Special Issue on Transmission and Distribution of Digital Video Part 1: Architecture, Control, and Management

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Welcome to this special issue of *IEEE Network*, which presents analyses and modeling of the emerging architecture, control, and management techniques related to the transmission and distribution of digital video for applications ranging from education to entertainment to videoconferencing.

Digital transmission and distribution of audiovisual information enables multimedia communication over the same network that supports data communication. This opens up possibilities for the consumer to interact with the audiovisual programming in ways that were not possible before. Automatic archiving, indexing, retrieval, and filtering of audiovisual data increase the value of video information. In addition, digital information is more robust to degradations during transport and storage.

Efficient delivery of high-quality digital video involves timely delivery of impairment-free bitstreams to terminals/end units/display devices, in addition to guaranteeing a certain amount of channel bandwidth, to maintain liveliness and interactivity of the video. The challenges in designing an acceptable end-to-end system involve the following:

- Compliance of video coding between source and receiver/display device, or transcoding and transmultiplexing as appropriate
- Interfacing with storage and display technologies
- Matching the video source and video transmission channel dynamics by managing network resources via quality of service (QoS) and routing information signaling
- Offering customized video distribution services in an efficient and scalable manner

Video Coding

The Motion Pictures Expert Group (MPEG) developed a common format for coding and storing digital video and associated audio information in the first phase of its work in 1991. The MPEG-1 standard (ISO/IEC 11172) was thus born with a goal to produce video with a quality similar to that of a VHS videotape recorder using a bit rate of approximately 1.2 Mb/s.

The MPEG-2 standard was originally designed for compressing broadcast-quality video into 4–6 Mb/s streams, although the standard can accommodate a wide range of rates and resolutions. MPEG-4 is targeted at videoconferencing applications with low delay and stringent bandwidth requirements. Although a host of other International Telecommunication Union (ITU) standards, such as H.26x and H.32x, are also emerging, it is expected that low-overhead/complexity transcoding will be available to support universal availability of multimedia services [1].

Some of the challenges associated with video coding involve:

- Understanding the characteristics of the traffic generated by compressed video applications
- Mapping user QoS requirements to compression parameters and network resource requirements
- Developing video compression standards that scale well over the spectrum of available bit rates
- Studying the interaction between the transport mechanisms and the coding techniques

Video Interface: Display and Storage Technology

Video over networks cannot be considered from a network perspective alone. Video networking is materially different from data networking in the sense that it involves a human consumer. The video stream must come from some storage device, perhaps a video-on-demand server, or a live-video source such as a camera or rendering engine, be carried across the network, and end up on a display device. Display technology ranges from relatively mature CRT-based technology to the newer flat panel display (FPD) devices [2]. The variations in characteristics such as resolution, refresh rates, dynamic contrast, luminance stability, and decay rates make high-quality video in a heterogeneous display environment challenging. Storage and retrieval of video information is also critical to the economic success of the entertainment industry, since a significant portion of the economic benefits comes from reruns. Automation of archiving and retrieval, and development of new search facilities and storage technologies (digital versatile disk, optical media, etc.) are revolutionizing the way video information is stored [3].

Video Transmission

A number of technologies are currently available for video transmission [1]. Narrowband integrated services digital network (N-ISDN) was initially developed with the goal of integrating voice and nonvoice services. Videoconferencing products over N-ISDN are available and enjoy some limited success, but the low bit rates supported by N-ISDN limit the applicability of this technology.

Asynchronous transfer mode (ATM) is the technology of choice [1,4] for the evolving broadband ISDNs (B-ISDNs). Since ATM uses small fixed-size (53 bytes) cells, it can handle both constant bit rate (CBR) audio/video and variable bit rate (VBR) video/data traffic well. ATM networks support QoS, meaning that they allow the user to specify the characteristics and requirements of the video/data stream to be transmitted over the network. The resources for the connection can therefore be tuned to the requirements of the video source. ATM networks route connections using the private network-to-network interface (PNNI) routing protocol, which supports dynamic link metrics to enable QoS-sensitive routing. This makes it especially suitable for routing the connections carrying video/audio traffic. It is also much easier to support broadcast and multicast using cell-switching technology than with circuit switching.

The arrival of gigabit Ethernet has shaken confidence in ATM, and raised the possibility that the Internet will provide end-to-end video connectivity, leapfrogging past ATM. However, ATM may continue to play an important role in the backbone of the network, and for high-speed real-time applications such as video production studios.

Synchronous optical network (SONET) is an ITU-T standard for optical transmission that deals with framing, encoding, and multiplexing. It defines how telephone companies transmit data across optical networks. The lack of flexibility in bandwidth allocation and the absence of network layer (routing) functionality limit the direct use of SONET for video networking, but it can play a role as the transmission technology for a higher-layer protocol, such as the Internet Protocol (IP).

The Internet is a hodgepodge of different transmission technologies, with IP acting as glue to bind them together. Traditionally, IP networks were not aimed at multimedia applications. However, advances in the underlying transmission technologies, such as the various digital subscriber line (DSL) technologies, cable modems, and gigabit Ethernet, and the potential to run IP directly over SONET in the backbone, are making the Internet a competitor for video services.

The traditional Internet services were best effort and did not provide any real-time guarantees. However, the Internet is evolving in this direction, and video is certainly one of the first services that will benefit from the deployment of QoS or class of service (CoS) support over the Internet. There are two possible architectures, IntServ and DiffServ, that could be used to provide such support.

The integrated services (IntServ) architecture provides support for QoS in the data forwarding path of Internet routers and switches. This involves appropriate scheduling mechanisms, per-flow queue management, and packet classification. The Resource Reservation Protocol (RSVP) is a signaling protocol that is responsible for setting up the flow classes, queues, and scheduling priorities for IntServ routers or switches. The IntServ model assumes per-flow QoS provisioning, and hence suffers from potential scaling problems.

While heavy-duty real-time services are required for some stringent applications, cruder forms of service differentiation may satisfy most users of the network. Differentiated services (DiffServ) aims to provide such coarse-grain service differentiation without necessarily introducing per-flow QoS. The DiffServ architecture is based on marking packets with a bit pattern (e.g., in the IPv4 TOS octet) at the edge of the network, and performing service differentiation on the basis of this information in the core of the network. Carrying the marker in the packet eliminates the need to maintain per-flow state in the core of the network, thereby increasing its scalability. The DiffServ architecture can be used to implement a wide range of network services, such as multiple classes of service (e.g., Gold, Silver) or virtual leased lines.

Video Distribution Networks

In true video on demand the user has complete control of the delivery of video content to the display device, while near video on demand provides pseudo control using less resources. The ability to deliver VCR-like control of video programs without using a dedicated per-client channel provides significant opportunity for revenue, since it will enable delivery of multiple customized video streams to the home at reasonable cost. Additional constraints like scalability, fairness, bandwidth limitations as in Internet, and error proneness (as experienced while using DSL modems over the public switched telephone network or in wireless networks) also demand solutions before the emerging paradigms of high-resolution video delivery can become a reality. A discussion of the existing video distribution networking technologies such as cable TV networks, hybrid fiber-coax networks, and direct-broadcast satellite networks can be found in [1, 4]. Emerging technologies such as those using various Earth-orbit-based satellites, fiber to the curb/node/home, and local/metropolitan area wireless networks such as local/multichannel multi-point distribution system (L/M-MDS) based networks or broadband personal communications networks (B-PCNs), are also discussed in [1, 4].

With the above introduction, we present leading edge articles discussing research and experience on the topics related to architecture, control, and management of digital video transmission and distribution networks.

The first article, "User-Oriented QoS in Packet Video Delivery," by O.Verscheure, X. Garcia, G. Karlsson and J.-P. Hubaux, introduces the human-visual-system-based QoS requirements and associated technical challenges for delivering digital video.

In the second article, "Dynamic Quality-of-Service Framework for Video in Broadband Networks," D. Reininger, D. Raychaudhuri, and M. Ott present performance analysis and experience with their proposed flexible object-based QoS management framework. The objective is to achieve efficient delivery of high-quality interactive video services in a transport-layer-independent fashion.

The third article, "Realizing the MPEG-4 Multimedia Delivery Framework," by J.-F. Huard, A. A. Lazar, K.-S. Lim, and G. S. Tselikis, discusses implementation of the MPEG-4 video delivery multimedia integration framework (DMIF) standard for ISO, including a complete specification of the DMIF application interface. The stability of network operation when a large number of channels with a variety of QoS requirements are dynamically established and torn down for one video session is an active research topic.

In the fourth article, "High-Performance Prefetching Protocols for VBR Prerecorded Video," M. Reisslein and K. W. Ross present a survey, and then develop centralized and decentralized schemes for the delivery of stored VBR-encoded MPEG video over a packet-switched network. Their schemes prefill client buffers during the periods when network resources are underutilized, and do not impose any playback delay at the client. Using simulation studies, the authors show that with prefetch client buffers capable of holding a few seconds of video, nearly 100 percent link utilization with negligible packet loss can be achieved, even when all the videos are highly bursty with complex scenes.

The fifth article, "Fast Low-Cost Failure Recovery for Reliable Real-Time Multimedia Communication," by K. G. Shin and S. Han, surveys the available techniques for offering reliable multimedia communications. The authors propose a reliable and scalable per-connection based method for efficiently recovering from faults in multimedia communications networks. Since the error-prone (e.g., PSTN) and unreliable (e.g., Internet) networks are being increasingly used for multimedia communications, the importance of this study does not need overemphasizing.

In the sixth article, "An Overview of Quality-of-Service Routing for the Next Generation High-Speed Networks: Problems and Solutions," S. Chen and K. Nahrstedt present a classification of QoS routing algorithms from the point of view of achieving efficient utilization of network resources while satisfying QoS requirements. It appears that locally optimal but globally suboptimal routing techniques will continue to be useful. Scalable techniques for accurate aggregation of route state are the subject of ongoing research.

The seventh article, "Broadcast/Multicast MPEG-2 Video over Broadband Fixed Wireless Access Networks," by H. Ma and M. El Zarki, describes forward error correction and duplicate transmission (of critical information) based techniques for CBR MPEG video distribution in L/M-MDS-based networks. The results show that the integrity of video transmission is maintained at the expense of additional bandwidth and processing overheads. It would be interesting to see whether it is possible to use VBR video streams in such environments with all the control and compensation mechanisms implemented at the receiver side only.

Finally, in "Traffic Shaping, Bandwidth Allocation, and Quality Assessment for MPEG Video Distribution over Broadband Networks," S. Gringeri, K. Shuaib, R. Egorov, A. Lewis, B. Basch, and B. Khasnabish present an overview of residential video delivery systems and discuss the issues in supporting variable-rate MPEG video on these systems. A technique for analyzing variable rate MPEG streams to determine ATM traffic contracts, which minimize network resources and maintain continuous uninterrupted video, is described. Effective bandwidth measurements are used to predict savings in transmission capacity and switch buffer requirements. However, applying these techniques to switched digital networks/architectures such as fiber-to-the-curb networks may still pose significant challenges.

We received a large number of outstanding articles, but could only accommodate eight in this special issue. We are preparing to publish a set of articles related to field trials and prototype implementations of digital video distribution networks/schemes in the March/April 1999 issue of this magazine.

We thank the authors who responded to our call for papers, and the reviewers who volunteered time to share their knowledge and experience to maintain the quality of publications in this special issue. In addition, we are grateful to Senior Editor Jorg Liebeherr, Editor-in-Chief John N. Daigle, and the staff of *IEEE Network*, especially Susan Lange and Catherine Kemelmacher, for providing excellent support and guidance. We enjoyed putting this special issue together and hope that you find it useful in your every future endeavor related to digital video transmission and distribution.

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