Evolution Toward Broadband

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Broadband technologies promise a new age of video, data, and voice communication applications. This promise will be fulfilled over a period of time, starting with the deployment of initial broadband technologies within the current telecommunications framework. The evolution of broadband technology will gradually lead to fundamental changes in the telecommunications infrastructure—changes needed to provide the services required for delivery of tomorrow's information technology. This paper discusses the evolution of broadband in the telecommunications network, some of the forces behind that evolution, and the importance of considering long-term evolutionary directions when establishing the initial stages of broadband equipment and services.

Introduction

The Broadband Integrated Services Digital Network (BISDN) promises to offer an astounding range of revolutionary new communications capabilities. These capabilities will improve productivity, collaboration, entertainment, and education as the Information Age continues to mature.[1] There has been some debate in the communications industry over whether the change to broadband networks will be an evolution or a revolution. This question will be decided by the market and technology forces that are driving the development and deployment of broadband networks and services. These same forces will also shape the details of the deployment of broadband services, network capabilities, network architectures, and communications equipment.

Market and Technology Forces

The need for broadband applications is driven by trends in business and society.[1] The ability to deploy broadband capabilities at an economically feasible cost is determined by advances in key technologies, including high-speed integrated circuits, fiber optics, photonics, and asynchronous transfer mode (ATM) communications.[2] The need for broadband applications will move communications networks toward ATM broadband technologies, but these technologies will be introduced in stages over a period of time. Multiple factors will lead to an evolutionary approach to the deployment of broadband technology, including:

- *Applications evolution*. The applications for BISDN will continue to evolve. Some of these applications, which are now beginning to emerge, include high-speed interconnection of local-area network (LAN)-based computing networks, video conferencing, and entertainment services, such as video on demand. But BISDN can provide such a wide range of applications and services that the specific drivers for widespread broadband deployment cannot yet be singled out. Broadband networks and services must evolve to match the needs of the most prevalent applications as they develop.
- *Technology evolution*. The hardware and software technologies that underlie BISDN and broadband applications will continue to evolve, and communications-network equipment will mature as it incorporates these ongoing technological advances.
- *ATM evolution*. ATM technology itself is relatively new and, as with any new technology, there are various networking and standards issues that remain unsettled.[3,4] As these issues are resolved, broadband

Panel 1. Acronyms, Abbreviations, and Terms

ATM — asynchronous transfer mode
BISDN — Broadband Integrated Services Digital Network
BRI — Basic Rate Interface
CATV — cable television
FDM — frequency-division multiplexing
frame relay — a packet switching protocol and technique
HDTV — high-definition television
ISDN — integrated services digital network
ISP — Integrated Services Platform
LAN — local area network
PVC — Permanent Virtual Circuit
PRI — Primary Rate Interface
SDH — Synchronous Digital Hierarchy
SMDS — Switched Multimegabit Data Service
SONET — Synchronous Optical Network
SVC — Switched Virtual Circuit

communications networks will evolve to accommodate them. The pace of evolution will be influenced by broadband experience, economics, the availability of high-speed transport facilities, and the development of broadband standards.

- *Capital limitations.* Deploying broadband capabilities will require investments in new facilities and equipment, both within the network and on customers' premises. Limitations in available capital and installation rates will result in the introduction of broadband services and applications in stages, as the benefits from broadband applications justify the investment in broadband technologies.

As broadband applications and technologies evolve over time, progress in technology and applications—combined with the importance of economic efficiency and cost-effectiveness in today's competitive communications marketplace—will result in following the evolutionary path to deployment of BISDN communication networks.

Network Evolution Directions

Broadband communications will have multiple facets, ranging from applications and services to network capabilities and architecture. The combination of applications and services[1] will set the direction for the future of network capabilities. In turn, the combination of network capabilities[3] and market penetration of broadband services will drive the advances in network architecture.

Today's embedded base of communications equipment, along with some of the current network modernization initiatives, form the starting point for the shift to broadband. Even before ATM services are offered in a particular region, the introduction of early broadband technologies into the network prepares the way for ATM technology. This represents the ***broadband introduction stage*** of network evolution, and will include such capabilities as frame relay (an update of X.25 packet switching), Switched Multimegabit Data Service (SMDS), and Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) transport.

The next step in the deployment of broadband ATM services will be the ***ATM overlay stage***. In this stage, new ATM equipment will be deployed as overlay networks, adding new broadband capabilities to the network base. These overlays will grow in concert with the growth of broadband applications and services.

As market penetration and service sophistication increase, the network will enter the ***ATM integration and consolidation stage***. In this stage, the broadband overlays will become more and more integrated with the narrowband components of the network, providing integrated broadband and narrowband capabilities.

These integrated broadband networks will continue to grow and evolve toward the ***ATM long-term target stage***. This stage will be characterized by a unified network architecture that takes full advantage of the communication flexibility provided by ATM technology.

Broadband Introduction Stage

Many network operators have been making changes to improve the capabilities and infrastructure of their current communications networks. These changes are targeted at permitting the deployment of new packet-based services, such as SMDS and frame relay, as well as improving the quality and responsiveness of today's services. Some of the objectives of these changes include increasing network reliability, improving response times to new service requests, and reducing operating costs. While these network modifications are not directly targeted at preparing for ATM services, they can be implemented in a way that will improve the ability of the service provider to offer future ATM services.

One key aspect of network evolution is the modernization of the transport network. Much of the new transport equipment being installed today is based on the Synchronous Digital Hierarchy (SDH), or the corresponding SONET. The installation of SONET/SDH transmission systems has many benefits for the overall efficiency, responsiveness, and reliability of the entire network infrastructure.[5] While these benefits alone can justify deployment of SONET/SDH, there is another benefit to this network modernization path. SONET/SDH is the most effective transport protocol for BISDN and ATM. Thus, the conversion to a network using a SONET/SDH infrastructure will facilitate the deployment of ATM technology, perhaps even defining the allowable pace of ATM service expansion.

Another aspect of network modernization is the deployment of frame-relay and SMDS services through a network overlay. The immediate objective of this deployment is to provide a new service for customers' data-networking applications. Deployment of frame relay and SMDS has the added benefit of facilitating the evolution to broadband ATM services. These services give the network operator experience with data networking technologies, which target the same markets and applications as early ATM services. For even greater benefits, network operators can provide these services from equipment that is ATM compatible or from equipment based on ATM technology. This provides experience with high-speed cell relay technology, while allowing migration to future ATM services.

ATM Overlay Stage

The *ATM overlay stage* begins with the initial deployment of equipment to provide direct ATM services to end-users. Network operators and their customers already have an embedded base of equipment that utilizes available services to meet specific applications. But some applications are not fully met by existing services.[1] Examples of business applications include very-high-speed LAN interworking, high-resolution image transfers, and interactive multimedia communications. Examples of residential applications include advanced entertainment services, which are only now becoming technologically feasible. These include adaptable, 500-channel cable systems and user-controllable video-on-demand services (see Panel 2).

Initial uses of ATM services, in both business and residential environments, will be to meet the needs of these new applications by exceeding the capabilities of existing alternatives. As a result, the initial ATM capabilities deployed by network operators will complement the existing set of services. The first ATM capabilities will consist of provisioned, connection-oriented ATM virtual-circuit services with typical access rates of 45 Mbits/s to 155 Mbits/s. Other rates—both lower and higher—may also appear as the range of applications spreads. Over time, the market penetration, complexity, and features of ATM services will grow as network operators and end-users gain experience with ATM technology.

An ATM overlay network will form the basis of the network architecture for initial Permanent Virtual Circuit (PVC) ATM service offerings. In this approach, the equipment to offer ATM-based services is added to the network almost as if it were a new subnetwork, sharing transmission infrastructure resources, but remaining separate from equipment for other applications, such as switched voice services. The overlay network approach is the most efficient for initial deployment and early growth of ATM services. It allows network operators to deploy equipment gradually as end-user demand for ATM services grows, keeping equipment investments tied to service revenues. This approach also enables network operators to gain experience gradually in this new market by building an overlay network tailored to the evolving service needs of ATM customers.

The overlay network approach offers additional benefits to the network operator. In the initial deployment and early growth stages of the market, the demand for ATM services will represent a relatively small proportion of the overall services provided by network operators. During this period, the overlay approach facilitates the development of ATM expertise by concentrating ATM operations experience in a small portion of the network operator's staff. This core of experience will help the network operator make the right decisions in the critical introduction and early growth phases of the market. And later, this core of experience will prove to be an essential "springboard" for supporting the ATM market as it grows larger.

In later phases of the ATM overlay stage, the network will need to offer additional ATM services, including Switched Virtual Circuit (SVC) connections. SVC capabilities greatly facilitate some applications, such as

Panel 2. Compressed Digital Video in Cable Television

The emergence of digital video-compression technology is one of the driving forces behind a wide range of new applications, including multimedia, high-definition television (HDTV), and advanced residential video-entertainment systems. Advanced residential-entertainment applications, such as 500-channel cable television (CATV) systems or interactive video-on-demand systems, require carrying multiple, compressed, digital video channels of various sizes in a single digital bit stream. ATM technology provides an excellent match to this service demand. As an example, consider the approach used to expand vastly the number of television programs carried by a CATV system.

The bandwidth of coaxial cable in a CATV system is divided into multiple 6-MHz analog channels by means of frequency-division multiplexing (FDM). In a normal analog cable system, each of these FDM channels carries a separate analog television signal, and a set-top box is used to tune to one of these channels. Digital technology can be used to increase the number of television channels that can be carried over each of the FDM channels in this system. Instead of placing an analog television signal in the FDM channel, radio-frequency modems are used to transmit a high-speed digital signal in its place. For example, modems using 64 quadrature amplitude modulation can provide a digital signal of approximately 30 Mbits/s in one 6-MHz FDM channel.

Using video-compression techniques now being standardized by the Motion Picture Experts Group, video signals can be encoded at rates ranging from 1.5 Mbits/s to 8 Mbits/s, depending on the amount of motion, and whether the source material was originally recorded on film, or recorded by a video camera. To complete the channel-expansion system, a flexible multiplexing structure is needed to place multiple, encoded video signals of varying rates into the 30-Mbits/s digital data stream, which was derived from a single 6-MHz analog FDM cable-channel slot. ATM's ability to carry multiple channels of arbitrary rates in a single bit stream makes it an excellent technology for this application. For example, one 30-Mbits/s stream could carry ten 3-Mbits/s channels, while another 30-Mbits/s stream could carry four 1.5-Mbits/s channels, two 3-Mbits/s channels, and two 8-Mbits/s channels. These multiple configurations would be less flexible and more difficult to manage with conventional circuit multiplexing techniques.

Applying these same techniques to multiple 6-MHz FDM channels can greatly expand the total number of channels that can be carried by a CATV distribution system. For example, one of many possible configurations would be to apply this technique to all channels of a cable system with 50 6-MHz channels, giving the system the ability to carry 500 digital video channels (assuming an average rate of 3 Mbits/s per digital channel). With many other variations possible, these techniques have the potential for providing a wide range of new entertainment and educational services.

residential video-on-demand services with a large number of competing video service providers, or general-purpose, intercompany video and multimedia calls. SVC services will be introduced as a service development of previously installed, connection-oriented PVC services, including the evolution to new multimedia services. As a result, network operators will need to follow an evolutionary path that adds switched services to the already existing provisioned-service capabilities.

Throughout this stage, there will be two critical links between the ATM overlay network and the rest of the network. The first link is the SONET/SDH transport infrastructure. This will support ATM services, as well as all the other services provided by network operators, as discussed earlier. The second link will be interworking devices that permit connections between selected ATM services and pre-ATM standard network services. For example, a business customer with a private branch exchange might carry voice traffic on an ISDN Primary Rate Interface (PRI) facility, or multiple Basic Rate Interface (BRI) facilities, which enter the network through an integrated ATM access line. Within the network, an interworking device will convert the BRI or PRI information streams back into circuit interfaces, and forward them to an ISDN switch for normal ISDN service termination. Similarly, SMDS cells can easily be translated to ATM cells for delivery through the ATM network to either SMDS customers, or to ATM customers with integrated access services.

ATM Integration and Consolidation Stage

The evolution of broadband applications will lead to broader market penetration, increasing traffic, and a demand for more sophisticated services.[1] Business customers will increasingly use video and interactive multimedia applications. ATM will become a native networking protocol on business premises, and business customers will move to consolidate their separate application networks into a single, more manageable ATM-based network. The sophistication of switched ATM services will increase until they rival—and potentially surpass—circuit-oriented voice services. Residential customers will expand from the base built by entertainment applications into such areas as distance learning, telecommuting, and multimedia database access.[6,7]

As the volume of broadband applications and services grows, the deployment of ATM technology in the network will become ubiquitous, and the demand for interworking between broadband services and other services will continue to grow. For example, a typical business teleconference may consist of three ATM video, voice, and data locations, one narrowband ISDN voice and data location, and two links to mobile cellular phones. In short, network operators will find that ATM services have become a key part of their business.

These changes will be reflected in the evolution of the broadband network. As ATM becomes a larger part of the network, and as it grows more entwined with other services, network economics will dictate a move to combined broadband and narrowband equipment to provide advanced services. The ATM overlay network will begin to consolidate with the rest of the network. This will facilitate widespread deployment of ATM services and extensive interworking with other services. As ATM becomes an integral part of the network itself, ATM expertise will spread across more of the network provider's organization. The ATM network infrastructure may begin to be used as the basis for circuit services, with the primary interoffice trunks using an ATM multiplexing structure over SONET/SDH clear channel links.

As ATM services begin to merge with circuit-based services, network equipment will need to support this evolution. Stand-alone ATM equipment with interworking devices, which was appropriate for the ATM overlay phase, will prove to be inefficient at handling the increased penetration rates of ATM services and service interworking. For example, using separate interworking devices to interconnect ATM-based and circuit-based equipment results in extra signaling messages, as well as extra line cards and interfaces in the signal path. With low penetration rates and small amounts of interworking, the resulting inefficiencies are small, especially when compared to the benefits gained by concentrating ATM operations experience in a small staff. As traffic and interworking increase, maintaining an efficient network design and effective network operations will require an appropriate level of integration between ATM equipment and circuit equipment.

ATM Long-Term Target Stage

The logical extrapolation of these evolutionary phases leads to the vision of an ATM core network, serving a wide range of sophisticated cell relay and circuit applications. Forecasts that extend this far are, of necessity, somewhat indistinct. Still, some of the characteristics of this phase's network architecture can be derived from the properties of ATM technology, as well as from changes needed to expand and enhance early ATM-based services.

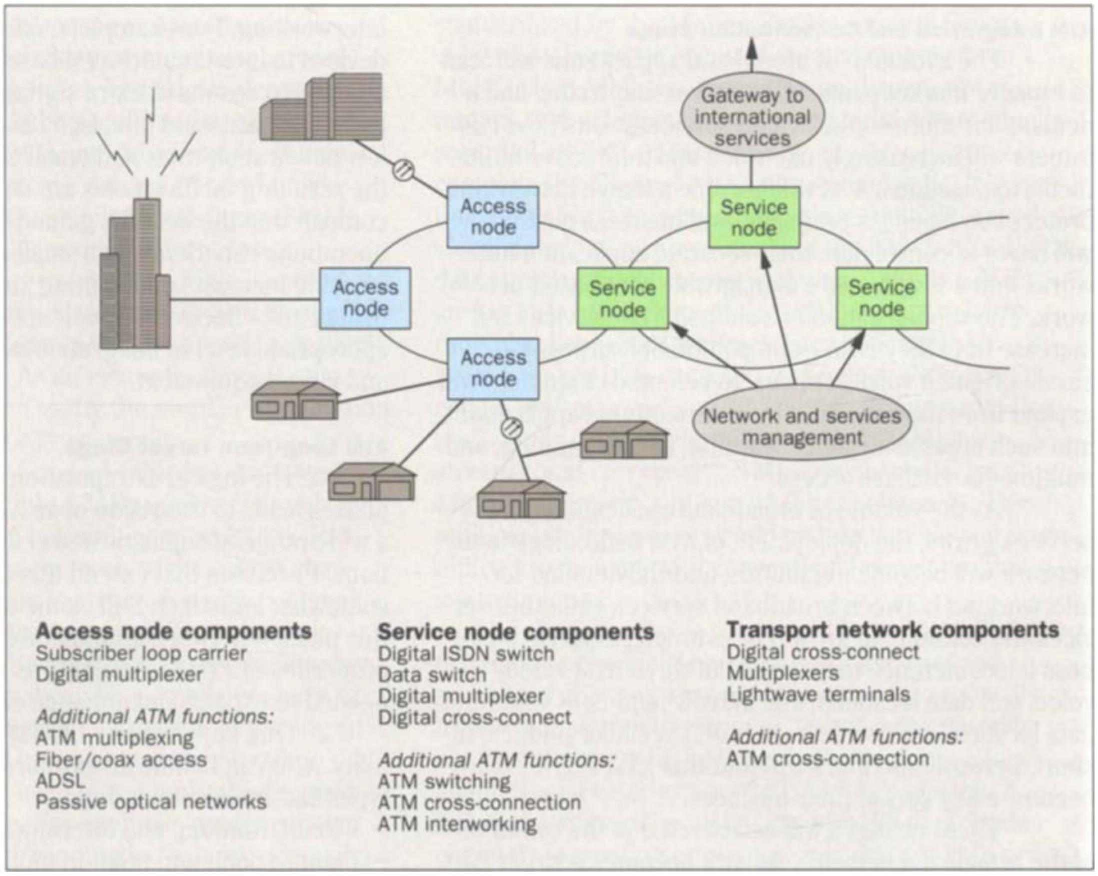
One key property of ATM technology is its flexibility. ATM can handle an extraordinary range of service types and speeds, including:

- Circuit, random, and intermittent traffic,
- Point-to-point and point-to-multipoint connections, and
- Speeds ranging from kilobits per second to gigabits per second and beyond.

This flexibility confirms the vision of an ATM core network supporting a wide variety of applications and services, including integrated combinations of services, which are now based on separate technologies.

Another key property of ATM is its extraordinary range of switching resolution, exemplified by its ability to switch arbitrarily small subchannels efficiently. An ATM switch can easily switch virtual circuits with both very large and very small bandwidths on the same line. This is in contrast to circuit-switching technologies, where the ability to switch small channels significantly increases the cost of switching large channels. (To switch both small and large channels in a time-division circuit switch, the large channels must be switched as a collection of small channels.) This property of circuit switches is one of the fundamental driving forces behind the separation of circuit-switching fabrics for telephony (64-Kbits/s

Figure 1. The AT&T Network Systems Service Net-2000 architecture remains consistent as network components shift from current functions to broadband ATM functions.



resolution) from cross-connect fabrics (1.5-Mbits/s or 45-Mbits/s resolution) in today's networks. ATM technology eliminates the need for this separation; network architectures can combine switching, multiplexing, and cross-connect functions into the same device.

Combined with an ATM-fabric technology, which can be scaled from small to large sizes,[8] these properties point to an *ATM long-term target stage* network architecture. In such an architecture, ATM nodes would combine multiplexing, cross-connect, and switching functions into a single, unified networking approach. The resulting transport, switching, and operations efficiency, as well as service flexibility, could provide the sophisticated, cost-effective communications services needed to realize the promise of the information age.

Evolvable Equipment for Evolvable Networks

The evolution of broadband capabilities will require corresponding changes in equipment. If equipment is not designed to take this change into account, network providers might be forced to replace much more equipment than would otherwise be necessary as the demands on their network change. In order to provide a cost-effective alternative to this expensive replacement path, the Network Systems division of AT&T is basing its family of Service Net-2000 ATM products on a common, evolvable, Integrated Services Platform (ISP).[3]

Service Net-2000 network architecture establishes the basic network structure for the evolution to broadband capabilities. Service Net-2000 is built around a SONET/SDH transport infrastructure, which provides the foundation for future growth. As the network evolves toward broadband and ATM, new capabilities are added to network nodes, but the fundamental network architecture remains consistent (see Figure 1). A network based on the Service Net-2000 structure provides benefits for current services, and also establishes a starting point that facilitates future evolution.

The Service Net-2000 architecture includes the AT&T BNS-2000 cell switch, which provides both frame-relay and SMDS services in the *broadband introduction stage*. BNS-2000 is based on ATM technology, and it has been designed to continue serving a key network role as the evolution of broadband services progresses.

When direct ATM services are needed, the GCNS-2000 ATM system provides the initial backbone for an ATM overlay network. GCNS-2000 can be deployed as an evolution of a previously deployed BNS-2000 network. When a network operator uses the AT&T BNS-2000 for frame-relay and SMDS services, the addition of the GCNS-2000 and AAN-2000 access nodes for ATM services results in a single overlay network. This overlay provides the full range of these new network services. In a typical configuration, the BNS-2000 continues to provide frame-relay and SMDS services. The GCNS-2000 nodes provide direct ATM services, and also serve as the backbone for the BNS-2000 nodes. The GCNS-2000 and AAN-2000 are also key components of a network for advanced residential entertainment services.

GCNS-2000 is based on the initial version of the ISP. This gives the GCNS-2000 connections to the future as well as to the past. As the ATM overlay stage progresses, SVCs must be provided as an extension to the previously existing provisioned services. These services will be provided through ATM switches with full SVC and high-reliability call processing capabilities, such as the AT&T BSS-2000 Broadband Switching System. The AT&T platform-based approach takes this into account by building the future BSS-2000 from the same set of ISP components as the GCNS-2000, permitting an effective evolution from the GCNS-2000 to the BSS-2000.

Another network component that may be introduced into the architecture during the ATM overlay stage is a high-capacity ATM cross-connect system. An example of this is the AT&T AXC-2000 system, which can provide the high-capacity cross-connect capabilities needed to support the infrastructure growth triggered, in part, by the growth in broadband applications. And, because the AXC-2000 system is based on the same set of ISP components described earlier, it also prepares the way for future stages.

During the ATM integration and consolidation stage, ATM equipment needs to start integrating with existing network equipment. Current AT&T ATM equipment has already been designed with this step in mind. The new ATM modules that make up the ISP are designed for incorporation into stand-alone products, as well as into integrated products. Furthermore, the hardware and software for processors, operations, call processing, and signaling components are designed to be common across all of the ATM products. These key product components are all based on modules from conventional AT&T networking products, such as the 5ESS®-2000 switch. As a result, the stand-alone network elements deployed during the overlay stage are ready to be integrated, when the market need arises, with the circuit-based components. This preserves the value of network operators' previous investments in both ATM equipment, such as the GCNS-2000, and circuit-based equipment, such as the 5ESS-2000 switch.

The ATM long-term target stage provides the ultimate driving force behind the AT&T ISP approach to ATM products. Recognition of the eventual integration of traditional switching and transmission functions has led to the design of a common set of platform elements. These elements are used across all AT&T Network Systems broadband ATM products. The elements combine into application packages that meet the reality of today's network needs and applications, while assuring a smooth path to the fully integrated ATM networks of the future.

Summary

New applications and services provided by BISDN and ATM technology will lead to revolutionary new services. The most effective path for network operators to offer these exciting new services is through a multiphased evolution of their current networks, progressing from overlay to integrated networks, and finally to a target-network structure. AT&T ATM networking equipment has been designed from the outset to accommodate these stages of network evolution by following an efficient and cost-effective path of its own. This path is specifically designed to protect network-operator investments in both AT&T ATM-based products, such as the GCNS-2000, and AT&T circuit-based products, such as the 5ESS-2000 switch.

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