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ATM TECHNOLOGY AND BEYOND

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Abstract

Networks based on Asynchronous Transfer Mode (ATM) are expected to provide cost-effective and ubiquitous infrastructure to support broadband and multimedia services. In this paper, we will give an overview of the ATM standards and its associated physical layer transport technologies. We use the experimental HIPPI-ATM-SONET (HAS) interface in the Nectar Gigabit Testbed to illustrate how one can use the SONET/ATM public network to provide transport for bursty gigabit applications.

Introduction

The phenomenal progress in telecommunication and computer technologies in the past decade has created an emerging demand for broadband and multimedia services. Such demand stimulated the development of the Broadband Integrated Services Digital Network (B-ISDN) [1-4]. B-ISDN is a standardized public switched telecommunications network infrastructure capable of supporting both broadband and narrowband services on a single flexible network platform. A key element of the standards is the use of Asynchronous Transfer Mode (ATM) for multiplexing and switching. ATM combines the advantages of both circuit- and packet-switching techniques, allowing many services to be transported and switched in a common digital format. Furthermore, the current recommendations include the Synchronous Optical Network (SONET) [5,6], also known internationally as the Synchronous Digital Hierarchy (SDH), as the physical layer transmission standard. ATM, together with SONET, is expected to provide the reliable high-speed transport, bandwidth flexibility, and integrated transmission and switching for a diverse set of traffic characteristics as required by B-ISDN.

This paper provides an overview of ATM and SONET standards and explores how the current broadband standards can be extended to accommodate bursty gigabit applications for supercomputers and high performance workstations. We use the experimental HIPPI-ATM-SONET (HAS) interface in the Nectar Gigabit Testbed as an example to illustrate how one can use the ATM-based public network to provide end-to-end transport for gigabit applications.

Asynchronous Transfer Mode (ATM)

ATM is a high-speed and low latency packet-like switching technique. It employs fixed size packets, or "cells", with a 5-byte header and a 48-byte information payload. It is a connection-oriented technology whereby user data is transported through a network of switches over pre-defined routes. Because it is a statistical multiplexing and switching technology, ATM can operate over a wide range of data rates with different physical media. The latter can be optical fiber, twisted copper pair, or wireless medium. Depending on the media, the data rates can vary from 1.5 Mb/s to 2.5 Gb/s and beyond.

The protocol stack for ATM is shown in Fig. 1. Each layer performs the function corresponding to a similar layer of the International Standards Organization (ISO) Open Systems Interconnect

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(OSI) communications protocol stack. The physical layer deals with the framing and physical transport of the data. The ATM layer addresses such issues as switching/routing and multiplexing. The ATM Adaptation Layer (AAL) converts the information from the higher layers to ATM cells and vice-versa. It handles the segmentation and reassembly of data packets into cells as well as service dependent functions such as timing and synchronization. The user plane deals with user application information while the control plane handles call and connection control. The management plane supports operations, administration, and management functions.

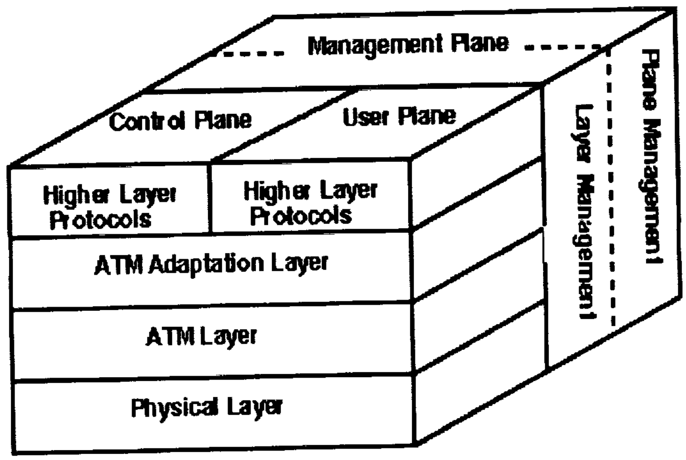

Fig. 1 ATM Protocol Reference Model

Unlike other communications technologies, ATM is designed to accommodate a variety of traffic types with different quality of service characteristics. ATM assigns all traffic to one of four basic classes as shown in Fig. 2. In Class A service, the data rate is constant and a timing relationship exists between the source and destination. Examples of such services are voice or fixed rate video. Class B services differ from those of Class A in that the bit rate can be variable. Examples include differentially encoded video. In Class C service, the connection between the source and destination is asynchronous and the data rate can be variable. An example is file transfer between computers. Finally, Class D is similar to Class C except that it is connectionless. An example of such services is connectionless data transport (e.g. UDP/IP or SMDS).

	Class A	Class B	Class C	Class D
Timing Between Source and Destination	related		unrelated	
Bit Rate	Constant	Variable		
Connection Mode	Connection-oriented			Connectionless

Figure 2: ATM Service Classes

Advantages of ATM

ATM offers significant advantages over earlier networking technologies in supporting broadband and high performance computer networks. A key advantage of ATM is its high speed and associated low-latency. Many organizations are beginning to store documents in image formats. A high resolution image may contain 4096 x 4096 pixels each with 16 bits of gray scale resulting in a file size of 256 megabits. It would take over 25 seconds to transmit the image over a 10 Mb/s Ethernet. However, an 155 Mb/s ATM link would require less than 2 seconds. This difference becomes more pronounced when a set of data contain a large number of images. Furthermore, these images might only constitute a part of a complete file such as a detailed medical record. The amount of data could reach gigabit range and lower-speed technologies perform inadequately. Also, unlike Ethernet or FDDI, which are shared media technologies, ATM connected workstations have dedicated links to the networks. As a result, a user performing network-intensive operations is unlikely to affect other network users.

Another advantage of ATM is its flexibility. Since it was designed to support different types of traffic over the same network, ATM can be used as the single network technology for the various systems within an organization. Image transfer applications, which require high bandwidth and low loss, can use the same network as video conferencing system, which requires low latency exchanges. A common network platform would facilitate the interconnection of the critical information systems of the organization.

An aspect of this flexibility is that ATM is both a local area network (LAN) and a wide area network (WAN) technology. It can potentially offer seamless connectivity between an organization's internal network and the public network. This would not only facilitate the interconnection of geographically distributed facilities allowing for greater sharing of data but would also spur "telecommuting" whereby services could be provided to remotely located business sites. Because there would be no need for special internetworking units connecting the LAN to the public network, this could result in decreased startup costs and increased performance and reliability. Furthermore, ATM has a well-defined set of performance and management functions. For end-to-end applications, a homogeneous management structure can be employed to manage most of the public and private networks. This could result in considerable savings in cost and management effort.

ATM has become an international standard with the support of both the telecommunications and computer industries. In addition to the international standard bodies such as ITU-TS (International Telecommunications Union -- Telecom Sector, formerly called CCITT), the ATM Forum appears to be evolving into a new standard body guiding the implementation of ATM products into the marketplace. These emerging standards (for example, Ref. 7) are under intense scrutiny from both equipment manufacturers and users to help ensure that the specifications are implementable. Even though the specifications are not yet completed, many companies are currently offering products. For example, almost every major router and bridge vendor is offering, or has announced, support for ATM LAN interconnectivity either by marketing small (up to 64 ports) switches or by adding ATM interfaces to their existing products. Several companies are also offering ATM adapter cards for workstations and PCs. For WAN connectivity, most large switch manufacturers are marketing first generation switches and many local and long distance carriers in the U.S. have announced plans for offering ATM services within the next several years.

Synchronous Optical Network (SONET)

Most of the ATM applications will likely be carried over the Synchronous Optical Network (SONET) [5,6] as the physical layer. SONET defines a standard set of optical interfaces for network transport in interoffice transmission and cross-connects, switching, local distribution, and local area networks in customer premises. It is a hierarchy of optical signals which are multiples (called OC-N) of a basic signal rate of 51.84 Mb/s called OC-1, or Optical Carrier at Level 1. The electrical counterpart of these optical signals are called STS-N, or Synchronous Transport Signal at Level N. The STS-N signals have standardized frame formats with a frame duration of 125 microseconds (8 kHz). The STS-1 frame consists of 90 columns and 9 rows of 8 bit bytes. The STS-N signal is formed by synchronously byte-interleaving N STS-1 signals. The OC-3 (155.52 Mb/s) and OC-12 (622.08 Mb/s) have been designated as the customer access rates in future B-ISDN networks. Other important SONET rates are OC-48 (2.488 Gb/s) and, in the future, OC-192 (9.953 Gb/s). Of special interest to B-ISDN and gigabit networking is the Concatenated Synchronous Transport Signal Level N (STS-Nc) which is an STS-N signal in which the N STS-1s have been combined together as a single entity and is transported not as several separate signals but as a single channel [5]. The concatenated signal provides a contiguous high speed channel to support services that require large bandwidths.

The orderly, synchronous structure of the SONET/SDH concept simplifies multiplexing, and reduces significantly the amount of network equipment for each node. As a result of international standardization, SONET/SDH allows the interconnection of different manufacturers' products at the optical level, and facilitates optical mid-span meets. The flexible payload structure can accommodate virtually any type of digital signal, and provides a flexible platform for future services. The definition of SONET also includes provisions for standardized operation and maintenance support which will become a key consideration in the implementation of future broadband networks.

Recently, there has been considerable standards activities at the ATM Forum to propose methods of sending SONET and ATM signals over unshielded twisted copper pairs (UTP) at data rates of up to 155 Mb/s (STS-3c rate) for short distances (up to 100 meters). A key application of SONET over UTP is to provide low cost ATM connectivity all the way to the desktop within an organization. The basic SONET rate of STS-1 (51.84 Mb/s) has further been extended to subrates of 25.92 and 12.96 Mb/s in modulo 2 fashion to support lower speed applications at the desktop. The most important SONET rates and their equivalent in the international SDH hierarchy are listed in Fig. 3.

OC Level	STS Level	SDH Level	Line Rate (Mb/s)	Remark
	Scalable SONET		12.96	Modulo 2 on UTP
	Scalable SONET		25.92	Modulo 2 on UTP
OC-1	STS-1		51.84	OK on UTP
OC-3	STS-3 (c)	STM-1	155.52	B-ISDN UNI OK on UTP
OC-12	STS-12 (c)	STM-3	622.08	B-ISDN UNI
OC-48	STS-48 (c)	STM-16	2488.32	
OC-192	STS-192 (c?)	STM-64	9953.28	

Fig. 3: Key SONET rates and their SDH equivalents

ATM over Satellite and Wireless Transport

In addition to the terrestrial networks, one may also carry ATM over satellites or other wireless means. Although satellites can support link rates that are orders of magnitude less than fiber links, the basic ATM transport rates — DS-3 (45 Mb/s), SONET STS-1 (51 Mb/s), and STS-3 (155 Mb/s) — can be supported over the current generation of satellites or other wireless media. It is expected that the next generation of satellites can support link rates of STS-12 (622 Mb/s) and higher data rates [8]. A hybrid fiber-satellite ATM-based computer network would significantly extend the reach of a terrestrial network to remote areas.

Extension of SONET/ATM to Support Gigabit Data Services

With the advent of gigabit networking, networks capable of transporting bursty gigabit/sec data packets will be necessary to satisfy the increasing bandwidth demands for communications among supercomputers and large data archives. An example of such a high speed network is the local area network employing the High Performance Parallel Interface, or HIPPI [9-11]. HIPPI was proposed by the ANSI X3 standards committee for transmitting digital data at peak rates of 800 or 1600 Mbit/s between high performance computer equipment. HIPPI, however, is defined only for twisted-pair copper cables over a maximum distance of 25 meters, or serial point-to-point HIPPI extenders over private fiber links. To take advantage of low-cost shared facilities of the ubiquitous public network, it would be highly desirable to interconnect HIPPI hosts over much longer spans across the public metropolitan and wide area networks. The SONET/ATM-based B-ISDN networks offers an attractive solution for such applications [12].

The HIPPI-ATM-SONET (HAS) Interface

In this section, we outline the experimental HIPPI-ATM-SONET (HAS) interface which is one of the first attempts in investigating the transport of bursty gigabit/sec data packets over a SONET/ATM-based public network. The HAS is a key component of the Nectar Gigabit Testbed [13], and is implemented in a collaboration between Bellcore and Carnegie Mellon University. The role of the HAS interface in the Nectar Testbed is shown in Fig. 4.

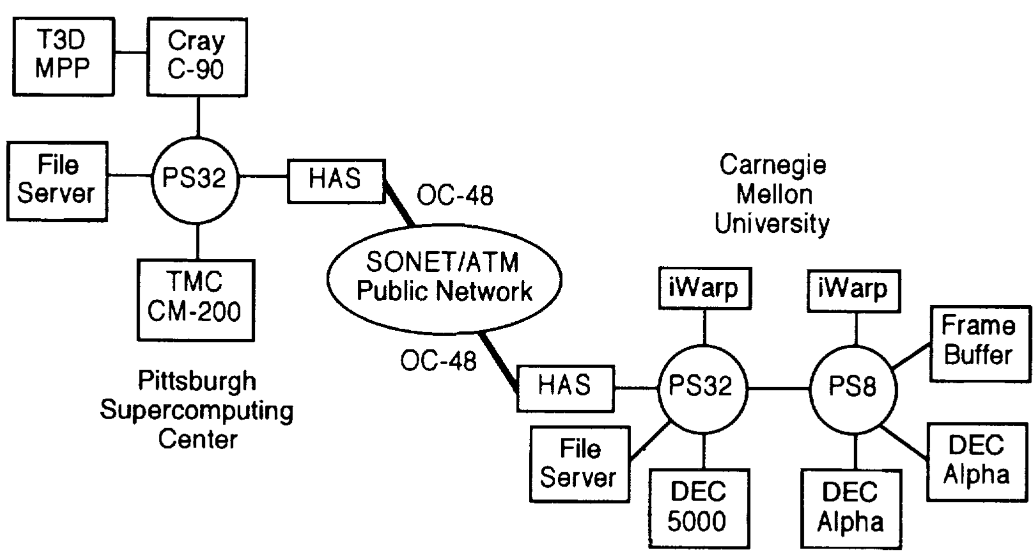

Fig. 4 The Nectar Gigabit Testbed

The basic functions performed by the HAS are as follows. In the transmit direction HIPPI packets from a HIPPI-based host computer or router are terminated on the HIPPI module (Fig. 5). The data within the packet, along with routing information is passed to one of eight ATM/ATM Adaptation Layer (ATM/AAL) modules, each corresponding to one SONET STS-3c channel. The ATM/AAL modules convert the routing information to ATM virtual circuit information, segment the HIPPI data into ATM cells and provide for various forms of error checking. The ATM cells are then passed to the SONET module where they are mapped into SONET STS-3c (155.52 Mb/s) channels. Eight STS-3c channels are used for one HIPPI channel; the testbed will accommodate up to 16 STS-3c channels so that eight additional channels could be used for a second HIPPI channel. The sixteen parallel STS-3c channels are then multiplexed up to the STS-48 rate (2.488 Gb/s) and converted to an optical OC-48 signal for transmission across the network. At the receive side, the OC-48 signal is received, converted to the electrical STS-48 signal and demultiplexed to sixteen parallel STS-3c channels. ATM cells are extracted out of the SONET payload and rassembled into HIPPI data units. ATM routing information is converted to HIPPI routing information and the HIPPI packet is then reconstructed. The architecture of the HAS interface is modular so that the HIPPI module could be replaced by another high-speed data communication interface.

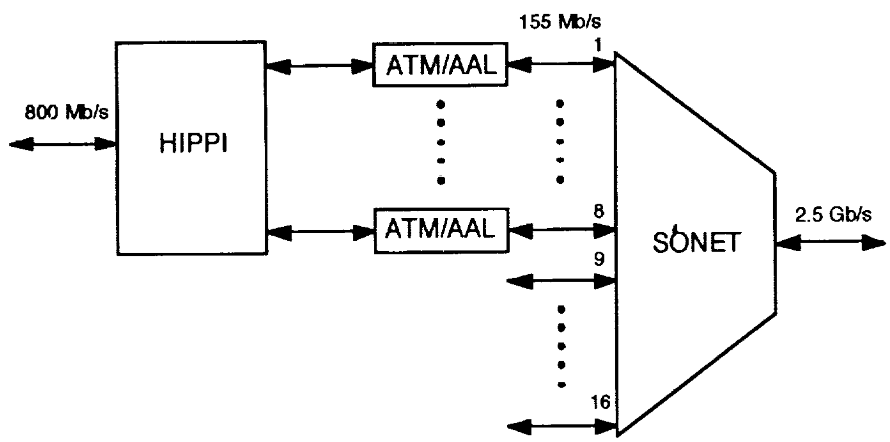

Fig. 5 Schematics of HIPPI-ATM-SONET Interface

As described above, the method chosen for transmitting HIPPI packets is to terminate HIPPI physical-layer signals, such as handshaking control signals, at the network interface rather than transporting them across the network. This approach has the advantage that it does not depend on HIPPI's link layer flow control mechanism, which resembles the window-based flow control mechanisms used in lower-speed data networks. Window-based flow control mechanisms may not scale well to gigabit/second speeds because they control only the number of outstanding packets in the network, not the traffic flow rate. The approach of terminating HIPPI and transporting the data in the form of ATM cells allows rate-based traffic control mechanisms to be used and also provides the flexibility to adapt the HAS interface to transport other types of data traffic.

Conclusion

We have reviewed the key features of the ATM and SONET standards for the B-ISDN public network which is expected to provide an ubiquitous infrastructure for the emerging broadband and multimedia applications. These applications will undoubtedly include gigabit/sec data transfer among high performance computing devices ranging from supercomputers to mass storage archives.

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