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New options for DTV and the converged IP network

Provisioning services over an IP-based cable system

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The worldwide explosion of the Internet over the past eight years has greatly changed the way that people communicate with one another as well as how we get information. The concept of real-time interactive media services is not new. We have been living with the telephone for more than 50 years; however, it wasn't until the proliferation of residential Internet services that the technology for provisioning multimedia services on demand was feasible. Traditional voice services are fundamentally circuit-based, point-to-point, one service at a time, one interaction at a time. The IP-based Internet, however, is different in that the technology that evolved from its birth introduced a new way of looking at how interactive media gets distributed.

The concept of a packet-based, standards-based, point-to-point or multipoint interaction was revolutionary in many ways. This technology, while well understood and utilized in the data world, is experiencing a new birth in the broadband communications world to meet the demand for high-quality digital video, integrated with other interactive digital voice and data services. Demand for cost-effective, high-speed Internet access, video-on-demand and digital television are growing at an astounding pace. IP offers a way to provision all of these services in a cost-effective single network.

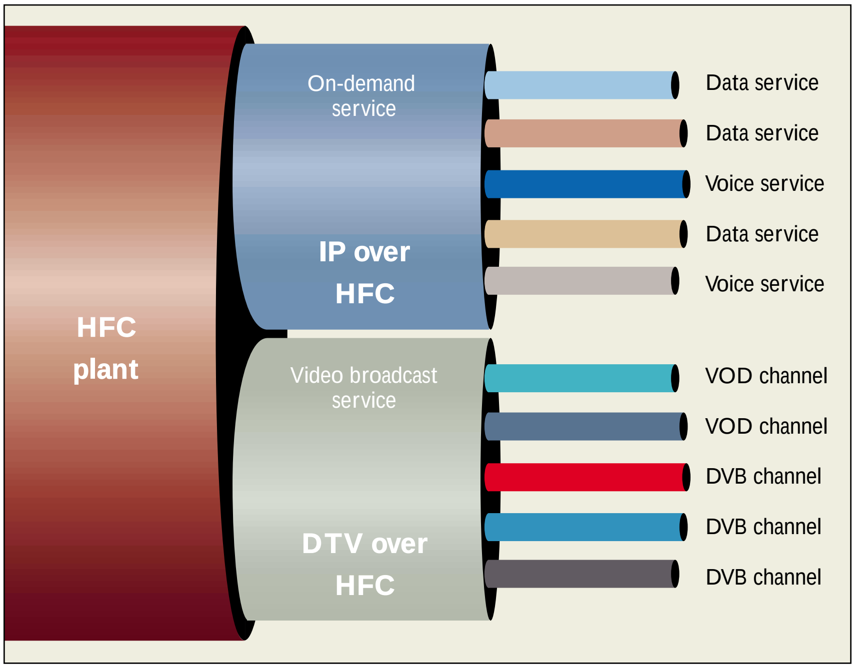

Figure 1: Partitioning the pipe.

IP and the future headend

IP, or Internet Protocol, will be the basis for the last mile and headend interconnect network of the future generation of broadband services. IP has many advantages in terms of provisioning interactive multimedia services over a broadband network. It also has its weaknesses.

What is IP? It is, essentially, a connectionless, packet switching protocol that provides packet routing, fragmentation and re-assembly. It allows bandwidth to be shared among multiple users to provision multiple services. Given the new types of services that MSOs are being driven to provide, the need for a technology that enables scalable and flexible bandwidth becomes apparent.

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The traditional cable TV network is a tree-and-branch topology that distributes content from a centralized headend out to the customer premises. These traditional headends act as satellite and microwave reception areas that collect broadcast information, modulate and upconvert analog and digital services and drive a one-way TV broadcast infrastructure.

This traditional model fundamentally changed when the demand for high-speed

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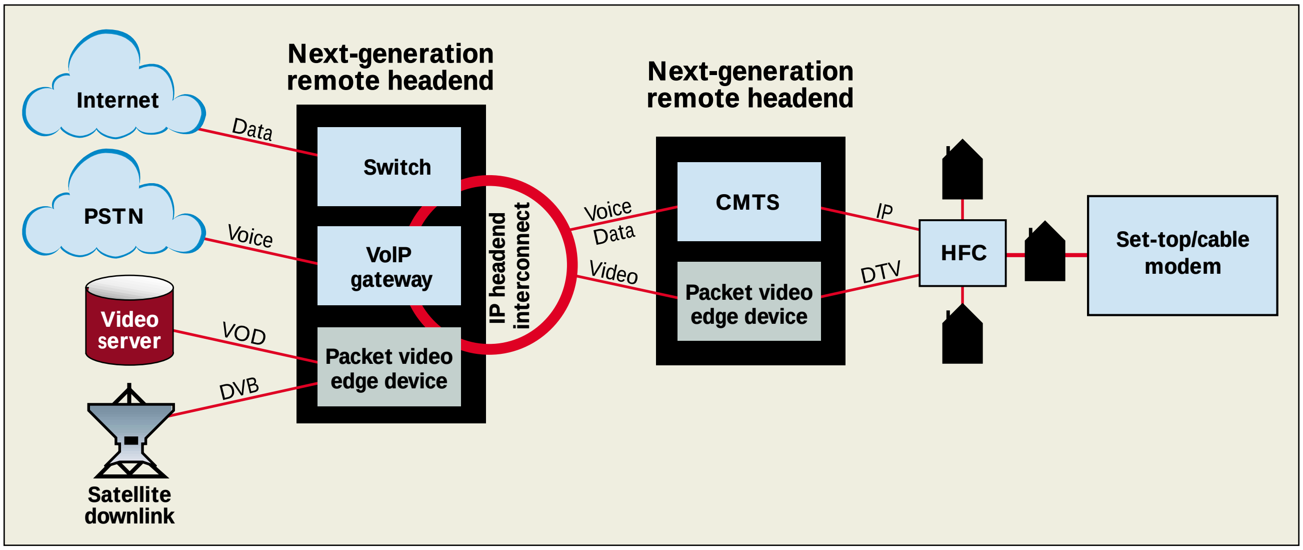

Figure 2: The converged cable plant.

Internet service burgeoned over the past two years. Cable operators, as owners and operators of the access broadband network, had a unique opportunity to tap in to the high-speed residential data delivery business. This opportunity spawned the birth of IP-based services in the cable plant. The old model of cable headends as a system of standalone, unidirectional broadcast facilities changed to become nodes on a bi-directional or full duplex wide area network, or WAN.

These WANs incorporate packet-based data networking technologies like ATM (asynchronous transfer mode) and Sonet (synchronous optical network). Cable modems evolved to act as high-speed, digital, packet-based IP gateways to the home. First-generation cable modems were initially targeted to provision IP-based data services only without provision for voice or digital television or VOD; however, that notion is changing. The challenge for MSOs is that these media types are fundamentally different in many ways from data and ultimately bring the issue of quality of service (QoS) to the forefront.

One would expect, in a truly convergent network, that set-top boxes and cable modems would collapse into a single box and that the core network from the headend interconnect to the last mile would collapse into a single-network, single-protocol architecture. The protocol of choice in the local area network and for multimedia "last mile" services is IP.

Ideally, if IP could be used as a headend interconnect technology, the cable network of the future could be even more seamlessly integrated with the emerging worldwide IP-based networks.

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This article will discuss the issues in provisioning VOD and DVB over a solely IP-based cable system. IP as a WAN technology is one that has been explored by many next-generation networking companies like Arrowpoint (now part of Cisco), Juniper and Luminous Networks. Billions of dollars have and will be spent over the coming year on IP-based convergent solutions, and the designers of the new cable infrastructure have new choices in architecting their networks for the new media market.

The issues with IP and QoS

One of the fundamental problems with IP is that it was originally designed as the transport protocol for data, which is inherently more tolerant to error and uncertainty than deterministic media such as real-time voice or digital video. IP technology breaks a digital stream of information into packets. Each of these packets are given a destination. IP-based edge devices' primary objective is to find a path through the available network links. Considerations such as packet delay variation, packet loss and bit error rate are secondary and accommodated on a "best effort" basis.

For data that was deemed of high priority where guaranteed delivery is necessary, protocols like TCP (transmission control protocol) were developed to determine whether or not packets had indeed arrived successfully. If not, the protocol would initiate a retransmission of lost or damaged packets.

While this is fine for non-real-time applications (e-mail, Web browsing, file transfer), this is a major inhibitor for real-time digital video. Also, there is no error correction mechanism that is effective in a real-time streaming application. Higher-layer protocols like TCP aren't effective because there is no opportunity to initiate a session to re-send lost or damaged packets. This problem is worsened by the high bandwidth demands of the video feeds. The reason digital video is so sensitive to packet delay variation, packet loss and bit error rate is related to the nature of how DTV or MPEG is created from the original video feed.

Why QoS is so important

MPEG-2 technology has emerged as the de facto compression standard for distributed, entertainment-quality video. Full-motion digitized and uncompressed NTSC-quality video has a data rate transfer of roughly 240 Mbps. With little perceived degradation, MPEG-2 can crunch this down to between 4 Mbps and 5 Mbps for distribution quality video.

MPEG-2 achieves this high-level compression factor through several lossy compression techniques. These techniques involve the deployment of chroma sub sampling to reduce the amount of color information (the human eye does not effectively discern small changes in color or chrominance), motion vector estimation (to avoid re-encoding temporally redundant information), and discrete cosine transform algorithms that convert spatial information into the frequency domain.

MPEG-2 uses information about past and future frames, so that the coded video is reused as often as possible. MPEG-2 is also dynamic to the degree that information is coded. When the content is rapidly changing, the eye is less sensitive to detail, so less detailed content has to be coded. When the change in content is slower, the encoder engine injects more detail, and thus more data.

The innate time sensitive nature of video makes managing the clocking of a video stream every bit as important, if not more so, than managing its content. MPEG-2 injects into the stream a free-running 27 MHz timing clock called a program clock reference (PCR). MPEG-2 DTV systems require that the encoder PCR time clock and the decoder's clock are kept in close synch. MPEG-2 compressed video is extremely sensitive to variances in propagation delay. Because the encoding process places vital information about past frames, as well as future frames, lost or corrupted data can result in very noticeable, visually objectionable, blocking artifacts. It is for this reason that MPEG-2 has stringent QoS parameters. For a typical DTV video stream, bit error rates (BER) of less than 1 in 10^{-10}, packet/cell loss rates of less than 1 in 10^{-8}, and packet/cell delays variations of less than 1µs must be maintained.

Services can be assigned different classifications based on sensitivity and priority, and the network is designed to handle them differently. By use of these differentiated classes of service, different levels of service and network handling can be accommodated.

So how can QoS be accommodated in a packet-based network where there are multiple services and multiple routing patterns? Let's begin by studying how ATM technology addresses the issue.

The ATM standard was defined in 1988 by the International Telecommunication Union (ITU) as a vehicle for the transport of broadband ISDN (B-ISDN). ATM addresses the issue of QoS by allocating bandwidth on-demand by a process of constructing virtual channels and virtual paths between source and destination points on the ATM network boundaries.

These channels are not dedicated, physical connections, but are either permanent virtual connections or switched virtual connections that are deconstructed after they are no longer needed. When an ATM device on one edge of the network wants to communicate with another ATM edge device, a "service contract" is negotiated for every switch in the network fabric that guarantees that a predetermined amount of bandwidth is available for the duration of the transmission. This allows the user to segment different classes of traffic by constructing separate and independent path/channel combinations for different media types, each with their own QoS contract.

One notable difference between ATM and IP is that ATM is a connection-based technology that establishes a virtual direct link between source and destination. IP is different in that it does not establish any analogous type of connection (thus IP's description as "connectionless"). However, the idea of tagging different services to be handled differently by the network is an aspect of QoS that can be accommodated in IP. Services can be assigned different classifications based on sensitivity and priority, and the network is designed to handle them differently. By use of these differentiated classes of service, different levels of service and network handling can be accommodated. This is the essence of QoS.

IP multi-service QoS initiatives

There are a number of "Differential Handling of Traffic" approaches to provision IP-based classes of services, in turn enabling QoS, including IEEE 802.1p, TOS marking and DiffServ marking. In all of these approaches, packets are marked with a priority that indicates how the packet should be treated by the network. The DiffServ standard gives priority to the packets that are forwarded from a network edge device (like a CMTS) based on defined service codes. Video, for example, would be given a different service code than Web traffic. While this, in itself, does not guarantee QoS, it does establish its priority relative to other traffic on the network.

Because a typical IP network itself has no direct knowledge of how to optimize the path for a particular application or user, the IP protocol provides a limited facility for upper-layer IP protocols to convey the service tradeoffs that should be made for the particular packet. This facility is known as the "type of service" or TOS facility. The TOS field in the IP header is not considered true QoS, but it is still a way to identify special handling. Although the TOS facility has been a part of the IP specification since the beginning, it has been little used in the past. Now, however, there is an opportunity for next-generation cable modems to provision multiple services to utilize this to drive IP-based multimedia over hybrid fiber/coax plants.

There are a number of resource reservation protocols like RSVP (Resource reSerVation setup Protocol) and MPLS (Multi Protocol Label Switching) that next-generation CMTS systems can use to implement differentiated services, including video.

MPLS is a core technology that handles traffic management for different types of media with different classes of service. It achieves this by differential traffic handling that is provisioned on the basis of a label attached to each packet. It also achieves this by separating the control plane from the data plane in its handling of traffic. MPLS' main objective is to inject predictability into the networks and thus deal with typical QoS issues, including bandwidth management, latency, jitter and packet/cell loss.

MPLS, in theory, can be enabled to provision QoS over multiple types of network technologies. The trick is getting MPLS to be provisioned end-to-end over multiple network types (ATM, IP, Sonet, DWDM), not just in the core or over small segments of the network. There is even an initiative that is a spin-off of MPLS, called multi-protocol lambda switching, to provision QoS on the fiber layer of the network. Currently, there is no standard that exists that would drive how MPLS would be provisioned in the optical (Sonet/SDH), ATM and IP layers to provision QoS from end-to-end.

Cable multi-service QoS initiatives

The cable industry itself has embarked on a set of standards that will allow for the provisioning of multiple service types over IP over the HFC plant. First-generation CMTS and cable modem systems were based on proprietary technology and mostly focused on provisioning data-only services over IP. The DOCSIS (Data-Over-Cable Service Interface Specification) was developed by CableLabs to standardize the implementation of high-speed data services over the cable infrastructure.

The future of multimedia networking will allow MPEG-based DTV services to be distributed over multiple headends through IP-based wide area networking technology

The initiative was kicked off with DOCSIS v1.0, which prescribed universal ground rules for the reliable routing of IP packets between the CMTS and the cable modem. More recent versions of DOCSIS have included QoS and security features that would ultimately make way for the addition of packet-based voice services to the mix. Latest generation DOCSIS standards do this by sub-partitioning bandwidth in the cable plant. Each sub-partition is then assigned a different service type and allows particular high-priority, jitter- and time-sensitive traffic priority over non-real-time critical information (see Figure 1). The natural extension of this logic would allow cable operators to provision video services like VOD, over standards-based equipment that was designed to provision multi-service media over a last-mile cable infrastructure.

IP-based DTV and the new cable headend

The technologies and standards are becoming mature enough for cable operators to begin consideration of IP-based video services in conjunction with data and voice services. What are the features of the next-generation cable system? Standards-based network equipment ensures interoperability with out-of-system networks. Collapsing the network layers into a single packet protocol ensures maximum revenue/cost by offering flexibility, scalability and simplicity.

The future of multimedia networking will allow MPEG-based DTV services to be distributed over multiple headends through IP-based wide area networking technology. Point-to-multipoint services over last-mile infrastructure will exploit the inherent benefits of IP routing, forwarding and multicasting while paying mind to QoS issues. Video-aware network edge devices, in conjunction with new-generation CMTS systems, will give cable operators what has been desired for decades: a single converged multi-service network that allows the dynamic provisioning of video, voice and data (see Figure 2).

The new cable plant will evolve to be a multi-service-based network over a broadband infrastructure from a dedicated channel-based single-service model. As advances are made in IP-based WAN technologies, in conjunction with dense wavelength division multiplexing, cable operators will not only be able to allocate bandwidth to specific types of services, but to individual subscribers. The long-term advantages of such a vision are obvious–a single, integrated multimedia infrastructure that is flexible, scalable, easy to maintain, and technologically poised to provision the next generation of interactive video, voice and data services. ■

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