IPTV Service Assurance

Ken Kerpez, Dave Waring, George Lapiotis, J. Bryan Lyles, and Ravi Vaidyanathan,
Telcordia Technologies

ABSTRACT

This article discusses service assurance aspects specific to IPTV services and video quality. Classic network monitoring generally ensures that each network element, network segment, and subnetwork is functioning reliably, and may also encompass routing and reachability across different network domains. IPTV service assurance can encompass much more, including subscriber management and authorization, capacity management, perceived video picture quality, and error correction and concealment; accomplished through integrated test and monitoring for rapid resolution of customer complaints. This is all needed to ensure that the customer has an overall video quality of experience (QoE) at least as enjoyable as current TV delivery methods.

INTRODUCTION

The deployment of broadband access to the mass market represents a paradigm shift in public networking. The evolution from dialup modem to integrated services digital network (ISDN) to lower-speed digital subscriber line (DSL) was somewhat gradual. But the more recent deployment of higher-speed DSLs, cable modems, and optical-based access represents a remarkable global phenomena. Users of broadband cannot imagine going back to lower speeds. The ability to browse content-rich Web sites, to remotely access corporate and institutional networks with similar performance to the office, and the "always on" nature of broadband are rapidly changing the way we use the network and live our lives.

However, this initial phase of deployment is almost exclusively based on a best effort Internet model. With just a few exceptions, broadband is offered for a flat monthly fee, and performance varies depending on the location of the Web server and current conditions on the Internet. This model has been remarkably successful, including streaming audio, collaboration, peer-to-peer applications, as well as voice over IP (VoIP) and new innovations. Broadband deployments should mature with service providers managing the network to provide secure and reliable services, without requiring great effort by the consumer.

Nonetheless, the Internet is not the only model for delivering services and applications. Entertainment video, for example, benefits from a managed networking environment, where performance metrics can be set by the service provider. This increased quality of service (QoS) will be necessary to deliver some service experiences; for example, a multichannel television offering similar to today's broadcast or cable television, where response to channel changing is nearly instantaneous and content is always available. Streaming digital video over IP core and access platforms, with various networking mechanisms in place to ensure QoS, has come to be called "IPTV." In the ultimate scenario, a user could obtain access to a virtually unlimited number of real-time broadcast "channels" as well as libraries of titles such as movies, syndicated programming, and a potential myriad of local content. The amount and immediacy of content may exceed that of cable television and satellite offerings, while the user interface can actually be simpler and more intuitive.

But bringing vision to reality is predicated on a network that can respond to millions of consumers frequently requesting different streams and expecting real-time response. Designing and implementing such a network in a cost-effective fashion that supports a commercial business model turns out to be quite a challenge. It may be necessary to provide services that provide value beyond bit transport, with assured quality.

IPTV is not the first attempt by the telecommunications industry to offer compelling real-time entertainment video services. A substantial effort was made in the latter 1990s. There are many speculations as to why this "video dial tone" failed. Certainly all of the technologies were early and expensive, from video servers to MPEG compression and decompression hardware, to the network switching fabric which was predominantly asynchronous transfer mode (ATM)-based at that time, to DSL access systems. Today commercial price points for these technologies have fallen dramatically, and very high capacity IP routers have emerged as an alternative to ATM switching. Digital video content is now pervasive, including studios where it has displaced traditional analog formats, the very successful DVD format, and HDTV, which is gaining traction in the United States.

Despite these advances, the commercial success of IPTV is not assured. Among the less visible issues with the early video dial tone platforms

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were scalability and maintainability. Several trials reached thousands of customers, but provisioning and maintenance were handled manually by special teams of highly trained staff. Similarly, early IPTV trials must scale up to hundreds of thousands, and ultimately millions of subscribers. Manual procedures need to be automated for rollout to become feasible. In particular, service assurance for IPTV will require a high level of integration and automation.

This article focuses on service assurance issues specific to IPTV. Monitoring and testing the transport network at the physical, link, and network layers has been addressed in many other papers [1–3], so it is de-emphasized here.

MANAGING IPTV FOR SERVICE ASSURANCE

New Triple Play services extend the range of classical telecommunications service assurance to new video services. The move from analog or time-division multiplex (TDM) production and distribution to packetized systems requires coordinated and sophisticated management, surveillance, and testing because the lower bound of a human user's expectations for TV and voice quality have been set by existing distribution methods. As shown in Fig. 1, the operator will need to control and monitor elements of an end-to-end video service chain consisting of subscriber management, video origination, and network services through to the set-top boxes. This is in contrast to classic network-based service level agreements (SLAs) that specify network performance and uptime without reference to the user-visible services running on top of the network. The key is correct configuration and proper management, surveillance, and testing of all parts of the end-to-end service chain.

IPTV [4] combines and expands the assurance challenges already present in delivering Internet voice and data services and cable video services. Like cable, IPTV has issues in subscription management, content rights control, and video picture quality. Many of these issues are magnified for IPTV because it will provide more personalized video content delivery. In addition, video delivery over an IP network raises issues in ensuring QoS that are analogous to, but often more difficult than, those of data services and VoIP, since highly compressed video is often highly sensitive to packet loss.

The customer and service provider both want problems to be resolved quickly, with as little human intervention as possible. This is possible with automated operations systems that ensure sufficient equipment and network capacity at service provisioning, automated network surveillance to spot and correlate troubles to find the root cause before customers start complaining, as well as trouble ticketing integrated with automated test, and work force administration to rapidly and accurately fix troubles. As illustrated in Fig. 2, systems should be linked to exploit synergies. Automated network test and surveillance integrates automated test, data from network elements and element management systems (EMSs), analyses, as well as operations including trouble ticketing and work force administration.

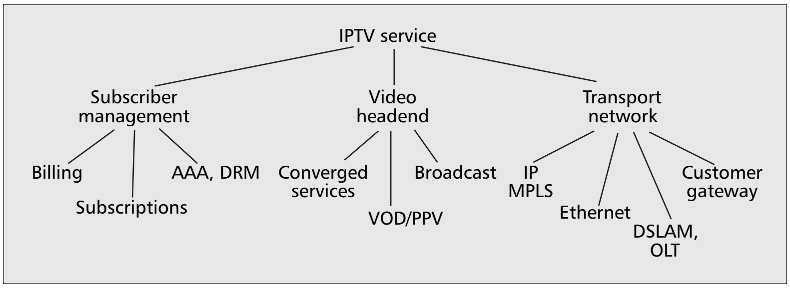


Figure 1. *IPTV service assurance elements.*

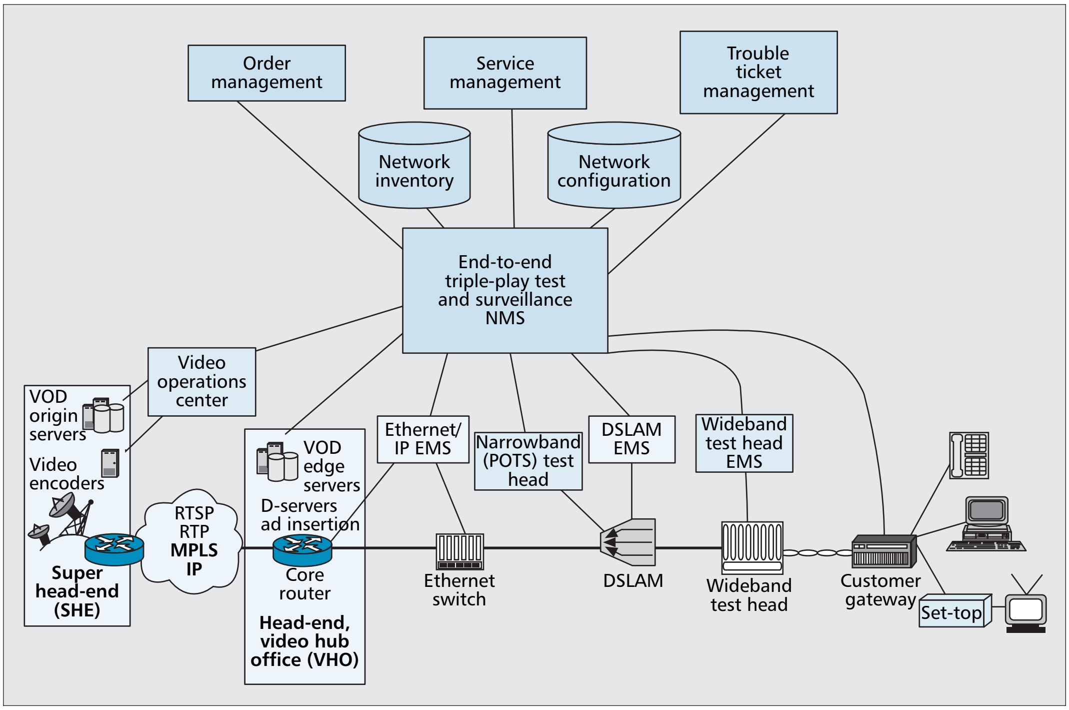
Among the key challenges in an end-to-end IPTV architecture is the ability to correlate the impact of error events and metrics at each of the application, IP, multiprotocol label switching (MPLS), Ethernet, and physical layers to the IPTV service.

SUBSCRIBER MANAGEMENT AND AUTHORIZATION

IPTV services are built on a protocol stack that encompasses much more than just IP, and involve content delivery. Consequently, it is not surprising that IPTV subscriber management is more complicated than subscriber management for a simple Internet service. Likewise, the richer networking environment presents challenges in video delivery that cable providers do not currently face. Compared to current cable systems, IPTV will likely involve larger content volumes, more personalized service delivery, and a far greater range of network architectures for content delivery. A comprehensive service management and assurance system must scale to meet these challenges.

Subscriptions — Like cable providers, IPTV providers must have systems that handle subscription services. Cable TV providers typically provide market segmentation via subscriptions to different program packages. Similarly, it is expected that IPTV customers will subscribe to view certain conditional access (CA) channels or channel packages. In addition, video on demand (VOD) may be authorized via a subscription or on an individual pay per rental basis. These permissions must percolate through the network, from the initial subscription ordering and billing system to the authorized device. Unlike the cable system where authorization is traditionally implemented on the set-top box, in an IP network or a switched network such authorization could be implemented at a variety of network points controlled by a network-based authentication and authorization server. Such flexibility adds to the assurance challenge but ensures that a break in the set-top box security will not completely compromise the carrier's control over content distribution. VOD access may require authentication, authorization, and accounting (AAA) to pay for rentals. Enhanced services such as network personal video recorder (NPVR) and special converged services may

To assure IPTV service, the network must provide sufficient bandwidth to assure delivery without too much loss or delay. Service assurance thus requires bandwidth provisioning in the access network and capacity management in the core network.



■ **Figure 2.** *Integrated network management system (NMS) for IPTV service assurance.*

require additional AAA mechanisms and may need to enable accounting for real-time transactions.

Subscription, authorization, and billing databases need to be kept consistent with each other and with network device configurations. Failure to maintain consistent AAA systems could result in an inability to receive desired service. For instance, if a subscriber were to query a server in the wrong headend, that subscriber could be denied service. Thus, server addresses need to be cross-checked. It should be possible to automatically query the AAA system, and to cross-correlate with the ordering and billing system records to see for which services a given subscriber is authorized.

Subscriber management servers should be monitored for uptime, reachability, delay, and overloaded utilization of CPU, memory, disk, network interface, and so on.

Digital Rights Management — Digital rights management (DRM) is similar to AAA in that it restricts access and use of program content to authorized contexts. However, DRM needs to work on (possibly) stored material; thus, it generally uses encryption and encoded permissions to control redistribution rather than controlling access to the content in the first place like AAA. Movie studios ensure that DRM is very tightly controlled, requiring several mechanisms, and making it likely that content will sometimes be blocked inadvertently by DRM. Several correct keys may be required to decrypt content: a unique fixed token for the set-top or home gateway, a key delivered by the DRM license server, and possibly some other public or private key. DRM rights need to persist through failures of system components. DRM authorizations and keys may need to be cross-checked for errors, and DRM server health should be monitored.

PROVISIONING FOR CAPACITY MANAGEMENT

Service quality requires adequate capacity. To ensure IPTV service, the network must provide sufficient bandwidth to ensure delivery without too much loss or delay. Service assurance thus requires bandwidth provisioning in the access network and capacity management in the core network.

DSL provisioning begins with loop qualification to determine the speed available to a customer on their copper loop. IPTV requires roughly 2 Mb/s for each standard definition TV (SDTV) channel and 9 Mb/s for each HDTV channel using advanced video compression. Typical FTTN IPTV architectures qualify service if more than 20 Mb/s can be delivered to the customer using asymmetric DSL2+ (ADSL2+) or very-high-rate DSL2 (VDSL2), typically with loop lengths up to about 1.5 km . Since the link to the customer can be a bottleneck, accurate loop qualification is critical to service assurance. Loops can be qualified by analyzing test-head or single-ended loop test (SELT) reflectometry, loop response, and noise spectrum data. Alternatively, loops can be qualified using exact loop make-up data read from a loop database and input to case-by-case transmission calculations to precisely qualify available bit rates.

Passive optical networks (PONs) share bandwidth among users. The PON protocols use time division with dynamic bandwidth allocation assigning slot times. Delay-sensitive narrowband applications such as voice can use up a high percentage of overhead to frequently transmit very small amounts of data. Calculating PON utilization is complicated, and capacity management may need to use sophisticated tools and monitoring if there are many IPTV services, as they may begin to exhaust the shared PON capacity.

For Web browsing, email, and other historical uses of the Internet, bandwidth needs are intermittent. As a result, providers are able to oversubscribe broadband Internet access bandwidth and typically aggregate at user to backhaul ratios of 20:1 to 50:1. TV traffic breaks the traditional Internet bandwidth utilization models; TV service has peak viewing hours where a significant fraction of the customers are watching programs. IPTV traffic is a very long-lived continuous stream of data that is not traditional "best effort" but rather real-time constant bit rate (CBR) or variable bit rate (VBR) [5] traffic. As a result, the statistical multiplexing historically used for Internet services is not acceptable for IPTV. Thus, the access network bandwidth utilization needs to be engineered and monitored on the fiber feeder, DSLAMs, and DSL lines, or on the PON and optical line terminal (OLT).

The vast bandwidth demands associated with IPTV are likely to require capacity management techniques in the core IP/MPLS network. If IP multicast technology is used in the core, this offers interesting challenges in capacity optimization. While there is little statistical multiplexing for constant bit rate TV traffic, key factors that affect capacity utilization are the packaging of channels into different IP multicast groups. At one end of the spectrum, each TV channel could be allocated its own IP multicast tree, potentially allowing for the bandwidth-efficient delivery of only requested channels to different branches of the IP multicast tree. Such a solution would typically result in higher management overhead and increased channel change latency. At the other extreme, the entire set of broadcast channels could be packaged into a single IP multicast tree. Multiple multicast trees allow for fine-grained traffic engineering, while smaller numbers of trees carrying multiple programs reduces signaling and other overhead. IPTV support systems must provide for the systematic evaluation of subscriber and channel profiles, which is required to decide the most effective channel packaging solutions.

VOD traffic is currently small compared to broadcast TV. However, depending on VOD server location, VOD streams can use substantial amounts of core network bandwidth since they are unicast. VOD server load and utilization of links from VOD servers need to be monitored and appropriately sized. VOD priorities and interactions with the capacity utilization of other services need proper surveillance and configuration.

In the Ethernet distribution networks, IPTV bandwidth requirements call for cost-effective deployment and management of VLANs. Layer 2 traffic engineering techniques [6] can be leveraged to effectively use redundant capacity in Ethernet networks that would otherwise be idled by the operation of the Spanning Tree Protocol (STP) and its variants.

SERVICE LEVEL SURVEILLANCE

The service level management process for video services is a challenging technical task. The quality management process applies to the end-to-end service traffic path and so requires that all network elements on this path should support Simple Network Management Protocol (SNMP) management information bases (MIBs) or similar TL1 accessible data for accumulating management information. In the case of triple play services, especially video delivery, special attention should be given to newly introduced devices such as Ethernet and IP-enabled DSLAMs as well as customer gateways and set-top boxes.

IPTV networks may present an array of problems whose resolution requires consistent multilayer monitoring and analysis functionality. Some typical quality metrics include subscriber-perceived picture and sound quality, including audio-video (A/V) synchronization, delays in channel change time (zap time), channel service access delays due to popular events (broadcasting), movies (VOD), or even massively synchronized channel changes due to startup of TV commercials. The basic requirements to detect, isolate, and resolve such complex problems are monitoring a multitude of appropriate performance metrics at multiple IPTV network layers and efficient correlation functionality.

Performance metric violations and hard faults trigger alarms that must be analyzed in order to report, identify, and troubleshoot existing or upcoming problems. The main functions of service level surveillance include integrated IPTV performance and fault event correlation, root cause analysis, and service impact analysis. To implement such functionality, service models are used that keep information of dependencies among IPTV network components and events in different layers. As a first step of automation, service models allow the network administrators to navigate on screen from end-effects to potential root-causes. More advanced tools automatically correlate large event streams and determine a minimum number of potential root causes. Another use of service models is the combination of multilayer metrics to evaluate key quality indicators and key performance indicators (KQIs and KPIs). These summarizing indicators allow IPTV network administrators to have an integrated view of the overall service health and inspect specific metrics only when deemed necessary.

INTEGRATED TROUBLE TICKETING, TEST, AND WORK FORCE ADMINISTRATION

As illustrated in Fig. 3, trouble complaints come into a call center and generate a trouble ticket. From here, trouble resolution can be automated to lower costs and speed resolution. The trouble ticketing system can automatically route the trouble to a test network management system (NMS), which then automatically initiates a set of tests. Tests results are then analyzed by automated maintenance routines which can isolate faults and indicate where the problem is, automatically issuing trouble tickets toward the correct work center: headend, CO, outside plant, home gateway, and so on. The trouble ticket also presents the test and analysis results to the technician, sometimes including recommended repair actions. This process is called *flow-through* test.

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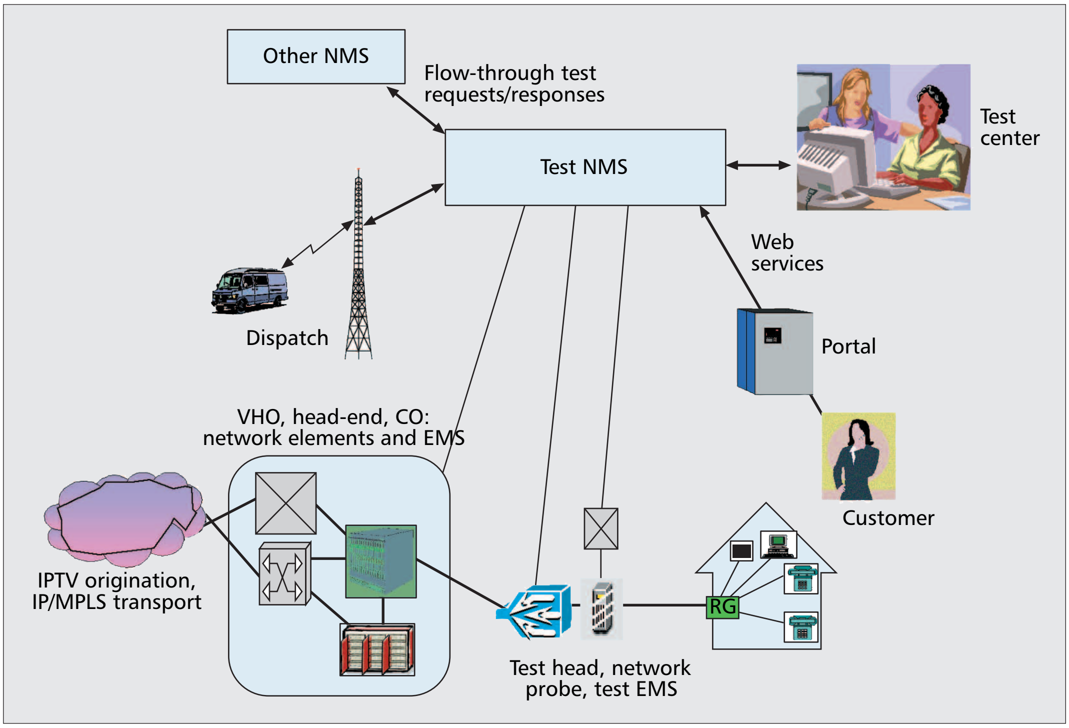
More advanced objective VQM calculations attempt to mimic user-perceived video MOS. These may compare the received video to a full reference version of the original video, to a partial reference signal, or may be calculated using only network quality statistics with no reference.



■ **Figure 3.** *Integrated call center, flow-through test, and work force dispatch.*

Network surveillance and test systems should be coupled together, since testing involves querying network elements as well as initiating tests from test heads or network probes. IPTV service uses many components in the network, so flow-through tests should comprise a limited and rapidly executed set. This includes tests traditionally handled by a network surveillance system, such as reading alarms and other fault indications.

IPTV service involves a myriad of enabling components and links, all of which need to be monitored and tested, from subscription information to the video headend, through the network to the in-home set-top. Integrating the many systems and practices involved in IPTV service assurance, and eliminating operations silos, is crucial for successful IPTV services.

VIDEO QUALITY METRICS

The relationship between the quality of the network and the quality of the video as perceived by the end customer is not simple. Moreover, reduction or elimination of network related defects can increase the capital cost of the infrastructure. Thus, in order to ensure video quality and maintain a reasonable cost structure, the service provider may need additional tools for assessing the user-perceived video quality of experience (QoE). QoE can be affected by many things: original content quality, encoding quality, picture impairments due to packet loss, audio, service delays and errors, usability, and so on. Video quality metrics (VQM) have been developed to assess the user-perceived video picture quality, a key part of video QoE.

Video mean opinion score (MOS) is analogous to voice MOS scores, and is obtained by averaging the subjective ratings of a panel of viewers. Like the analogous voice scores, it is rated on a scale of 1 to 5, where 5 is the best possible score. Obtaining a subjective video MOS score is impractical in an operational network, so service assurance needs to use an *objective* VQM that is calculated algorithmically and can be integrated into automated test and analyses. Objective VQM measures such as mean square error (MSE) and peak signal-to-noise ratio (PSNR) quality assessment metrics are relatively easy to compute. The MSE is the average squared difference between the original and received video. The PSNR is the ratio of the peak signal to the root mean square (RMS) noise observed between a reference composite video signal and a captured test signal, and objectively measures degradation primarily of the luminance signal.

More advanced objective VQM calculations attempt to mimic user-perceived video MOS [7]. These may compare the received video to a full reference version of the original video [8], to a partial reference signal [9], or may be calculated using only network quality statistics with no reference [10].

Audio quality has a pronounced effect on perceived video quality. Models combining audio and video quality into a single metric have been presented [11] to standards bodies including the Video Quality Experts Group (VQEG) [7] and the Alliance for Telecommunications Industry Services (ATIS) IPTV Interoperability Forum (IIF). A frequent problem with digital video is for audio to arrive out of synchronization with video, called lip synch. Lip synch can be intolerable if it is greater than about 185 ms [12].

NETWORK TEST AND MONITORING

Network performance can be monitored directly to ensure video service delivery. Some necessary performance metrics for IPTV surveillance can be collected from layer 2 (GigE and/or asynchronous transfer mode [ATM]) [2] and the IP/MPLS network elements and element management systems, including network traffic loss/delay/jitter statistics. Broadcast service surveillance requires continuous health monitoring of the IP multicast router using standard SNMP MIBs, and multicast reachability maps. Higher-layer monitoring such as MPEG stream analysis and Real-Time Protocol (RTP) and Real-Time Control Protocol (RTCP) stream statistics [4] can provide more insight on the video stream transport quality and detect potential problems such as mistimed or skipped video frames. RTP or MPEG time stamps (PCR) can provide delay, jitter, and sequencing information. User-perceived quality should also be monitored using video picture quality metrics. Other useful service metrics include multicast join/leave latencies and join rates that can be derived by analyzing activity and logs of IPTV servers handling authorization and processing of subscriber channel change requests.

For high quality video streaming services, a packet loss ratio (PLR) of 10^{-4} to 10^{-7} or less, latency on the order of hundreds of milliseconds and jitter on the order of a few tens of milliseconds may be tolerated. An informative example in International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) J.241, which was used by one service provider, is in Table 1. Exact PLR requirements for video have not yet been established and are being worked into several standards, including DSL Forum WT-126, ITU-T Y.1541, and ATIS IIF.

Packet loss rate	QoS
$PLR \leq 10^{-5}$	Excellent service quality (ESQ)
$10^{-5} < PLR \leq 2*10^{-4}$	Intermediate service quality (ISQ)
$2 * 10^{-4} < PLR < PLR\_out = 0.01$	Poor service quality (PSQ)
$PLR\_out = 0.01 < PLR$	IP end-to-end service not available

Table 1. *Example informative classification used for digital television services, from ITU-T J.241 Appendix A.*

Error Concealment — H.264 (MPEG-4 part 10) provides ways to overcome data errors or losses encountered when transmitting over a network, using the H.264 network adaptation layer (NAL). The loss of a few key bits of information such as picture header information could have a severe negative impact on the decoding process, so this key information may be separated into partitions and handled in a specialized manner in H.264 [4, 5].

Audio quality is an integral part of QoE, and errors such as lost packets need minimum-artifact concealment. This can be significantly more complicated than simply holding the audio output constant

It is far better to detect a significant error in a video stream and conceal it than to simply allow the picture to degrade. Loss of a single frame or two of video can be concealed by simply freezing the picture or interpolating adjacent frames. However, an undetected error can make the picture vary wildly. Error concealing decoders, retransmissions, and forward error correction can all help alleviate occasional lost and errored packets if applied carefully while considering interactions with similar lower-layer mechanisms.

CONCLUSIONS

IPTV service assurance assumes all of the challenges in assuring broadband access networks while adding layers of complexity for monitoring and managing video content origination, authorization, and distribution through QoS-enabled IP networks.

Current IPTV deployments are experimenting with various monitoring solutions. Early deployments sometimes use expensive dedicated test probes or extensive manual testing to ensure that they function. However, this is often not scalable and may inadvertently ignore aspects such as subscriber authorizations. Dedicated test hardware will continue to be used to ensure quality in head-ends and at key network points, but as time progresses network elements and servers can provide much of the required test and monitoring functionality.

This article details several of the key system and design issues associated with providing a comprehensive management and service assurance system for IPTV. Critical features of a successful IPTV management solution involve the following:

- Integrated surveillance and fault management systems across all the multilayer technologies that enable end-to-end IPTV service
- Ability to correlate the impact of networking events and metrics at each of the video application, IP/MPLS, Ethernet, and physical layers for the subscriber IPTV service
- Objective, scalable monitoring of all aspects of subscriber service quality, including picture quality, delays, and availability
- Automated and integrated capacity provisioning, test, and workforce procedures
- Standardized testing and monitoring procedures for subscriber equipment such as residential gateways and set-top boxes

IPTV services offer great opportunities for service providers to diversify their revenue stream and move aggressively into the potentially lucrative broadcast TV and emerging interactive video markets. At the same time, the deployment and assurance of IPTV service incorporates enormous challenges in the management of complex multilayer technology to provide a service that has historically been associated by customers with high quality and availability. Effective and efficient service assurance techniques could help enable service providers to efficiently deliver a suite of new secure, reliable, managed IPTV services.

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IPTV Services offer great opportunities for service providers to diversify their revenue stream and move aggressively into the potentially lucrative broadcast TV and emerging interactive video markets. At the same time, the deployment and assurance of IPTV service incorporates enormous challenges.

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BIOGRAPHIES

KENNETH KERPEZ [F] (kkerpez@telcordia.com)received his B.S. in electrical engineering from Clarkson University in 1983, and his M.S. and Ph.D. in electrical engineering systems from Cornell University in 1986 and 1989. Since then he has been at Telcordia Technologies, where he initially performed pioneering work on characterizing and coding for HDSL, ADSL, and VDSL. He later also worked on wireless, hybrid fiber/coax access systems, home networking, residential gateways, and PON optical fiber broadband access systems. He is now working on broadband service assurance and testing, IPTV, and triple-play services. He is the author of numerous technical papers and is a frequent contributor to industry standards.

GEORGE LAPIOTIS (lapiotis@research.telcordia.com) has been with Telcordia's Applied Research since 1998, where he currently holds a senior research scientist position. Previously, he was a senior research assistant with Polytechnic University's State Center for Advanced Technologies in Telecommunications (CATT), where he was from 1993 until 1998. His current research is on next-generation service architectures and management, with focus on IPTV and vehicular telematics services. His general research interests are in the areas of network management and next-generation operations support systems, with emphasis on network performance and QoS, policy-based network management, and security management. He obtained a Ph.D. (1999) and an M.S. (1994) from Polytechnic University, Brooklyn, New York, both in electrical engineering, and a Diploma in electrical engineering (1993) from the National Technical University of Athens, Greece.

J. BRYAN LYLES (blyles@research.telcordia.com) manages the Mobile Networking Research Department at Telcordia. He received his B.A. degree from the University of Virginia, and his M.S. and Ph.D. degrees from the University of Rochester. Previous to Telcordia he was senior scientist at Sprint and a member of research staff at Xerox PARC.

RAVI VAIDYANATHAN (vravi@research.telcordia.com) has served in the role of IP/OSS architect and technology expert for Telcordia's Managed IP Solution portfolio for a variety of technologies such as IPTV, MPLS VPNs, Ethernet and optical services, and VoIP. He is an active contributor to standards bodies such as the IETF and TMF, and has authored several research papers on IP and next-generation network configuration and management.

DAVID WARING [SM] (waring@research.telcordia.com) is chief scientist and managing director in the Applied Research organization of Telcordia Technologies. He has over 27 years of experience in the telecommunications industry. He began his career at Bell Laboratories designing loop carrier systems. At Bellcore, the R&D organization for the Baby Bells, he was project manager for early work on MANs, DSL, video dial tone, and home networks. He currently leads research focused on last-mile broadband networks. He was program manager of a NIST research grant on critical infrastructure protection, and leads related research initiatives in support of government clients. He received a B.S. in electrical engineering from Drexel University and an M.S. in electrical engineering from Georgia Tech.