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ABSTRACT

Internet Protocol Television (IPTV) will be the killer application for the next-generation Internet and will provide exciting new revenue opportunities for service providers. However, to deploy IPTV services with a full quality of service (QoS) guarantee, many underlying technologies must be further studied. This article serves as a survey of IPTV services and the underlying technologies. Technical challenges also are identified.

INTRODUCTION

Internet Protocol television (IPTV) provides digital television services over Internet Protocol (IP) for residential and business users at a lower cost. These IPTV services include commercial-grade multicasting TV, video on demand (VoD), triple play, voice over IP (VoIP), and Web/email access, well beyond traditional cable television services. IPTV is a convergence of communication, computing, and content [1], as well as an integration of broadcasting and telecommunication. IPTV has a different infrastructure from TV services, which use a push metaphor in which all the content is pushed to the users [1]. IP infrastructure is based on personal choices, combining push and pull, depending on people's needs and interests [1]. Therefore, IPTV has two-way interactive communications between operators and users, for example, streaming control functions such as pause, forward, rewind, and so on, which traditional cable television services lack. Triple play is a service operator's package including voice, video, and data. Video adopting either MPEG-2 or MPEG-4 format is delivered via IP multicast.

The IPTV service first started in Japan in 2002, then became available in Korea [2]. IPTV is a convergence of broadcasting and telecommunication. Many free IPTV services are avail-able on the Internet and can be accessed freely with Internet-connected computers, iPods, and cellular phones. The current quality of IPTV in the United States does not yet approach that of cable TV services, but the gap will shrink as bandwidth increases and video codecs improve [2]. In 2005, there were about four million homes in the world that already had IPTV. Minerva has about 50 IPTV deployments that cover 150,000 users with VCR quality services [2]. Asia has been at the forefront of IPTV services, launching IPTV service tests in eight out of thirteen economies in the Asia-Pacific region [2]. It is an appealing consumer application that can use the 20-Mb/s promise of asymmetric digital subscriber line 2+ (ADSL2+), the 50-Mb/s capability of very high digital subscriber line (VDSL2), and the 100-Mb/s potential of fiber to the x (FTTx) [2]. Microsoft TV IPTV Edition is a software platform to develop TV services over broadband networks including features such as instant channel change (ICC) and multiple picture-in-picture (PIP), VoD, and digital video recorder (DVR). BellSouth, a telecommunication service provider, recently performed trials of Microsoft IPVT [3]. AT&T and Verizon recently announced significant investments in adopting fiber optic cables to deliver IPTV channels to residential customers.

The challenges of IPTV include integration of different operators with different infrastructures and back-office systems, stability of long term, quality of service (QoS) matching cable providers, and so on [3]. The current systems won't be able to keep up with the changes in the video distribution model for IPTV [2]. The Video Networks Ltd. (VNL) rollouts of its HomeChoice video, triple play service over DSL use a Cisco Internet Protocol next-generation network (IP NGN) solution in the United Kingdom (UK) [4]. HomeChoice offers up to 4 Mb/s Internet access, IPTV with over 70 channels, and thousands of movies, videos, and hit TV programs on-demand with up to 10 Gb/s per slot for

next-generation IP multiprotocol label switching (MPLS) [4].

A chicken and egg situation exists: The industry needs IPTV to justify the investment in broadband, but there is no good IPTV without broadband [2]. However, the investment is a way to survive for some telecommunication companies [2]. IPTV is a convergence of IP-based communication and broadcasting.

It is claimed that IPTV is the killer application for the next-generation Internet (NGI). In this article, we provide a survey of IPTV, as well as a description of its technical support. Some technical challenges and research issues also are identified.

The rest of this article is organized as follows. We first introduce IPTV and then present access networks and core networks for IPTV. Then, mobile TV and peer-to-peer (P2P) IPTV are introduced. Finally, we present technical challenges.

IPTV

To bring IPTV to reality requires changes in physical infrastructure. IPTV uses IP protocol to deliver multicasting TV, VoD, triple play, VoIP, and so on, to consumers via broadband connections, with a QoS guarantee. IPTV has unique features in addition to simply broadcasting ordinary TV programs over the Internet. IPTV can be incorporated with high-speed DSL access technologies, such as ADSL2, ADSL2+, and VDSL, as well as high-speed carrier-grade Ethernet and the emerging high throughput IEEE 802.11n wireless LAN.

IPTV is an integration of voice, video, and data services using high bandwidth and high speed Internet access. IPTV includes several components as shown in Fig. 1:
• IPTV sources including VoD database and other programs
• High-speed Internet with functions of multicasting, QoS guarantee, and so on, including an optical backbone network to serve as an IP multicast core network
• High-speed access networks such as ADSL, ADSL2+, VDSL, a combination of fiber-to-the curb (FTTC) and DSL, fiber-to-the-home (FTTH) access, carrier-grade Ethernet, and the emerging IEEE 802.11n wireless LAN
• IPTV user devices such as digital televisions including high definition televisions (HDTVs)
 IPTV features [5] include:
• Selection (users are able to select their TV programs with fast channel selection and short channel changing time)
• Storage (TV programs are stored in local storage devices so that users can watch them anytime; furthermore, service providers should store at least 100 hours of TV programs and videos)
• QoS (QoS must be guaranteed; a standard definition TV and a high definition TV need bandwidth of 1~4 Mb/s and 4~12 Mb/s, respectively)
• Low cost (cost to the user must be low; this is the key to success)
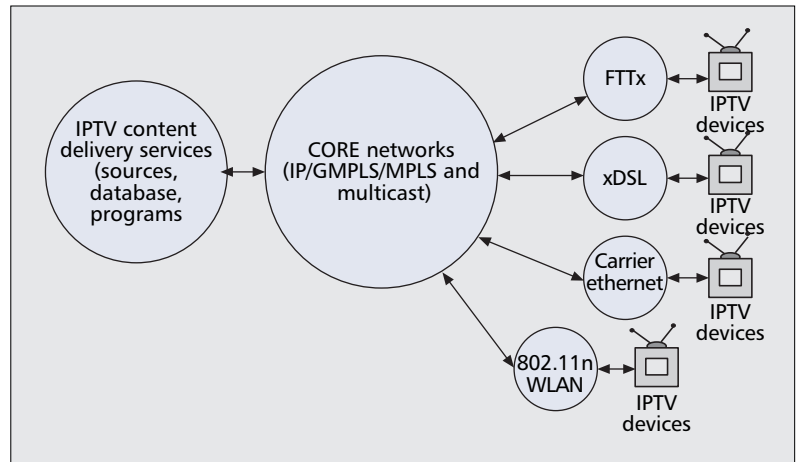
■ **Figure 1.** *IPTV services.*

Successful deployment of IPTV services requires excellent QoS for video, voice, and data. QoS metrics for video include jitter, number of out-of-sequence packets, packet-loss probability, network fault probability, multicast join time, delay, and so on. QoS metrics for voice include mean opinion score (MOS), jitter, delay, voice packet loss rate, and so on. QoS metrics for IPTV services include channel availability, channel start time, channel change time, channel change failure rate, and so on. Before system deployment, accurate testing should be performed to test high-quality IPTV services for TV service, video, voice, as well as interactive service.

MPEG-2 and MPEG-4-Part 10 /H.264 are typically used for encoding video with a large range of compression rates, allowing a trade-off between quality and bandwidth with either a constant bit rate or a variable bit rate [6]. Much of the compression comes from inter-frame difference encoding instead of intra-frame coding, particularly when there is relatively little change in each scene [6]. For an I frame, with intra-frame encoding, its image frame consists of blocks converted to a set of coefficients using discrete cosine transform (DCT). A group of blocks forms a slice carried within one packet. If the first block is damaged, the whole group may be lost, which creates a strip in the image [6].

ACCESS NETWORKS

In this section, we introduce access networks such as DSL technologies, carrier-grade Ethernet, high-speed 802.11n wireless LAN, fiber-to-the-home (FTTH), and fiber-to-the curb (FTTC). All these networks can contribute to the IPTV service deployment.

DSL TECHNOLOGIES

DSL technologies, shown in Fig. 2, provide high-speed digital data transmissions over a telephone local loop from users to end offices. Downlink speed of a typical DSL is about 128 kb/s ~ 24Mb/s, depending on the service providers. ADSL standards can deliver 8 Mb/s over about 2 km, and ADSL2+ can deliver up to 24 Mb/s, depending on the distance between a user and the nearby end office. ADSL is the most widely deployed DSL technology.
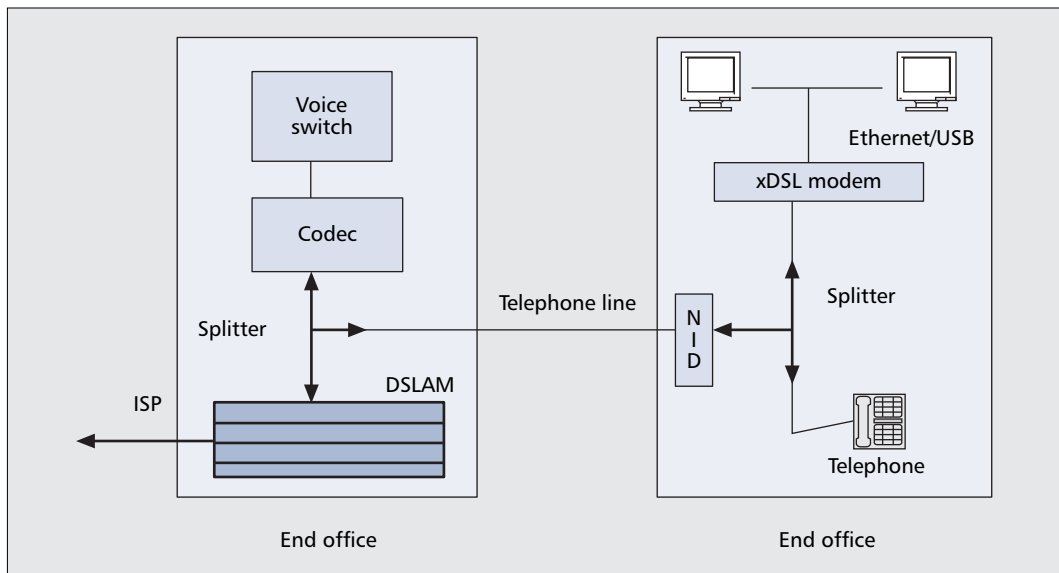
■ **Figure 2.** *DSL.*

DSL improves dial-up phone service via the same local loop of the fixed phone system. The phone system normally filters about 4-MHz voice traffic at end offices to save bandwidth and to let a voice be intelligible. End offices can go beyond the 4-MHz limit over a phone line to provide higher bandwidth using DSL. A DSL modem can connect multiple computers via Ethernet, HomePlug, or the IEEE 802.11 wireless local area network (WLAN).

VDSL (very high bit-rate DSL) has a theoretical limit of 52 Mb/s downstream and 12 Mb/s upstream, using up to two frequency bands for upstream and two frequency bands for downstream, with quadrature amplitude modulation (QAM) or discrete multitone (DMT) modulation techniques.

VDSL2 (very-high-bit-rate digital subscriber line 2, ITU-T G.993.2 Standard) provides full-duplex aggregate data rates up to 200 Mb/s using a bandwidth up to 30 MHz.

DSL techniques are the first choice for access networks in IPTV.

CARRIER-GRADE ETHERNET

Ethernet has been the dominant technology in LAN for a long time and still is.

Carrier-grade Ethernet can provide up to 10 Gb/s access speed, eight classes of service (CS) and unicast/multicast/broadcast modes via a virtual local area network (VLAN) technique [1]. In IEEE 802.3ae, 10 Gb/s Ethernet with full duplex has been standardized for optical single-mode interfaces, maintaining the IEEE 802.3 frame and format size.

Carrier-grade Ethernet can be one of the candidates for the access networks for IPTV services. With its high data access rate, it provides a better QoS guarantee.

HIGH THROUGHPUT IEEE 802.11N WIRELESS LAN

Recently, AT&T announced that it is working with MobiTV to deliver live TV to its Wi-Fi hotspot networks across the country, enabling customers to view live television on Wi-Fi-enabled devices on 15 channels of news, sports, entertainment, and full-length music videos, available May 2006 to 7,000 hotspots nationwide for a monthly fee of $11.99.

The high-speed IEEE 802.11n wireless LAN can be one of the underlying infrastructures to assist IPTV service as the access network with better QoS via high data access rates. We call it wireless IPTV.

The IEEE 802.11 Task Group (TGn) was announced in January 2004 to improve throughput of the IEEE 802.11 WLAN to 100Mp/s ~ 600 Mb/s, as well as offering a better operating range than current networks [7]. There were two competing PHY proposals for the IEEE 802.11n standard:
• World-Wide Spectrum Efficiency (WWiSE) supported by Broadcom, Texas Instruments, and others
• TGn Sync supported by Intel, Philips, and others

Both proposals adopt multiple-input multiple-output (MIMO), using multiple transmitter and receiver antennas for better throughput with spatial multiplexing and spatial diversity to increase range. The two proposals are different in terms of how to use MIMO: TGn Sync adopts 40-MHz mandatory channel width with a minimum of two antennas; whereas WWiSE adopts the mandatory channel width with four antennas. In January 2006, the IEEE 802.11n Task Group approved a joint proposal specification based on an enhanced wireless consortium (EWC) specification. The 802.11n Draft was sent for letter ballot at the March 2006 meeting but did not pass a majority vote in the May 2006 meeting. However, it was scheduled to complete the 802.11n standard in the middle of 2007 [7].

In [7], the author presented a potential IEEE 802.11n medium access control (MAC) via aggregation techniques and classified frame aggregation mechanisms into many different and orthogonal aspects, such as distributed versus

centrally controlled, ad hoc versus infrastructure, uplink versus downlink, single-destination versus multidestination, physical (PHY)-level versus MAC-level, single-rate versus multirate, immediate acknowledgment (ACK) versus delayed ACK, and no spacing versus short interframe spaces (SIFS) spacing.

FTTH

FTTH and fiber to the premises (FTTP) use fiber-optic cables for IPTV services to businesses and homes. They will be ideal choices for access networks as fiber deployment cost decreases. FTTP includes active FTTP and passive FTTP architectures. In the active FTTP architecture, an equipment cabinet is built for every 400–500 users, performing layer 2–3 functions. The IEEE 802.3ah standard provides full-duplex 100 Mb/s to the premises. The passive FTTP architecture avoids building equipment cabinets by using passive splitters to optically split fibers into multiple (e.g., 64) fibers to different users' homes, and layer 2–3 functions are performed at the carrier's central offices instead of at equipment cabinets in the active FTTP.

FTTC

To reduce cost, FTTC is used to install fiber to within 1000 feet of a home or business, and then cable or carrier-grade Ethernet can be used to further connect to home or business.

CORE NETWORKS

In this section, we briefly introduce GMPLS/MPLS and IP multicast as the core network technologies.

GMPLS/MPLS

MPLS provides better IP traffic engineering. Connectionless IP behaves more like connection-oriented so that a path between a source and a destination is pre-determined and labeled. This looks similar to ATM protocols. The labels are used to establish end-to-end paths that are called label switched paths (LSPs). MPLS is a switching protocol between layer 2 and layer 3, adding labels in MPLS packet headers and forwarding labeled packets in corresponding paths using switching instead of routing. However, an MPLS header does not identify the type of data carried in the path such that Internet service providers (ISPs) could manage different kinds of data streams based on priority and service. Major applications of MPLS are traffic engineering and the virtual private network (VPN). MPLS is similar to differentiated services (DiffServ) in marking traffic at ingress boundaries and unmarking at egress points.

Generalized MPLS (GMPLS) extends MPLS to add a signaling and routing control plane for devices in packet domain, time domain, wavelength domain, and fiber domain, providing end-to-end provisioning of connections, resources, and QoS.

GMPLS is a better protocol for broadband and IPTV services, controlling all the layers, including packet layer, time division multiplexing layer, lambda layer, and fiber layer; effectively
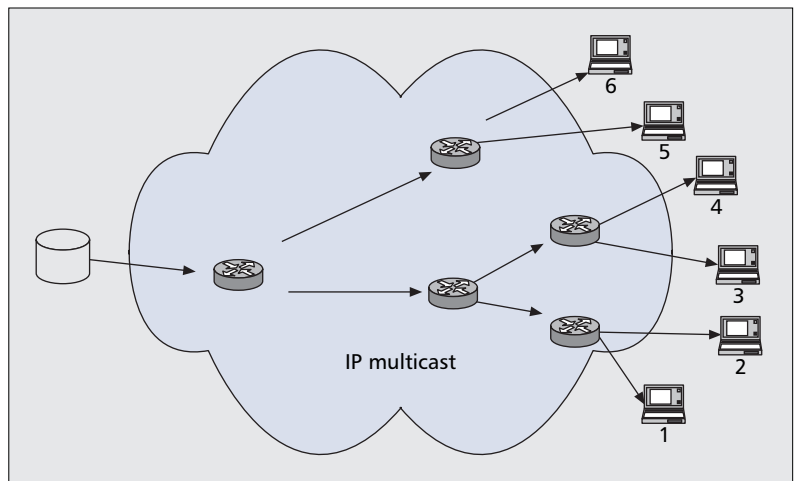
■ **Figure 3.** *IP multicast.*

manipulating optical network resources, with a separation of media data plane and control plane [2–4].

MULTICAST

Multicast delivers information to a group of destination stations. IP multicast, shown in Fig. 3, sends voice, video, and data to multiple receivers using RTP/TCP/IP protocols, with a multicast address.

Currently, IP multicast has a scalability problem when there are a large number of users and groups. Furthermore, there is not a fully deployed multicast application in the commercial Internet, with the exception of some applications limited in location, such as multicast backbone (Mbone) and private IP networks.

There are three kinds of multicast delivery: dense multicast, sparse multicast, and source-specific multicast.

• Dense multicast is to construct a tree for sending packets to the multicast users. A source node broadcasts to all routers and all nodes, which in turn send pruned packets if they do not want the multicast so that the routers do not send corresponding packets to these nodes or routers. Reverse-path forwarding is used for preventing loops.

• Sparse multicast does not depend on any particular unicast routing protocol and is to construct a tree for sending packets to the multicast users. If a node wants to join/prune a multicast group, it sends a join/prune message via Internet Group Management Protocol (IGMP) to a router, which forwards data packets to the multicast group. Join/prune messages are sent periodically to a group-specific rendezvous point (RP) by a designated router (DR) for each active group. A term route entry is the state maintained in a router to represent the distribution tree including source address, group address, timers, and so on. This state creates a distribution tree that reaches all group members. Routers also use reverse-path forwarding to ensure that there are no loops for packet forwarding among routers.

• Source-specific multicast delivers multicast packets originating in a specific source address to those that request them.

IP multicast is an approach for sending a message simultaneously to multiple nodes instead of one. Multicast group addresses range from 224.x.x.x to 239.x.x.x.

IP multicast is required to provide IPTV services, and it saves bandwidth in both core networks and access networks because there is a high probability that more than one user watches the same program, and both core networks and access networks are capable of multicasting. Both IGMP and real time streaming protocol (RTSP) are required. Both multicast and unicast are useful for IPTV.

MOBILE TV

Current video services over cellular networks are either downloadable video (i.e., the download time exceeds the video's playing time) or still images with real-time voice (e.g., Sprint PCS brings real-time television content to mobile phones at a rate of one or two frames per second).

In the near future, mobile television (mobile TV) will combine IP and digital video broadcast (DVB) to broadcast TV content over 3G cellular networks. DVB is a suite of standards of the European Telecommunications Standards Institute (ETSI), defining the PHY layer and data link layer of a distribution system and MPEG-2 transport streams as the format of video content. Mobile TV services can be treated as an extension of IPTV services.

IP multimedia subsystem (IMS) is for next-generation networking (NGN) architecture to provide mobile and fixed multimedia services. IMS may be a good candidate for future mobile TV.

P2P IPTV

A new kind of IPTV, different from the infrastructure-based scheme introduced previously, is P2P IPTV, in which each IPTV user is potentially a server, multicasting received content to other IPTV users [8]. In a P2P IPTV system, users serve as peers and participate in video data sharing. A popular P2P IPTV system such as PPLive supports 100,000 users simultaneously with proprietary signaling and video delivery protocols [8]. PPLive has more than 400 channels with an average channel data rate of 325 kb/s. PPLive does not own video content but limited information about its video content distribution mechanism, and is mostly fed from TV channels in Mandarin, encoded with windows media video (WMV) or real video (RMVB) [8].

A user must download and install the PPLive software to use PPLive P2P IPTV. When the PPLive software is running, the user becomes a PPLive peer node, sending out a query message to a PPLive channel server for an updated channel list. When the user selects one channel, the software requests an online peer list (including IP addresses and port numbers) for this channel and sends probes to peers to find active peers that may provide more peers. The software downloads video chunks from peers, streams them into a local media player using two buffers (to smooth video variation and to efficiently distribute video content among peers), uploads the cached video chunks to other peers, and launches a media player when the streaming file length reaches a predefined threshold.

TECHNICAL CHALLENGES

In this section, we first describe the QoS guarantee and traffic management for IPTV services. Since admission control mechanisms are essential for IPTV services, we then present multicast admission control, admission controls for Ethernet, congestion control, WLAN (wireless IPTV), and DSL. Finally, we briefly mention security and standardization aspects, as well as communications among admission control schemes.

QoS GUARANTEE AND TRAFFIC MANAGEMENT

The QoS guarantee and traffic management are challenging for core networks and access networks, in particular for IPTV services. For downstream traffic, differentiated services are used for different users with different schedulers. For upstream, user traffic is monitored. Each user class requires a separate scheduler to prevent the starvation of lower classes. Admission controls are required for a QoS guarantee.

In normal TV services, multiple program channels to users are achieved by sending all the programs and filtering out the unsubscribed channels. A channel changing program is to select one channel and filter the rest of channels. The mechanism is not suitable for IPTV services due to bandwidth limitation.

In IPTV services, a user requests channel changing by sending a request for a video channel. After the request is accepted by admission control, a multicast tree is built to send video and voice of the requested channel with QoS guarantees. The procedure causes a channel changing delay. If the IPTV sets in a household are off, the available bandwidth can be used for Internet access and other uses.

The goal of traffic management is to efficiently support QoS requirements for diverse services, including policing, scheduling, flow control, multicasting, traffic differentiation, admission control, and so on. It is implemented via either a centralized manner or a distributed manner. The latter approach is more scalable and flexible. Policing ensures that traffic conforms to a service level agreement (SLA). Scheduling ensures the handling of voice, video, and data traffic to meet QoS requirements such as delay, its variation, and so on, as well as efficient utilization of bandwidth. Flow control is to control traffic flow to avoid or reduce temporary congestion. Multicasting is used both in downstream and upstream to efficiently utilize bandwidth. Traffic differentiation gives higher priority traffic such as voice, audio, and video a higher priority to be transmitted and gives data a lower priority. This should be done in both the core network and the access network. Admission control decides to accept or reject upstream and downstream bandwidth requests, ensuring an accepted flow of bandwidth that satisfies the QoS requirement.

Service providers must indicate the level of the QoS that is guaranteed in an SLA, which may cause communication costs for the service providers.

Detailed QoS guarantee mechanisms and traffic management for IPTV services require further investigation and research.

MULTICAST ADMISSION CONTROL

Large scale IP-multicast deployment has not been seen at ISPs. However, IPTV services will be one of the main drivers for upcoming IP-multicast deployments. This means the capability of end-to-end QoS, accounting, and service availability, as well as supporting multicast layer 3 VPNs and multicast MPLS.

Differentiated service (DiffServ) is for unicast QoS in IP networks. For IPTV services, multicast is another way to provide better QoS, but there are three problems for multicast as follows [9]:
- Multicast trees should have different QoS levels on different branches for the customers demanding different levels of quality.
- DiffServ is scalable with stateless routers, whereas IP multicast is not scalable with group information and router forwarding states; therefore, IP multicast running over DiffServ should be more scalable.
- The neglected reserved subtree (NRS) problem exists because one flow can be replicated into many egress nodes.

Since DiffServ resources are consumed based on pre-negotiated SLA, IP multicast in DiffServ may cause the actual consumed resources to exceed the pre-negotiated SLA because a multicast tree can branch at any node so that outgoing traffic may exceed incoming traffic [10]. This is called the NRS problem.

Admission control in IP multicast over DiffServ is difficult because policing is not intelligent enough. Resources must be checked whenever a new user joins a group [9]. A bandwidth broker can be a centralized solution, but it is not scalable due to its huge database [9]. A scalable approach should be a distributed method, in which edge routers make decisions locally based on measurement-based algorithms [9].

DSMCast [11] solves the problem of heterogeneous trees and scalability and gives a competent framework for solving the NRS problem.

In [9], a distributed admission control, an extension of DSMCast at edge nodes, is presented to solve the NRS problem, based on filtering join requests:
- A join request is accepted if an edge router receiving the request is already forwarding the particular group.
- Otherwise, the process inspects paths (with increased utilization) between egress edge node and branching node if there is enough capacity on the links for the new request.
- Measurements are conducted first on several obtained packets by temporary acceptance to see whether measurements are beyond the history limits.

Designing more comprehensive, distributed, efficient, and scalable multicast admission control mechanisms requires further investigation and research.

ADMISSION CONTROL FOR ETHERNET

Carrier-grade Ethernet is no longer a contention-based Ethernet, but an aggregation and switching technology. A carrier-grade Ethernet should provide QoS guarantees on throughput and delay for leased-line and real-time services [11]. For carrier-grade Ethernet, distributed admission control can be implemented using an in-band signaling protocol to reserve bandwidth in each network node, and centralized admission control can be implemented by using a central controller to allow polices at the edge to track load on each network link [11].

Designing efficient and distributed admission control for carrier-grade Ethernet requires further investigation and research.

ADMISSION CONTROL FOR IEEE 802.11N WLANS

Although contention-based MAC protocols are very successful commercially and are robust for best effort traffic, they are unsuitable for multimedia applications with QoS requirements [15]. On the other hand, centrally controlled MAC protocols and reservation-based protocols manage QoS more easily but are rarely implemented in today's products due to several reasons, such as high complexity, inefficiency, lack of robustness, global synchronization, and so on. Without QoS support at the MAC layer, it is impossible to provide a QoS guarantee solely from higher layers.

IEEE 802.11 WLANs have achieved tremendous success in terms of deployment and usage. The popularity of the IEEE 802.11 WLAN is due mainly to the contention-based MAC distributed coordination function (DCF), whereas the optional point coordination function (PCF) is barely implemented in today's products due to its complexity and inefficiency for normal data transmissions. However, the current contention-based MAC is unsuitable for multimedia applications with QoS requirements. To support the MAC-level QoS, the IEEE 802.11 Working Group published the IEEE 802.11e specification, providing QoS features and multimedia support to existing 802.11a/b/g WLANs, while maintaining full backward compatibility with these legacy standards. The IEEE 802.11e MAC employs a channel access function, the hybrid coordination function (HCF), which includes both contention-based and centrally controlled channel access mechanisms. The contention-based channel access mechanism is also referred to as the enhanced distributed channel access (EDCA). The EDCA provides a priority scheme by differentiating the interframe space, as well as the initial and maximum contention window sizes for back-off procedures. IEEE 802.11e cannot provide guaranteed QoS, and multimedia traffic cannot be protected. In [15], distributed QoS admission control mechanisms and data control mechanisms are proposed to provide a QoS guarantee and provisioning at the contention-based wireless MAC layer, which can be coupled with the emerging IEEE 802.11n high throughput WLANs to support IPTV services.

> *Since DiffServ resources are consumed based on pre-negotiated SLA, IP multicast in DiffServ may cause the actual consumed resources to exceed the pre-negotiated SLA because a multicast tree can branch at any node so that outgoing traffic may exceed incoming traffic.*

Designing efficient contention-based admission control and bandwidth allocation requires further investigation and research.

ADMISSION CONTROL FOR DSL

One challenge for DSL networks is that the broadband and voice services are separated at the physical layer so that they lack resource sharing. Therefore, IP-based QoS support for access network is required.

Voice, video, and data packets are carried over IP from customer premises equipment (CPE) to a DSL access multiplexer (DSLAM), which then routes or switches them toward the core network. Voice packets are encapsulated by Real Time Protocol (RTP) and User Datagram Protocol (UDP) before being sent to the IP layer. At the CPE, multiple sources such as two IPTV video and audio channels, voice over IP (VoIP) phone, and Internet access (via fixed PC or WLANs) are aggregated together via DSL services. Therefore, without admission control at DSL, the QoS of video and voice traffic can not be guaranteed if either there are too many video/voice flows, or there is too much Internet access traffic (e.g., downloading large files such as movies). An admission control is required at the CPE to guarantee QoS of IPTV services such as video/voice delay, and so on.

Furthermore, normally DSL providers offer users with rates of upstream and downstream and the SLA is defined by transport parameters, but IPTV services are defined by application experience, such as the number of channels provided, quality of video, functionality, and so on, and they are so-called quality of experience (QoE) [12]. It is difficult to translate between QoE and QoS. Admission control is important to avoid oversubscription with degraded QoE and QoS.

Per-flow admission control for DSL QoS is required to provide bandwidth on demand, and application-level admission control also can be applied in addition to network-based admission control. Usage of IPTV services depends on time of day, location, and so on. Some services have higher priorities than others. Therefore, different admission control thresholds are required for different applications. It also can limit the number of channels simultaneously sent to the DSLAM.

There are typically two kinds of admission control methods: end-point admission control and network admission control. In end-point admission control, end-hosts send probe packets to networks to measure the QoS to make admission decisions, while network admission control makes decisions based on end-hosts' request via a signaling mechanism such as Session Initiation Protocol (SIP).

For either a voice flow or a video flow, admission control should track its activities such that in case there is no activity for a maximum period, the resource should be recollected. For voice flows, admission control should consider whether silence suppression is used or not. For video flows, both constant bit rate (CBR) video and variable bit rate (VBR) video should be considered.

Furthermore, for either voice flows or video flows, they may be differentiated with regular voice/video and premium voice/video.

Single packets such as changing a channel of IPTV services should have the highest priority and can be sent via SIP.

IPTV CONGESTION CONTROL

Congestion control is critical when many IPTV flows are transmitted simultaneously. The congestion control is an end-to-end protocol, that is, it is implemented in either the sender side (i.e., IPTV video sources) or the receiver side (i.e., customers' machines). The typical approach to congestion control is to adjust the sending rates of different IPTV sources (i.e., TV channels) such that the IPTV traffic does not overwhelm the Internet routers.

Although the congestion control algorithm in TCP is efficient for bulk data transfers, applying a typical multiplicative decrease to the data rate available to a real-time video stream can severely affect the video quality perceived by the end user. Thus new congestion control algorithms, tailored to the rate acceleration and variability requirements of IPTV applications, should be developed. Because of the coexistence of video traffic with normal TCP traffic, some TCP-compatible congestion control algorithms have been proposed for audio/video-streaming applications [13]). To compete with TCP flows in a fair manner, these algorithms have two important characteristics in common:

- Slow responsiveness in order to smooth data throughput
- *TCP friendliness*

A flow is TCP-friendly if, and only if, in a steady state, it uses in the long term no more bandwidth than a conforming TCP flow that would be used under comparable conditions. Among the principal representatives of the TCP-friendly congestion control algorithms is the TCP-friendly rate control (TFRC) algorithm [13].

Shortcomings of current congestion control schemes when implemented in IPTV are stated as follows. Although these schemes can ensure that the video streams do not overload or underutilize the available network bandwidth, they can not simultaneously maximize the perceived IPTV video quality. For instance, in the slow-start phase, they just start from one packet per round-trip-time (RTT) and slowly approach the maximum available rate, which can greatly harm the QoS of video traffic in the entire slow-start duration. Even though TFRC [13] tries to smooth out rate variability, it does not take the properties of the overlying media application into consideration when protecting media flows from short-term congestion.

COMPATIBILITY OF COMMUNICATION AND BROADCASTING

The following are compatibility issues between communication and broadcasting:

- Harmonization between ubiquitous traffic and multicast traffic
- Harmonization between telecommunication signaling and multicast signaling
- Separation of media transport network and signaling network [14]

Ubiquitous traffic is defined as data traffic from

communication networks, normally has narrower bandwidth, and is non-real-time, whereas multicast traffic is one-to-many real-time video; harmonization between telecommunication signaling and multicast signaling should be further investigated because multicast signaling, having different signaling mechanisms for core networks and access networks, is quite different from telecommunication signaling, which has an end-to-end signaling mechanism; separation of media transport network and signaling network may be required due to a congestion consideration caused by the conflict of multicasting and priority of real-time traffic.

SECURITY AND PRIVACY

There are possible attacks and network outage failures for IPTV services. Rapid recovery after attacks/failures is important to minimize negative impact. IPTV services should provide user security and privacy with confidential delivery of data such as program channels and content, prevention of attacks from malicious users/software, and denial of service (DoS).

Designing secure and anonymous IPTV services requires further investigation and research. Especially, the following issues must be solved: distributed digital rights management (DRM) to protect the copyright of video contents, the authentication of clients to verify their access privileges, and the prevention of traffic flooding / bandwidth over-consumption attacks.

STANDARDIZATION OF IPTV

Standardization of IPTV is important and difficult; however, it is mandatory for successful deployment. There are no established standards at this stage. Lack of standardized technologies causes unnecessary investments and unavailable new services, and therefore it is feared that some businesses may be forced to use proprietary solutions [14]. Standardization of NGN has progressed in the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) that includes IPTV services [14].

COMMUNICATIONS AMONG ADMISSION CONTROLS

Further studies are required to learn how different admission control schemes become consistent and communicate well, for example, between multicast admission control and xDSL admission control, between multicast admission control and carrier-grade Ethernet, between carrier-grade Ethernet and carrier-grade Ethernet, between multicast admission control and 802.11 admission control, and so on. For example, changing a channel in IPTV services may require of DSL admission control only a small action, such as changing parameters, but multicast admission control may involve join and leave operations at a multicast tree so that DSL admission control should communicate with multicast admission control to work together.

CHALLENGES FOR MOBILE TV

Current cellular networks cannot support high bandwidth, real-time applications such as video, whereas mobile broadcast networks support many users within a cell with downlinks only. Both broadcasting uplinks and downlinks should be used with a high capacity broadcast network. Due to limited bandwidth, mobile TV service may degrade performance and capacity of cell sites, and it is difficult to provide personalized interactive services. The most challenging issue of mobile TV is, of course, the bandwidth issue.

Wireless multicast plays an important part for mobile TV. For purposes of robustness, mobile TV is normally distributed from two or more video content sources to multiple destinations. Most of the research about multicast does not address the problem of multiple sources and multiple destinations.

Wireless multicast is similar to wired multicast in concept. However, minimizing energy consumption of mobile devices should always be considered for wireless multicast. Computing an optimal-energy-consumption multicast tree is nondeterministic polynomial time (NP)-hard.

There is still some work required for IMS to provide IPTV services.

CHALLENGES OF P2P IPTV

Challenges of P2P IPTV services include providing QoS, which is difficult because the services are provided via the public Internet so that the video quality is subject to network traffic conditions.

CONCLUSIONS

This article presents an overview of IPTV services and its key technologies in terms of access networks, core networks, mobile TV, P2P IPTV, and challenging issues including QoS guarantee, traffic management, congestion control, multicast admission control, Ethernet/WLAN/DSL admission control, standardization, communications among admission controls, and security and privacy issues.

For purposes of robustness, mobile TV is normally distributed from two or more video content sources to multiple destinations. Most of the research about multicast does not address the problem of multiple sources and multiple destinations.

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