from the home to the local access point might appear to be a challenge. The coaxial cable of the CATV provider has considerable capacity, but this capacity is being utilized fully to transmit conventional video programs and there is not sufficient spare capacity to transmit Internet television to hundreds of individual users. Systems in which a single circuit is shared, such as CATV, could be overwhelmed by many simultaneous users. One solution would be to use fiber rather than coaxial cable because fiber has tremendous capacity. However, technologies to enable sharing of fiber by many simultaneous users on the same fiber strand are still costly, although they surely will be developed. Another solution is to dedicate a separate fiber to each home, but this too is a costly architecture to install.

The local telephone network uses a separate twisted pair of copper wire to each home and does not suffer from being overwhelmed by many simultaneous users. The only problem is the capacity of the twisted pair that depends on distance. Over relatively short distances (under a mile), twisted pair can easily carry a conventional analogue television channel. Digital subscriber line (DSL) technology exploits this capacity by placing digital information in frequencies above the 4-kHz voice baseband signal. However, DSL is currently limited to distances less than 15,000 feet. One solution is to bring fiber to the neighborhood and then complete the high speed connection over copper wire. The local access architecture will continue to evolve, and as one bottleneck is resolved, another will appear.

Clearly, there is considerable transmission capacity in today's network, particularly the intra-premises and backbone portions, with plenty of options for local access. The real challenge to Internet television is switching. Internet video pushes packet switching by a factor of 100 beyond Internet access at conventional 56 kbps rates. In addition, because everyone watches television at the same prime time, the requirement for simultaneous access makes it difficult to time share switching facilities. The switching of all the packets required for video would overwhelm today's packet backbone along with local Internet access facilities. It is switching, and not transmission, that would be overwhelmed by Internet television.

Switching is closely related to computers, particularly because digital switches look much like a digital computer. Servers are computers that handle the information needs of many simultaneous users. Servers to handle videos accessed and delivered to thousands of simultaneous users do not exist and will be a challenge to develop. One solution is to distribute many servers throughout the network as close to users as possible so that each server handles an acceptable number of simultaneous viewers. But such a large investment in technology would be costly and would be quickly obsolete as the technology progressed.

OTHER TECHNOLOGICAL CHALLENGES

The issue of the convergence of the home TV set with the home personal computer is perplexing. Although TV sets increasingly are utilizing computer technology and although personal computers utilize visual displays, TV sets and computers remain much apart. Most consumers do not care about convergence. The TV set is used in a passive manner to watch television and view videos. The personal computer is used to access and send e-mail and to obtain information from various Web sites. As Internet users become more experienced, their web surfing decreases as they discover and bookmark their favorite sites. If television is ever delivered over the Internet, then software reliability will need to be improved greatly. It seems that most personal computers crash a few times a day. This will not be tolerated by most consumers for simply watching television. Internet TV will need to be robust.

One challenge facing Internet television is navigation through thousands of choices to reach the desired video program. This problem occurred with DirecTV and was solved through on-screen program listings to assist the viewer in navigating to a desired program. The use of an Internet-like interface to assist in the navigation through listings of hundreds and thousands of programs would make sense.

Set-top boxes are supplied by CATV providers as an interface between the home TV set and the coaxial cable. These boxes are costly to develop and install on a massive level. The use of the Internet protocol to deliver television over CATV will require a new generation of set-top boxes. Moreover, before such boxes are developed, standards must be agreed on and adopted.

Many standards questions abound with Internet television. Systems must be interoperable, compatible, and reliable. In terms of compression, MPEG is already the "HTML" of video. But Internet television will introduce the need for a host of new standards.

FREEING UP THE AIRWAVES

Internet television is a switched service that could be delivered over coaxial cable, optical fiber, and twisted pair of copper wire. Thus, Internet TV would continue the trend of moving broadcast television away from the air waves of the VHF/UHF spectrum. Cable television and direct broadcast satellite television are the ways most Americans receive their television. Only about 20% of Americans presently receive their television directly over VHF/UHF (Noll, 1999). If Internet TV were to decrease the use of VHF/UHF television, then interesting policy questions arise concerning whether or not the VHF/UHF channels should be returned to the public by the broadcasters and used for more valuable purposes, such as wireless cellular telecommunication. As policy, the government might then require CATV and Internet TV to offer a minimum "lifeline" television service for free. The former VHF/UHF broadcasters might be required to pay these alternative media to distribute their programs for free. This would be fair because the broadcasters would be saving the expense of over-the-air broadcast transmission.

SWITCHED VIDEO

Television currently is transmitted over broadcast, nonswitched networks. One definition of Internet television is the transmission of television over the Internet, which is a packet-switched network. Why would television migrate from a broadcast medium to a switched medium? One reason would be that the switched medium was less costly, but the packet-switched Internet is more costly than conventional broadcast media. Another reason would be new features for viewers. But, thus far, all attempts at interactive television (other than teletext in Europe) have met with poor consumer acceptance.

There is one video service that requires a two-way, switched network, namely, the videophone or picturephone. Will Internet TV then evolve into the videophone? This is doubtful, because all evidence indicates that most people would rather not be seen while speaking on the telephone (Noll, 1992). However, many people are using the Internet to send videos of children and family trips to their friends and family. This trend could expand and ultimately evolve into the videophone.

During the early days of the picturephone in the 1970s, there was discussion of the use of cameras at public places that could form a switched video network. But the need for such switched video was not clear back then. Today, web-cams are located at key traffic places, such as bridges and tunnels in the New York City area, to show the current traffic situation. The still images of these web-cams could evolve into full motion, a form of Internet television.

Most people care most about the news that has the most impact and interest to them, and that is mostly about their immediate family and friends. The larger the scope of information, the less the importance to individuals. This hierarchy of the need for information starts at the individual and extends to the universe with family and friends, neighborhood, city and state, and country in between (see Fig. 3.2). Broadcast radio and television do fine at broadcasting news of broad interest, but do nothing for the neighborhood and family news

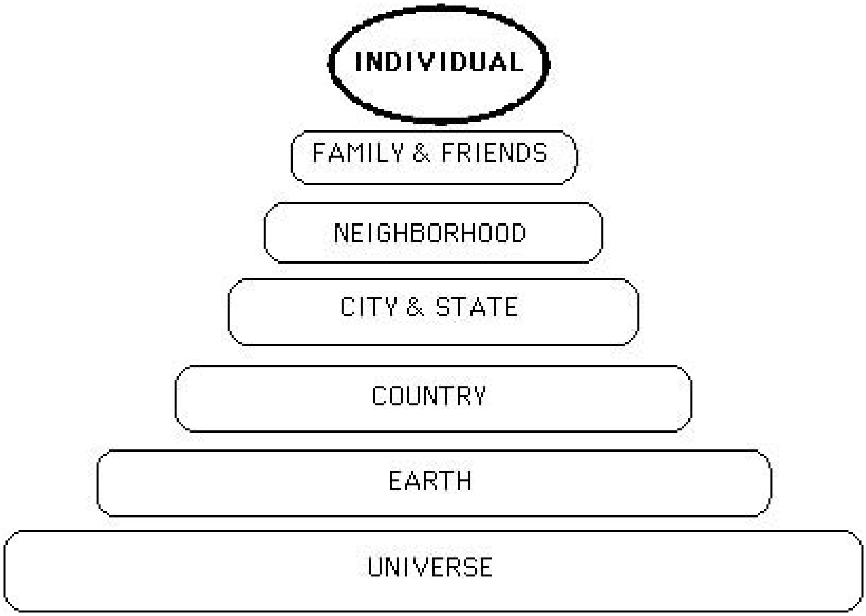

FIG. 3.2. The need for information forms a hierarchy. Most people are most interested in information that impacts on their immediate family and friends. Information about the Earth and the universe might be interesting, but the need is not very strong or pressing.

that concern people most. Internet TV might have an ability to serve more focused, narrower content of such neighborhood and family news.

REFERENCES

Noll, M. A. (1991, June). Voice vs. data: An estimate of future broadband traffic. *IEEE Communications Magazine, 29*(6), pp. 22, 24–25, 78.

Noll, M. A. (1992, May/June). Anatomy of a failure: Picturephone revisited. *Telecommunications Policy, 16*(4), pp. 307–316.

Noll, M. A. (1999a, June). Does data traffic exceed voice traffic? *Communications of the ACM, 42*(6), pp. 121–124.

Noll, M. A. (1998). *Introduction to telephones and telephone systems,* (3rd ed., p. 114). Boston: Artech House.

Noll, M. A. (1999b, October). The impending death of over-the-air television. *Info, 1*(5), pp. 389–391.