Bridging Core and Edge Networks for Residential Subscribers

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ABSTRACT

In this article, we survey various internetworking scenarios between core and edge networks for residential users. The focus is not on individual protocols. Instead we will try to show how these protocols can work together. We divide an end-to-end network into core networks and edge networks. We then consider two options for core networks: ATM-based and IP/MPLS-based. For each core/edge architecture, we further consider various access architectures for residential users. We try to show how these access architectures can be integrated with the two core architectures. Based on the specific requirements of core and edge networks, we discuss the benefits and problems of each solution.

INTRODUCTION

We are experiencing phenomenal growth of Internet and data networks. Meanwhile we still need to support legacy services such as plain old telephony service (POTS). It is not uncommon that a data service has to be transported over an existing synchronous transfer mode (STM) network or vice versa. To solve problems that exist in both legacy STM networks and data networks, various protocols have been proposed. These have caused an explosion of network protocols and internetworking scenarios. While each protocol is proposed to solve a specific problem, it has to work together with other protocols to provide end-to-end services. An end-to-end network is typically divided into core and edge networks. Although all networks must provide some kind of connectivity, core networks have significantly different requirements from edge networks.

With the exponential growth of Internet traffic, the foremost requirement for core networks is clearly scalability in the sense of total capacity and total number of micro-flows a network can handle. As core networks start using higher- and higher-speed links (e.g., OC-48, OC-192), reliability becomes an important issue since the failure of a high-speed link can impact thousands of customers. Also related to scalability is manageability. With thousands of wavelength channels and millions of virtual connections, management

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of core networks is becoming a major challenge. In this article, we will consider two options for core networks: an asynchronous transfer mode (ATM)-based core and an Internet Protocol/multiprotocol label switching (IP/MPLS)-based core.

While scalability is the key requirement of core networks, multiservice support is the key requirement of edge networks. An edge network typically needs to support different access technologies — such as POTS, asynchronous digital subscriber line (ADSL), and hybrid fiber coax (HFC) — and different services (e.g., voice, data, video). Supporting these access technologies and services in an efficient and manageable way is the challenge for the architecture of edge networks. In this article, we will consider both narrowband and broadband networks as edge networks. Within broadband networks, we will consider both ADSL and HFC as local loops to connect residential customers. While Ethernet switches can be used by edge networks, we will only consider multiservice ATM switches in this article. The reason is that we feel multiservice ATM switches provide much better fairness control, security tracking, accounting, and performance management for residential customers, although Ethernet switches can be somewhat cheaper.

With the deployment of digital subscriber line (xDSL) speeding up, the deployment of ATM switches in edge networks will continue to grow. Multiservice ATM switches may become dominant in the central offices of local carriers in the future, while legacy narrowband networks will gradually phase out. On the other hand, both ATM and IP/MPLS networks exist in the current core networks of local and long distance carriers[1]. Traditional long distance carriers like Sprint and many regional Bell operating companies (RBOCs) have large embedded ATM core networks. Other carriers like MCI WorldCom and Cable & Wireless are building their new core networks based on IP/MPLS architecture. The requirement to interwork multiservice ATM edge networks and legacy narrowband networks with ATM or IP/MPLS core networks is becoming a key issue for an end-to-end network architecture. This article is designed to address this issue.

The article is organized as follows. We study the use of ATM in core networks. We consider

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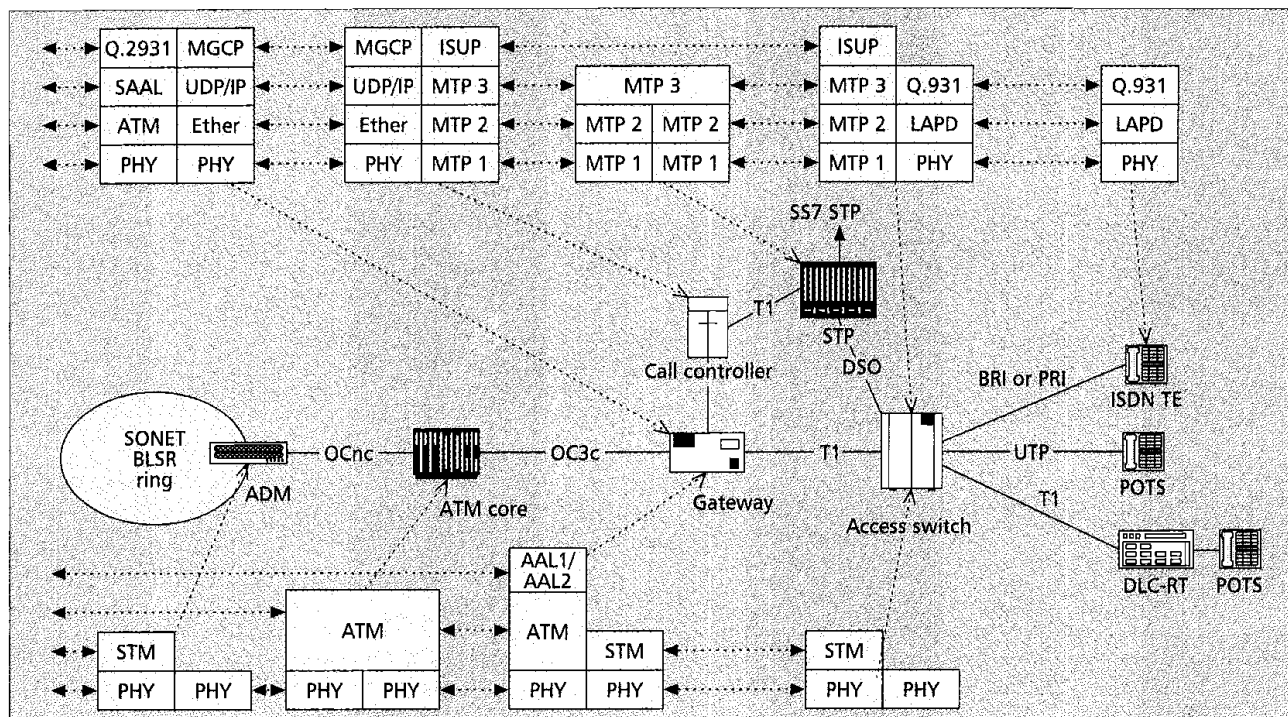
■ Figure 1. *IETF media gateway approach for ATM core network.*

internetworking scenarios to bridge both narrowband and broadband edge networks to these ATM-based core networks. For broadband residential subscribers, we further consider two options: ADSL and HFC. We study the use of IP/MPLS in core networks. As in the ATM case, we consider both narrowband and broadband edge networks.

AN ATM-BASED CORE NETWORK

In contrast to traditional STM circuit-switched networks, ATM networks are data networks. ATM is a connection-oriented packet-switching technology that uses fixed-size packets, referred to as *cells*, to carry the traffic in the network. With the deployment of ATM-based core networks, carriers can provide full data service as well as voice service over the same ATM-based core network. The scalability of the ATM network makes it an ideal replacement for tandem switches in a traditional PSTN. In order to facilitate communication between the narrowband PSTN access network and the new ATM-based core network, internetworking between ATM networks and traditional PSTN networks is required.

INTERNETWORKING WITH NARROWBAND EDGE NETWORKS FOR VOICE SERVICE

Support of POTS in an independent local exchange carrier (ILEC) network will include a variety of access mechanisms. A local access telephone switch, such as a class 5 switch, will provide the termination of the access telephone lines. In many cases, DLCs will also be used to provide remote termination of the analog telephone lines, and transport of this traffic into the

local access office via wideband interfaces. The local access telephone switch would then utilize trunk groups to route calls to other switches in the network, either other local access switches for direct connections or tandem switches for further network routing. Concentration is typically provided on the access switch to enhance trunk utilization.

The local access switch also terminates the Digital Signaling System 1 (DSS1) signaling protocol stacks if the subscriber line provides integrated services digital network (ISDN) or DLC service, mapping the DSS1 signaling messages to Signaling System No. 7 (SS7) signaling messages and sending them to the signaling transfer point (STP). If the subscriber line is POTS, the access switch will terminate dual-tone multifrequency (DTMF) signals, mapping them to SS7 messages and sending them to the STP. In SS7 terminology, the access switch is acting as an SSP [2].

The ATM Forum Circuit Emulation Approach — The earliest method for internetworking ATM networks with the PSTN is the circuit emulation switching (CES) approach, where ATM switches are used to replace the bearer service of tandem telephony switches [3]. A CES interworking unit (IWU) packs incoming DS0 traffic into ATM cells using ATM Adaptation Layer 1 (AAL1). The ATM cells are delivered through an ATM permanent virtual circuit (PVC) (switched VC, SVC, in some cases). While this approach may be easy to implement, it introduces a packetization delay. To solve this problem, another approach is also proposed. It allows the CES IWU to pack a block of DS0 channels into one AAL1 cell and share one PVC (or SVC). The CES IWU can be a standalone device, or integrated into either ATM or access
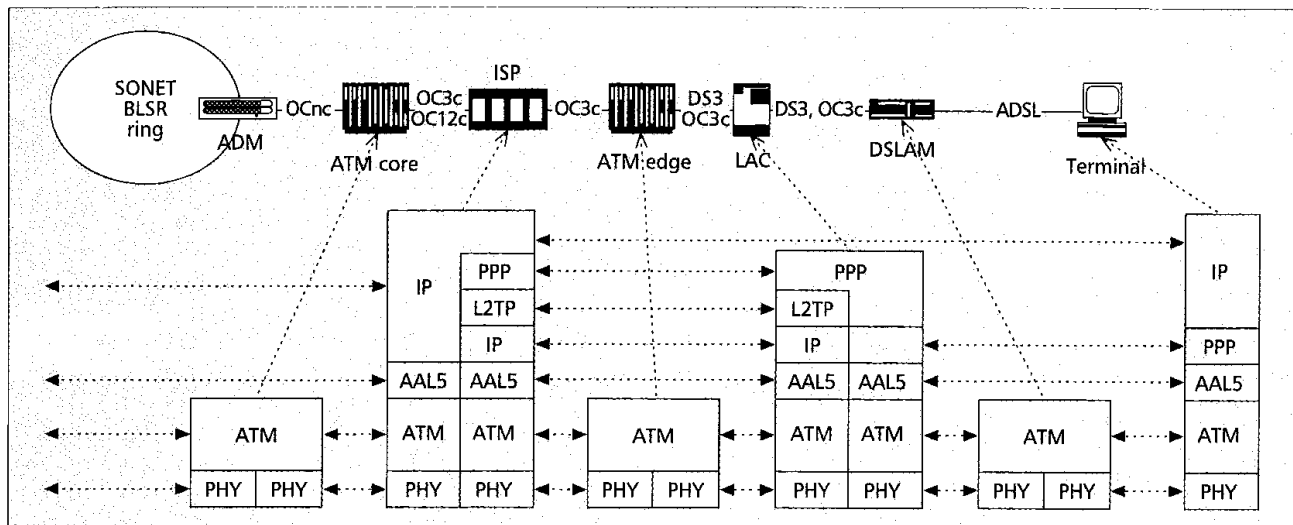
■ Figure 2. *L2TP access aggregation architecture.*

telephony switches. The CES IWU does not handle signaling interworking functions (limited ATM signaling functions are provided in some cases). End-to-end signaling is still handled by SS7 networks. Circuit emulation is a trunk replacement approach. It uses ATM switches to provide preconfigured trunks. It does not use ATM dynamic signaling capability (limited dynamic signaling capability in some cases); nor does it use ATM data switch capability for handling bursty data traffic. Therefore, its value is limited. The ATM Forum is working on other approaches which can utilize ATM signaling and its data network capabilities.

The IETF Media Gateway Approach — To fully utilize data network capability, the Internet Engineering Task Force (IETF) has developed a protocol called Media Gateway Control Protocol (MGCP) [4]. MGCP is a protocol between a call controller, which handles SS7 signaling, and a media gateway, which provides the conversion between the audio signals carried on telephone circuits and data packets carried over packet networks. By using peering gateways, the SS7 network as an end-to-end out-of-band signaling network can be preserved. A key function provided by MGCP is to map SS7 domain names to ATM addresses through ISUP+ so that an ATM SVC can be dynamically set up to provide trunking service. An implementation scenario is shown in Fig. 1. One of the major benefits of the media gateway approach is that it is not limited to ATM networks. Other data networks can be supported under the same architecture. We will discuss this approach in detail later.
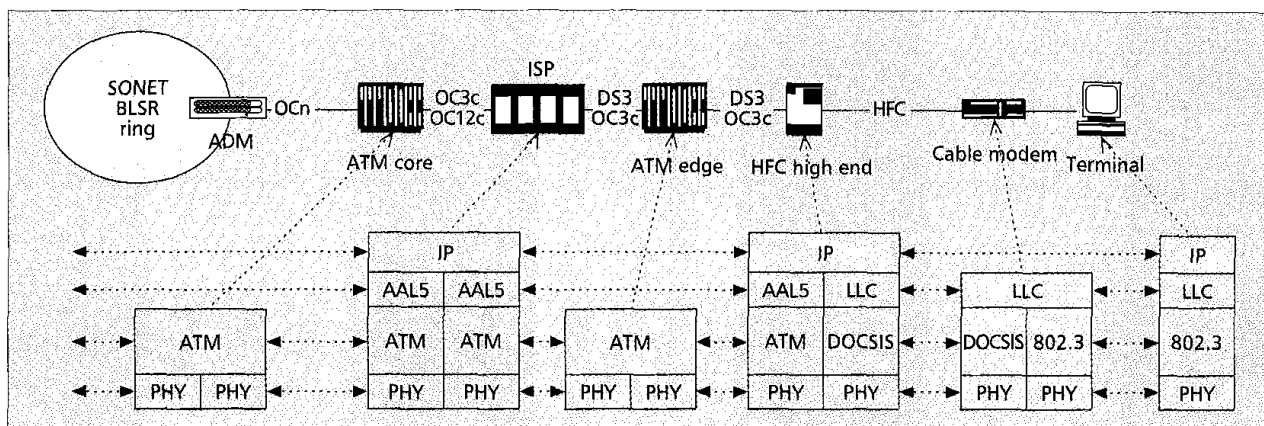
INTERNETWORKING WITH BROADBAND EDGE NETWORKS FOR DATA SERVICE

Most broadband edge networks are ATM-based. Although an Ethernet switch is typically cheaper than an ATM switch, it has less support for quality of service (QoS), accounting,

security tracking, and policy control. ATM switches can allocate specific VCs to support specific QoS requirements and also apply policy control to a particular VC. Accounting and security tracking can also be provided on a per-customer basis. In contrast, the Ethernet switch can only assign different customers to different virtual local area networks (VLANs) and different priorities. Therefore, it can only support class-based QoS and VLAN-based accounting.

There should be no significant internetworking issue if the end-to-end service to be provided is ATM service. But with the explosion of the Internet, most traffic is converging to IP traffic. It is natural that end users will expect IP rather than ATM service. Methods for using an end-to-end ATM network to provide IP service are the topic of this section.

One of the key issues of running IP over ATM is mapping the destination IP address to an ATM address and then setting up an ATM connection to forward a packet to the destination. There are two approaches proposed to solve this problem. The ATM Forum approach is LAN emulation (LANE) over ATM. The IETF defined another approach, classical IP over ATM. Both approaches use servers to track address mappings [5]. While both approaches are limited to support of LAN switching only, classical IP over ATM is further limited to support only IP as the layer 3 protocol. To solve these limitations, the ATM Forum further defined a protocol called Multiprotocol over ATM (MPOA). MPOA allows addresses and topological information to be exchanged over servers sitting in different subnetworks so that a server can map IP addresses which span multiple subnetworks. Therefore, MPOA will lower latency by allowing direct connectivity between end systems that can cut across subnet boundaries. In this section we will first examine two popular broadband access technologies: ADSL and HFC. For IP directly over ATM, RFC 1483 encapsulation will be assumed.

■ Figure 3. *Internetworking with HFC access.*

ADSL Access — Since Internet service providers (ISPs) already have an infrastructure to support dialup access based on Point-to-Point Protocol (PPP), it is natural to require any new broadband Internet access solution to take this into account. This has led to the first solution, called PPP over ATM, which requires that PPP be carried over an end-to-end ATM SVC using AAL5. Since PPP itself supports protocol multiplexing, IP and other protocols can run above the PPP layer. This allows the usage of null encapsulation for the mapping of PPP over AAL5. Unfortunately, this solution requires end-to-end SVC setups which not all carriers are ready to offer. It is possible to deploy ADSL with short-reach ATM PVCs and a gateway. This class of architectures allows ADSL deployments to progress while the industry develops a mature set of ATM SVC capabilities. Two specific architectures for the core network supporting ADSL access services have been proposed [6].

The first architecture is called L2TP Access Aggregation (Fig. 2), where LAC stands for L2TP Access Concentrator. L2TP is a protocol for extending PPP sessions over an arbitrary network to a remote network server. Typically the user initiates a session by establishing a PPP connection between the user's customer premises equipment (CPE) and the LAC over a pre-provisioned ATM PVC. The user can select its ISPs through a username along with a domain name which are carried by PPP options. Authentication can also be done during this phase. Based on the username, the LAC will establish an L2TP tunnel to the required ISP. Upon completion of tunnel establishment, an end-to-end PPP connection exists between the user and the ISP. Multiple classes of service (CoSs) can be supported with multiple tunnels. While L2TP is scalable, it is incapable of supporting per-connection QoS. Therefore, it is typically used as a short-term migration solution.

Another approach, which does not require the L2TP protocol, is PPP Terminated Aggregation. This architecture uses layer 3 to authenticate users rather than layer 2, as in PPP. The user initiates a PPP session to the BAS over the preprovisioned ATM PVC. The BAS extracts the domain string portion of the username and sends off a query to the ISP's RADIUS database

to authenticate and obtain address information. The ISP's RADIUS server replies with an IP address and other IP configuration information (e.g., DNS server's address). The BAS maps a user identifier (port, session identifier, etc.) to the outgoing ISP port. The achievable QoS depends on the transport network capability. This architecture is limited to IP service. Compared to the L2TP access aggregation approach, this approach requires ISPs to support RADIUS rather than PPP. This may be a shift from their current configurations, but in the long run, it will allow ISPs to leverage RADIUS to provide more features than authentication only.

HFC Access — HFC is another important vehicle for high-speed access. An important objective of the system architecture and protocol design for HFC networks is to support multiple services which include real-time service. The DOCSIS specs defined by MCNS use 188-byte MPEG packets for the downstream traffic [7]. The upstream traffic uses a reservation-based slotted time-division multiple access (TDMA) approach. The cable high end provides mapping between logical links and ATM VCs. The end-to-end architecture is shown in Fig. 3. To provide IP service, an IP over ATM architecture is used, as discussed at the beginning of this section.

AN IP/MPLS-BASED CORE NETWORK

With the introduction of the Web browser, IP traffic has been growing exponentially. It is a task both challenging and urgent to design a core network that can handle IP traffic in a scalable way. ATM is not optimized to handle IP functions; therefore, its routing and addressing structures are not naturally compatible with IP networks. Interworking technologies like MPOA help solve the address-mapping problem but introduce new scalability problems. MPOA typically maps IP micro-flows to ATM SVCs. This mapping generates a significant amount of SVC setups, which are far beyond the capability of current ATM switches. A typical Web browser runs four TCP sessions in parallel. If each TCP session requires a separate ATM SVC to satisfy
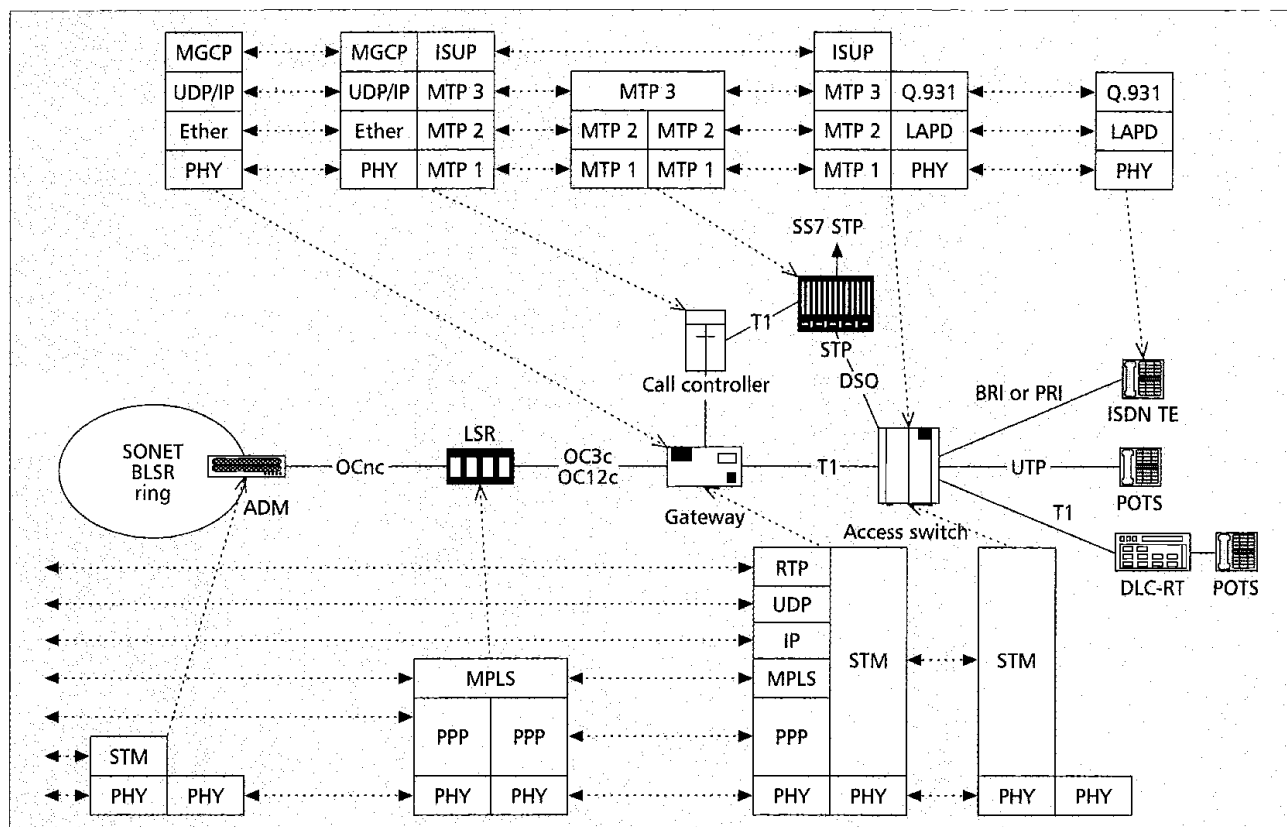
■ Figure 4. *The IETF media gateway approach to an IP/MPLS core network.*

its QoS requirements, there will be four ATM SVC signaling processes for each Web site. If a browsing session lasts 30 min and runs over 10 different Web sites, 40 ATM SVC signaling processes will be required. This is significantly different from the behavior of traditional voice. To avoid this signaling problem, carriers typically provide PVCs or permanent virtual paths (PVPs) rather than SVCs to interconnect edge networks.

With PVCs or PVPs, a mesh-connected structure is required. This causes the so-called N square problem where N is the number of layer 3 nodes that require peering over the ATM network because every edge node may require a connection to every other edge node. To solve this problem, the IETF is working on the MPLS mechanism [8]. MPLS uses label-based forwarding rather than IP forwarding, and therefore greatly reduces the latency of IP forwarding. In comparison with legacy routers, MPLS switches are connection-oriented. Packets with the same label will travel through the same path. This makes traffic engineering much easier with MPLS than with legacy routers. With better traffic engineering capability, MPLS can support CoS better than legacy routers. MPLS LSPs are geographically decided and can be limited to one MPLS domain. Therefore, different micro-flows can share one label if they travel the same path within a domain. MPLS can be run on different interfaces (e.g., ATM, frame relay, POS) and can therefore provide a smooth migration from existing networks.

For the control plane, MPLS uses LDP to distribute labels based on IP addresses and sets up LSPs automatically. Labels can also be distributed by piggybacking over routing protocols. Label binding is done in a distributed way rather than through a centralized server as in MPOA. Because LSPs are geographically decided, they are relatively stable. All this improves MPLS scalability. MPLS can also support network reliability by preconfiguring backup LSPs.

INTERNETWORKING WITH NARROWBAND EDGE NETWORKS FOR VOICE SERVICE

The IETF media gateway approach discussed earlier was originally designed for using IP networks as the core network. The internetworking architecture is shown in Fig. 4. Instead of using a sophisticated transport protocol like TCP, the media gateway approach assumes Real-Time Transfer Protocol (RTP) as the transport protocol. The delay of TCP makes it difficult for real-time applications. Most audio playback algorithms, for example, can tolerate missing data much better than lengthy delays. Instead of introducing delays with retransmissions, these applications prefer the transport layer to simply forget about missing data. They do not need a transport protocol to guarantee in-sequence delivery. RTP is such a lightweight protocol. It provides a simple framing structure for different applications. To support real-time applications, a timestamp is carried by each message. The playback algorithm can handle misordered packets
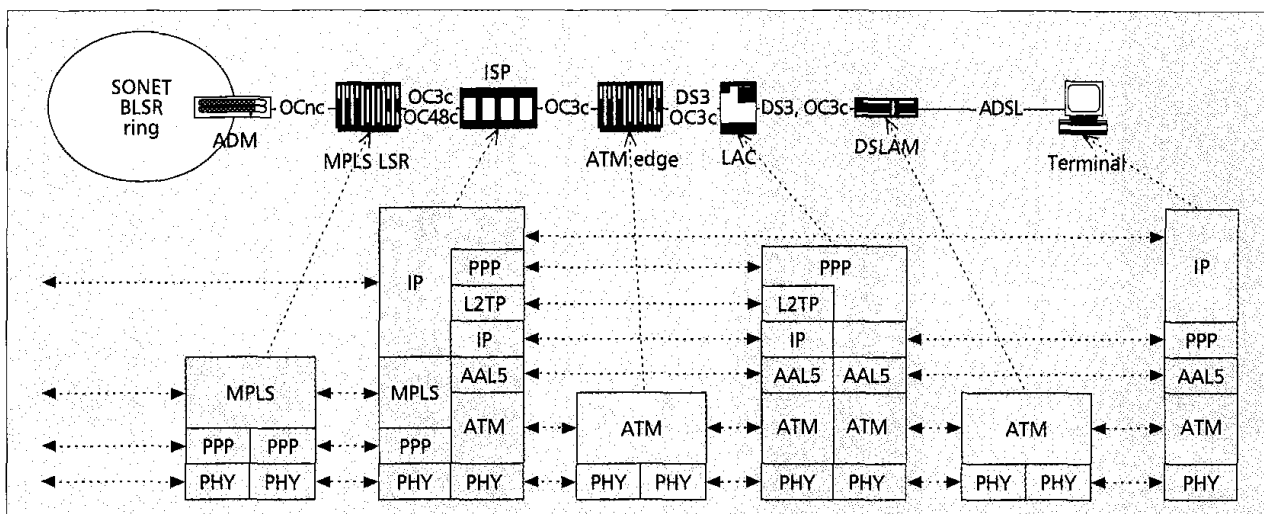
Figure 5. *Internetworking IP/MPLS with ADSL access.*

automatically based on their timestamps. RTP also supports multicast applications.

For the control plane, SS7 can still be the end-to-end signaling protocol. Instead of being mapped to ATM addresses, DNs are mapped to IP addresses and UDP port numbers. A call setup example can be as follows: After receiving the incoming SS7 IAM message, the ingress call controller asks the originating gateway to *create a connection*. The originating and terminating call controllers then proceed to exchange a *session description* which contains the information necessary for a third party to send packets toward the newly created connection. For example, this session description might include IP address, UDP port, and packetization parameters. The session descriptions are carried by IAM and ACM messages. Once this is done, communication can proceed in both directions.

IP/MPLS networks do not support per-connection QoS. This has become a key issue with the media gateway approach. Because MPLS has no knowledge of micro-flows, operators must support QoS through proper traffic engineering. In association with RTP there is a protocol called Real-Time Transfer Control Protocol (RTCP) which provides feedback information on delay and delay jitter. Media gateways can use this information to estimate network congestion and decide whether to block new calls to avoid further congestion. While this mechanism has not completely removed the QoS problem in the media gateway approach, it can certainly make QoS better. A new protocol called Megaco/H.248 is being jointly developed by the IETF and International Telecommunication Union (ITU) [9]. While it is similar to MGCP in most parts, there are two new concepts: context and transaction. They will allow more flexibility to support new features like call waiting. Another issue with the media gateway approach is the IP and RTP overheads. This may become nontrivial because voice packets tend to be small to avoid packetization delay. The IETF is working on MPLS-based solutions to this problem.

INTERNETWORKING WITH BROADBAND EDGE NETWORKS FOR DATA SERVICE

MPLS achieves scalability partly by using coarser granularity. In the edge networks, there are management requirements to track each user. Consequently, finer granularity on a per-customer or per-flow basis is required, and this is provided by ATM networks. Thus, a key issue of internetworking an IP/MPLS-based core network with an ATM-based edge network is handling this mismatch of granularities.

Granularity has significant impact on QoS. ATM networks are connection-oriented, and QoS is supported by ATM networks on a per-connection basis. Each ATM node has to maintain state for each connection that runs through the node. Resources must also be reserved for each connection. The amount of forwarding state maintained at each node scales in proportion with the square of the number of hosts. This is not acceptable for a core network. MPLS improves scalability through aggregation and label merging. The amount of forwarding state at each MPLS node scales in proportion to the number of edge nodes of the network. But MPLS can only support QoS on a per-LSP basis. DiffServ [10] further improves scalability by supporting CoS rather than QoS. This assumes a connectionless network instead of a connection-oriented network. This makes it easier to port this capability on IP networks. The CoS provided by DiffServ has been divided into three major types or per-hop behaviors: PHBs: EF, AF, and best effort forwarding. The EF PHB can be used to build a low-loss low-latency low-jitter assured-bandwidth service at a DiffServ node. AF PHB is a means to offer different levels of forwarding assurances for IP packets. Four AF classes have been defined. AF PHB will provide better assurance than best effort but less than EF PHB.

In addition to PHB, conditioning and provisioning will be required to support CoS. Traffic conditioning refers to those control functions performed to enforce rules specified in a traffic contract. Traffic conditioning mechanisms

include metering, marking, shaping, and policing. Traffic conditioning is performed at the boundary of a DiffServ domain.

Service provisioning defines how traffic conditioners are configured at the boundary and how traffic streams are mapped to the aggregate PHB on each node to achieve a range of services. Service provisioning can be static and performed by the management plane, or dynamic and performed via the control plane. Static provisioning uses a network planning tool to estimate traffic growth and allocate resources. Due to traffic burstiness, overprovisioning is unavoidable. To achieve higher utilization and better QoS guarantees, some kind of dynamic signaling mechanism may be required. There is no consensus right now among the IP community on the best signaling approach for the IP network. One possibility is to use RSVP as the end-to-end signaling protocol and use either COPS [11] or DIAMETER [12] as the admission control protocol. Both COPS and DIAMETER are based on client/server architecture. In addition to client-server communication, DIAMETER also supports server-server communication. Because of the mismatch of granularities at the boundary between core and edge networks, some kind of nesting structure may be required for an end-to-end signaling protocol like RSVP to work.

An implementation scenario with ADSL access is shown in Fig. 5. It is easy to see that HFC access will not change the architecture significantly. The interface between the edge and core networks can be governed by service level agreements (SLAs) and enforced through the use of protocols like COPS or DIAMETER. ATM signaling can be terminated at the ISP site, and new signaling using RSVP generated toward the core network. The QoS parameters carried in the ATM signaling messages can be mapped to the aggregate CoS parameters carried in RSVP messages.

SUMMARY

In this article we discuss several scenarios of internetworking core networks with edge networks. We consider two types of core networks: ATM-based and IP/MPLS based. For edge networks, we consider three options: narrowband local loop, ADSL, and HFC. A key issue in interworking with narrowband access is how to preserve an SS7 network for end-to-end signaling. For interworking IP/MPLS-based core networks with broadband edge networks, a key issue is the mismatch of granularities. We have shown several solutions in this article. It should be noted that the topics in this article are highly dynamic. It is far from finished, since many of the mechanisms described here are evolving rapidly. It would not be a surprise to see changes to the solutions described in this article in the very near future.

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BIOGRAPHIES

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