White Paper

Gigabit Ethernet and ATM

A Technology Perspective

Bursty, high-bandwidth applications are driving the need for similarly high-bandwidth campus backbone infrastructures. Today, there are two choices for the high-speed campus backbone: ATM or Gigabit Ethernet. For many reasons, business and technical, Gigabit Ethernet is selected as the technology of choice. This paper briefly presents, from a technical perspective, why Gigabit Ethernet is favored for most enterprise LANs.

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In the past, most campuses use shared-media backbones — such as 16/32 Mbps Token-Ring and 100 Mbps FDDI — that are only slightly higher in speed than the LANs and end stations they interconnect. This has caused severe congestion in the campus backbones when these backbones interconnect a number of access LANs.

A high capacity, high performance, and highly resilient backbone is needed-one that can be scaled as end stations grow in number or demand more bandwidth. Also needed is the ability to support differentiated service levels (Quality of Service or QoS), so that high priority, time-sensitive, and mission-critical applications can share the same network infrastructure as those that require only best-effort service.

Until recently, Asynchronous Transfer Mode (ATM) was the only switching technology able to deliver high capacity and scalable bandwidth, with the promise of end-to-end Quality of Service. ATM offered seamless integration from the desktop, across the campus, and over the metropolitan/wide area network. It was thought that users would massively deploy connection-oriented, cell-based ATM to the desktop to enable new native ATM applications to leverage ATM's rich functionality (such as QoS). However, this did not come to pass. The Internet Protocol (IP), aided and abetted by the exploding growth of the Internet, rode roughshod over ATM deployment and marched relentlessly to world dominance.

When no other gigabit technology existed, ATM provided much needed relief as a high bandwidth backbone to interconnect numerous connectionless, frame-based campus LANs. But with the massive proliferation of IP applications, new native ATM applications did not appear. Even 25 Mbps and 155 Mbps ATM to the desktop did not appeal to the vast majority of users, because of their complexity, small bandwidth increase, and high costs when compared with the very simple and inexpensive 100 Mbps Fast Ethernet.

On the other hand, Fast Ethernet, with its auto-sensing, auto-negotiation capabilities, integrated seamlessly with the millions of installed 10 Mbps Ethernet clients and servers. Although relatively simple and elegant in concept, the actual implementation of ATM is complicated by a multitude of protocol standards and specifications (for instance, LAN Emulation, Private Network Node Interface, and Multiprotocol over ATM). This additional complexity is required in order to adapt ATM to the connectionless, frame-based world of the campus LAN.

Meanwhile, the very successful Fast Ethernet experience spurred the development of Gigabit Ethernet standards. Within two years of their conception (June 1996), Gigabit Ethernet over fiber (1000BASE-X) and copper (1000BASE-T) standards were approved, developed, and in operation. Gigabit Ethernet not only provides a massive scaling of bandwidth to 1000 Mbps (1 Gbps), but also shares a natural affinity with the vast installed base of Ethernet and Fast Ethernet campus LANs running IP applications.

Enhanced by additional protocols already common to Ethernet (such as IEEE 802.1Q Virtual LAN tagging, IEEE 802.1p prioritization, IETF Differentiated Services, and Common Open Policy Services), Gigabit Ethernet is now able to provide the differential qualities of service that previously only ATM could provide. One key difference with Gigabit Ethernet is that additional functionality can be incrementally added in a non-disruptive way as required, compared with the rather revolutionary approach of ATM. Further developments in bandwidth and distance scalability will see 10 Gbps Ethernet over local (10G-BASE-T) and wide area (10G-BASE-WX) networks. Thus, the promise of end-to-end seamless integration, once only the province of ATM, will be possible with Ethernet and all its derivations.

Today, there are two technology choices for the high-speed campus backbone: ATM and Gigabit Ethernet. While both seek to provide high bandwidth and differentiated QoS within enterprise LANs, these are very different technologies.

Which is a "better" technology is no longer a subject of heated industry debate — Gigabit Ethernet is an appropriate choice for most campus backbones. Many business users have chosen Gigabit Ethernet as the backbone technology for their campus networks. An Infonetics Research survey (March 1999) records that 91 percent of respondents believe that Gigabit Ethernet is suitable for LAN backbone connection, compared with 66 percent for ATM. ATM continues to be a good option where its unique, rich, and complex functionality can be exploited by its deployment, most commonly in metropolitan and wide area networks.

Whether Gigabit Ethernet or ATM is deployed as the campus backbone technology of choice, the ultimate decision is one of economics and sound business sense, rather than pure technical considerations.

The next two sections provide a brief description of each technology.

Asynchronous Transfer Mode (ATM)

Asynchronous Transfer Mode (ATM) has been used as a campus backbone technology since its introduction in the early 1990s. ATM is specifically designed to transport multiple traffic types — data, voice and video, real-time or non-real-time — with inherent QoS for each traffic category.

To enable this and other capabilities, additional functions and protocols are added to the basic ATM technology. Private Network Node Interface (PNNI) provides OSPF-like functions to signal and route QoS requests through a hierarchical ATM network. Multiprotocol over ATM (MPOA) allows the establishment of short-cut routes between communicating end systems on different subnets, bypassing the performance bottlenecks of intervening routers. There have been and continue to be enhancements in the areas of physical connectivity, bandwidth scalability, signaling, routing and addressing, security, and management.

While rich in features, this functionality has come with a fairly heavy price tag in complexity and cost. To provide backbone connectivity for today's legacy access networks, ATM — a connection-oriented technology — has to emulate capabilities inherently available in the predominantly connectionless Ethernet LANs, including broadcast, multicast, and unicast transmissions. ATM must also manipulate the predominantly frame-based traffic on these LANs, segmenting all frames into cells prior to transport, and then reassembling cells into frames prior to final delivery. Many of the complexity and interoperability issues are the result of this LAN Emulation, as well as the need to provide resiliency in these emulated LANs. There are many components required to make this workable; these include the LAN Emulation Configuration Server(s), LAN Emulation Servers, Broadcast and Unknown Servers, Selective Multicast Servers, Server Cache Synchronization Protocol, LAN Emulation User Network Interface, LAN Emulation Network-Network Interface, and a multitude of additional protocols, signaling controls, and connections (point-to-point, point-to-multipoint, multipoint-to-point, and multipoint-to-multipoint).

Until recently, ATM was the only technology able to promise the benefits of QoS from the desktop, across the LAN and campus, and right across the world. However, the deployment of ATM to the desktop, or even in the campus backbone LANs, has not been as widespread as predicted. Nor have there been many native applications available or able to benefit from the inherent QoS capabilities provided by an end-to-end ATM solution. Thus, the benefits of end-to-end QoS have been more imagined than realized.

Gigabit Ethernet as the campus backbone technology of choice is now surpassing ATM. This is due to the complexity and the much higher pricing of ATM components such as network interface cards, switches, system software, management software, troubleshooting tools, and staff skill sets. There are also interoperability issues, and a lack of suitable exploiters of ATM technology.

Gigabit Ethernet

Today, Gigabit Ethernet is a very viable and attractive solution as a campus backbone LAN infrastructure. Although relatively new, Gigabit Ethernet is derived from a simple technology, and a large and well-tested Ethernet and Fast Ethernet installed base. Since its introduction, Gigabit Ethernet has been vigorously adopted as a campus backbone technology, with possible use as a high-capacity connection for high-performance servers and workstations to the backbone switches.

The main reason for this success is that Gigabit Ethernet provides the functionality that meets today's immediate needs at an affordable price, without undue complexity and cost. Gigabit Ethernet is complemented by a superset of functions and capabilities that can be added as needed, with the promise of further functional enhancements and bandwidth scalability (for example, IEEE 802.3ad Link Aggregation, and 10 Gbps Ethernet) in the near future. Thus, Gigabit Ethernet provides a simple scaling-up in bandwidth from the 10/100 Mbps Ethernet and Fast Ethernet LANs that are already massively deployed.

Simply put, Gigabit Ethernet is Ethernet, but 100 times faster!

Since Gigabit Ethernet uses the same frame format as today's legacy installed LANs, it does not need the segmentation and reassembly function that ATM requires to provide cell-to-frame and frame-to-cell transitions. As a connectionless technology, Gigabit Ethernet does not require the added complexity of signaling and control protocols and connections that ATM requires. Finally, because QoS-capable desktops are not readily available, Gigabit Ethernet is no less deficient in providing QoS. New methods have been developed to incrementally deliver QoS and other needed capabilities that lend themselves to much more pragmatic and cost-effective adoption and deployment.

To complement the high-bandwidth capacity of Gigabit Ethernet as a campus backbone technology, higher-layer functions and protocols are available, or are being defined by standards bodies such as the Institute of Electrical and Electronics Engineers (IEEE) and the Internet

Engineering Task Force (IETF). Many of these capabilities recognize the desire for convergence upon the ubiquitous Internet Protocol (IP). IP applications and transport protocols are being enhanced or developed to address the needs of high speed, multimedia networking that benefit Gigabit Ethernet. The Differentiated Services (DiffServ) standard provides differential QoS that can be deployed from the Ethernet and Fast Ethernet desktops across the Gigabit Ethernet campus backbones. The use of IEEE 802.1Q VLAN Tagging and 802.1p User Priority settings allow different traffic types to be accorded the appropriate forwarding priority and service.

When combined with policy-enabled networks, DiffServ provides powerful, secure, and flexible QoS capabilities for Gigabit Ethernet campus LANs by using protocols such as Common Open Policy Services (COPS), Lightweight Directory Access Protocol (LDAP), Dynamic Host Configuration Protocol (DHCP), and Domain Name System (DNS). Further developments, such as Resource Reservation Protocol, multicasting, real-time multimedia, audio and video transport, and IP telephony, will add functionality to a Gigabit Ethernet campus, using a gradual and manageable approach when users need these functions.

There are major technical differences between Gigabit Ethernet and ATM. A companion white paper, *Gigabit Ethernet and ATM: A Business Perspective*, provides a comparative view of the two technologies from a managerial perspective.

Technological Aspects

Aspects of a technology are important because they must meet some minimum requirements to be acceptable to users. Value-added capabilities will be used where desirable or affordable. If these additional capabilities are not used, whether for reasons of complexity or lack of “exploiters” of those capabilities, then users are paying for them for no reason (a common example is that many of the advanced features of a VCR are rarely exploited by most users). If features are too expensive, relative to the benefits that can be derived, then the technology is not likely to find widespread acceptance. Technology choices are ultimately business decisions.

The fundamental requirements for LAN campus networks are very much different from those of the WAN. It is thus necessary to identify the minimum requirements of a network, as well as the value-added capabilities that are “nice to have.”

In the sections that follow, various terms are used with the following meanings:

- “Ethernet” is used to refer to all current variations of the Ethernet technology: traditional 10 Mbps Ethernet, 100 Mbps Fast Ethernet, and 1000 Mbps Gigabit Ethernet.
- “Frame” and “packet” are used interchangeably, although this is not absolutely correct from a technical purist point of view.

Quality of Service

Until recently, Quality of Service (QoS) was a key differentiator between ATM and Gigabit Ethernet. ATM was the only technology that promised QoS for voice, video, and data traffic. The Internet Engineering Task Force (IETF) and various vendors have since developed protocol specifications and standards that enhance the frame-switched world with QoS and QoS-like capabilities. These efforts are accelerating and, in certain cases, have evolved for use in both the ATM and frame-based worlds.

The difference between ATM and Gigabit Ethernet in the delivery of QoS is that ATM is connection-oriented, whereas Ethernet is connectionless. With ATM, QoS is requested via signaling before communication can begin. The connection is only accepted if it is without detriment to existing connections (especially for reserved bandwidth applications). Network resources are then reserved as required, and the accepted QoS service is guaranteed to be delivered “end-to-end.” By contrast, QoS for Ethernet is mainly delivered hop-by-hop, with standards in progress for signaling, connection admission control, and resource reservation.

ATM QoS

From its inception, ATM has been designed with QoS for voice, video and data applications. Each of these has different timing bounds, delay, delay variation sensitivities (jitter), and bandwidth requirements.

In ATM, QoS has very specific meanings that are the subject of ATM Forum and other standards specifications. Defined at the ATM layer (OSI Layer 2), the service architecture provides five categories of services that relate traffic characteristics and QoS requirements to network behavior:

- **CBR:** Constant Bit Rate, for applications that are sensitive to delay and delay variations, and need a fixed but continuously available amount of bandwidth for the duration of a connection. The amount of bandwidth required is characterized by the Peak Cell Rate. An example of this is circuit emulation.
- **rt-VBR:** Real-time Variable Bit Rate, for applications that need varying amounts of bandwidth with tightly regulated delay and delay variation, and whose traffic is bursty in nature. The amount of bandwidth is characterized by the Peak Cell Rate and Sustainable Cell Rate; burstiness is defined by the Maximum Burst Size. Example applications include real-time voice and video conferencing.
- **nrt-VBR:** Non-real-time Variable Bit Rate, for applications with similar needs as rt-VBR, requiring low cell loss, varying amounts of bandwidth, and with no critical delay and delay variation requirements. Example applications include non-real-time voice and video.
- **ABR:** Available Bit Rate, for applications requiring low cell loss, guaranteed minimum and maximum bandwidths, and with no critical delay or delay variation requirements. The minimum and maximum bandwidths are characterized by the Minimum Cell Rate and Peak Cell Rate respectively.
- **UBR:** Unspecified Bit Rate, for applications that can use the network on a best-effort basis, with no service guarantees for cell loss, delay and delay variations. Example applications are e-mail and file transfer.

Depending on the QoS requested, ATM provides a specific level of service. At one extreme, ATM provides a best-effort service for the lowest QoS (UBR), with no bandwidth reserved for the traffic. At the other extreme, ATM provides a guaranteed level of service for the higher QoS (that is, CBR and VBR) traffic. Between these extremes, ABR is able to use whatever bandwidth is available with proper traffic management and controls.

Because ATM is connection-oriented, requests for a particular QoS, admission control, and resource allocation are an integral part of the call signaling and connection setup process. The call is admitted and the connection established between communicating end systems only if the resources exist to meet a requested QoS, without jeopardizing services to already established connections. Once established, traffic from the end systems are policed and shaped for conformance with the agreed traffic contract. Flow and congestion are managed in order to ensure the proper QoS delivery.

Gigabit Ethernet QoS

One simple strategy for solving the backbone congestion problem is to over-provision bandwidth in the backbone. This is especially attractive if the initial investment is relatively inexpensive and the ongoing maintenance is virtually ‘costless’ during its operational life.

Gigabit Ethernet is an enabler of just such a strategy in the LAN. Gigabit Ethernet, and soon 10-Gigabit Ethernet, will provide all the bandwidth that is ever needed for many application types, eliminating the need for complex QoS schemes in many environments. However, some applications are bursty in nature and will consume all available bandwidth, to the detriment of other applications that may have time-critical requirements. The solution is to provide a priority mechanism that ensures bandwidth, buffer space, and processor power are allocated to the different types of traffic.

With Gigabit Ethernet, QoS has a broader interpretation than with ATM. But it is just as able — albeit with different mechanisms — to meet the requirements of voice, video and data applications.

In general, Ethernet QoS is delivered at a high layer of the OSI model. Frames are typically classified individually by a filtering scheme. Different priorities are assigned to each class of traffic, either explicitly by means of priority bit settings in the frame header, or implicitly in the priority level of the queue or VLAN to which they are assigned. Resources are then provided in a preferentially prioritized (unequal or unfair) way to service the queues. In this manner, QoS is delivered by providing differential services to the differentiated traffic through this mechanism of classification, priority setting, prioritized queue assignment, and prioritized queue servicing. (For further information on QoS in Frame-Switched Networks, see WP3510-A/5-99, a Nortel Networks white paper available on the Web at www.nortelnetworks.com.)

Differentiated Services

Chief among the mechanisms available for Ethernet QoS is Differentiated Services (DiffServ). The IETF DiffServ Working Group proposed DiffServ as a simple means to provide scalable differentiated services in an IP network. DiffServ redefines the IP Precedence/Type of Service field in the IPv4 header and the Traffic Class field in the IPv6 header as the new DS Field (see Figure 1). An IP packet's DS Field is then marked with a specific bit pattern, so the packet will receive the desired differentiated service (that is, the desired forwarding priority), also known as per-hop behavior (PHB), at each network node along the path from source to destination.

To provide a common use and interpretation of the possible DSCP bit patterns, RFC 2474 and RFC 2475 define the architecture, format, and general use of these bits within the DSCP Field.

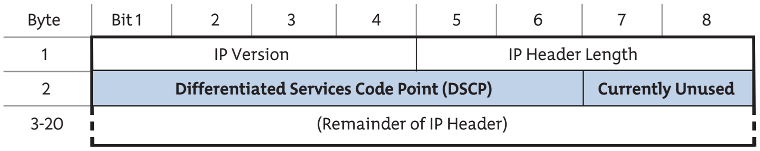
These definitions are required in order to guarantee the consistency of expected service when a packet crosses from one network's administrative domain to another, or for multi-vendor interoperability. The Working Group also standardized the following specific per-hop behaviors and recommended bit patterns (also known as code points or DSCPs) of the DS Field for each PHB:

- Expedited Forwarding (EF-PHB), sometimes described as Premium Service, uses a DSCP of b'101110'. The EF-PHB provides the equivalent service of a low loss, low latency, low jitter, assured bandwidth point-to-point connection (a virtual leased line). EF-PHB frames are assigned to a high priority queue where the arrival rate of frames at a node is shaped to be always less than the configured departure rate at that node.
- Assured Forwarding (AF-PHB) uses 12 DSCPs to identify four forwarding classes, each with three levels of drop precedence (12 PHBs). Frames are assigned by the user to the different classes and drop precedence depending on the desired degree of assured — but not guaranteed — delivery. When allocated resources (buffers and bandwidth) are insufficient to meet demand, frames with the high drop precedence are discarded first. If resources are still restricted, medium precedence frames are discarded next, and low precedence frames are dropped only in the most extreme lack of resource conditions.
- A recommended Default PHB with a DSCP of b'000000' (six zeros) that equates to today's best-effort service when no explicit DS marking exists.

In essence, DiffServ operates as follows:

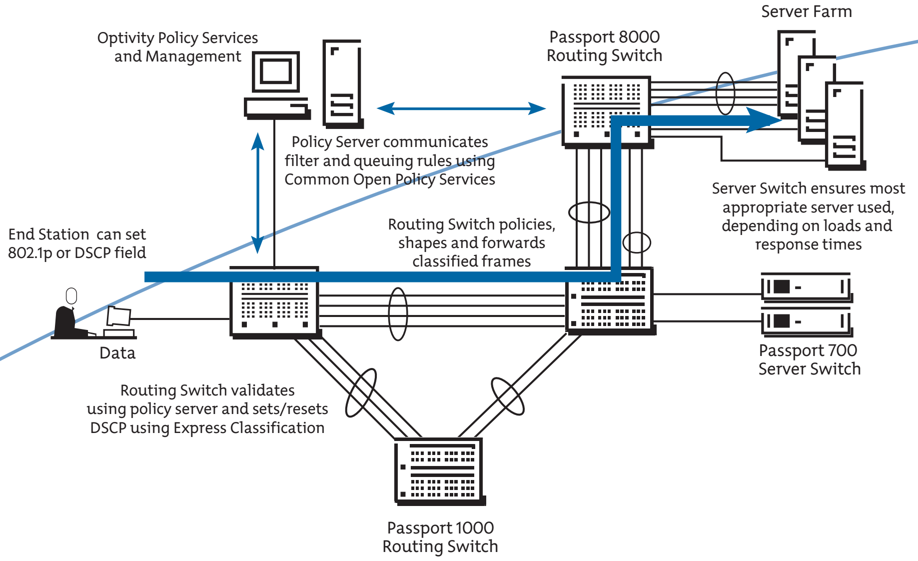
- Each frame entering a network is analyzed and classified to determine the appropriate service desired by the application.
- Once classified, the frame is marked in the DS field with the assigned DSCP value to indicate the appropriate PHB. Within the core of the network, frames are forwarded according to the PHB indicated.
- Analysis, classification, marking, policing, and shaping operations need only be carried out at the host or network boundary node. Intervening nodes need only examine the short fixed length DS Field to determine the appropriate PHB to be given to the frame. This architecture is the key to DiffServ scalability. In contrast, other models such as RSVP/Integrated Services are severely limited by signaling, application flow, and forwarding state maintenance at each and every node along the path.

Figure 1: Differentiated Services Field (RFC 2474).



<table>
<tr><th>Byte</th><th>Bit 1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td>1</td><td colspan="4">IP Version</td><td colspan="4">IP Header Length</td></tr>
<tr><td>2</td><td colspan="6">Differentiated Services Code Point (DSCP)</td><td colspan="2">Currently Unused</td></tr>
<tr><td>3-20</td><td colspan="8">(Remainder of IP Header)</td></tr>
</table>

Figure 2: Passport Campus Solution and Optivity Policy Services.



- Policies govern how frames are marked and traffic conditioned upon entry to the network; they also govern the allocation of network resources to the traffic streams, and how the traffic is forwarded within that network.

DiffServ allows nodes that are not DS-capable, or even DS-aware, to continue to use the network in the same way as they have previously by simply using the Default PHB, which is best-effort forwarding. Thus, without requiring end-to-end deployment, DiffServ provides Gigabit Ethernet with a powerful, yet simple and scalable, means to provide differential QoS services to support various types of application traffic.

Common Open Policy Services

To enable a Policy Based Networking capability, the Common Open Policy Services (COPS) protocol can be used to complement DiffServ-capable devices. COPS provides an architecture and a request-response protocol for communicating admission control requests, policy-based decisions, and policy information between a network policy server and the set of clients it serves.

With Gigabit Ethernet, the switches at the network ingress may act as COPS clients. COPS clients examine frames as they enter the network, communicate with a central COPS server to decide if the traffic should be admitted to the network, and enforce the policies. These policies include any QoS forwarding treatment to be applied during transport. Once this is determined, the DiffServ-capable Gigabit Ethernet switches can mark the frames using the selected DSCP bit pattern, apply the appropriate PHB, and forward the frames to the next node. The next node need only examine the DiffServ markings to apply the appropriate PHB. Thus, frames are forwarded hop-by-hop through a Gigabit Ethernet campus with the desired QoS.

In Nortel Networks' Passport* Campus Solution, COPS will be used by Optivity* Policy Services (COPS server) and the Passport Enterprise and Routing Switches (COPS clients) to communicate QoS policies defined at the policy server to the switches for enforcement (see Figure 2).

Connection-oriented vs. Connectionless

ATM is a connection-oriented protocol. Most enterprise LAN networks are connectionless Ethernet networks, whether Ethernet, Fast Ethernet and Gigabit Ethernet.

Note: Because of Ethernet's predominance, it greatly simplifies the discussion to not refer to the comparatively sparse Token-Ring technology; this avoids complicating the comparison with qualifications for Token-Ring LANs and ELANs, Route Descriptors instead of MAC addresses as LAN destinations, and so forth.

An ATM network may be used as a high-speed backbone to connect Ethernet LAN switches and end stations together. However, a connection-oriented ATM backbone requires ATM Forum LAN Emulation (LANE) protocols to emulate the operation of connectionless legacy LANs. In contrast with simple Gigabit Ethernet backbones, much of the complexity of ATM backbones arises from the need for LANE.

ATM LAN Emulation v1

LANE version 1 was approved in January 1995. Whereas a Gigabit Ethernet backbone is very simple to implement, each ATM emulated LAN (ELAN) needs several logical components and protocols that add to ATM's complexity. These components are:

- LAN Emulation Configuration Server(s) (LECS) to, among other duties, provide configuration data to an end system, and assign it to an ELAN (although the same LECS may serve more than one ELAN).
- Only one LAN Emulation Server (LES) per ELAN to resolve 6-byte LAN MAC addresses to 20-byte ATM addresses and vice versa.

Figure 3: LAN Emulation v1 Connections and Functions.

Connection Name	Uni- or Bi-directional	Point-to-point or Point-to-multipoint	Used for communication
Configuration Direct VCC	Bi-directional	Point-to-point	Between an LECS and an LEC
Control Direct VCC	Bi-directional	Point-to-point	Between an LES and its LECs**
Control Distribute VCC	Uni-directional	Point-to-multipoint	From an LES to its LECs
Multicast Send VCC	Bi-directional	Point-to-point	Between a BUS and an LEC
Multicast Forward VCC	Uni-directional	Point-to-multipoint	From a BUS to its LECs
Data Direct VCC	Bi-directional	Point-to-point	Between an LEC and another LEC

**Note: There is a difference between LECS with an uppercase “S” (meaning LAN Emulation Configuration Server) and LECs with a lowercase “s” meaning LAN Emulation Clients, or more than one LEC) at the end of the acronym.

- Only one Broadcast and Unknown Server (BUS) per ELAN to forward broadcast frames, multicast frames, and frames for destinations whose LAN or ATM address is as yet unknown.
- One or more LAN Emulation Clients (LEC) to represent the end systems. This is further complicated by whether the end system is a LAN switch to which other Ethernet end stations are attached, or whether it is an ATM-directly attached end station. A LAN switch requires a proxy LEC, whereas an ATM-attached end station requires a non-proxy LEC.

Collectively, the LECS, LES, and BUS are known as the LAN Emulation Services. Each LEC (proxy or non-proxy) communicates with the LAN Emulation Services using different virtual channel connections (VCCs) and LAN Emulation User Network Interface (LUNI) protocols. Figure 3 shows the VCCs used in LANE v1.

Some VCCs are mandatory — once established, they must be maintained if the LEC is to participate in the ELAN. Other VCCs are optional — they may or may not be established and, if established, they may or may not be released thereafter. Unintended release of a required VCC may trigger the setup process. In certain circumstances, this can lead to instability in the network.

The most critical components of the LAN Emulation Service are the LES and BUS, without which an ELAN cannot function. Because each ELAN can only be served by a single LES and BUS, these components need to be backed up by other LESs and BUSs to prevent any single point of failure stopping communication between the possibly hundreds or even thousands of end stations attached to an ELAN. In addition, the single LES or BUS represents a potential performance bottleneck.

Thus, it became necessary for the LAN Emulation Service components to be replicated for redundancy and elimination of single points of failures, and distributed for performance.

ATM LAN Emulation v2

To enable communication between the redundant and distributed LAN Emulation Service components, as well as other functional enhancements, LANE v1 was re-specified as LANE v2; it now comprises two separate protocols:

- **LUNI:** LAN Emulation User Network Interface (approved July 1997)
- **LNNI:** LAN Emulation Network-Network Interface (approved February 1999).

LUNI, among other enhancements, added the Selective Multicast Server (SMS), to provide a more efficient means of forwarding multicast traffic, which was previously performed by the BUS. SMS thus offloads much of the multicast processing from the BUS, allowing the BUS to focus more on the forwarding of broadcast traffic and traffic with yet-to-be-resolved LAN destinations.

LNNI provides for the exchange of configuration, status, control coordination, and database synchronization between redundant and distributed components of the LAN Emulation Service.

However, each improvement adds new complexity. Additional protocols are required and additional VCCs need to be established, maintained, and monitored for communication between the new LAN Emulation Service components and LECs. For example, all LESs serving an ELAN communicate control messages to each other through a full mesh of Control Coordinate VCCs. These LESs must also synchronize their LAN-ATM address databases, using the Server Cache Synchronization Protocol (SCSP — RFC 2334), across the Cache Synchronization VCC. Similarly, all BUSs serving an ELAN must be fully connected by a mesh of Multicast Forward VCCs used to forward data.

Figure 4: LAN Emulation v2 Additional Connections and/or Functions.

Connection Name	Uni- or Bi-directional	Point-to-point or Point-to-multipoint	Used for communication
LECS Synchronization VCC	Bi-directional	Point-to-point	Between LECSs
Configuration Direct VCC	Bi-directional	Point-to-point	Between an LECS and an LEC, LES or BUS
Control Coordinate VCC	Bi-directional	Point-to-point	Between LESs
Cache Synchronization VCC	Bi-directional	Point-to-point	Between an LES and its SMSs
Default Multicast Send VCC	Bi-directional	Point-to-point	Between a BUS and an LEC (as in v1)
Default Multicast Forward VCC	Uni-directional	Point-to-multipoint	From a BUS to its LECs and other BUSs
Selective Multicast Send VCC	Bi-directional	Point-to-point	Between an SMS and an LEC
Selective Multicast Forward VCC	Uni-directional	Point-to-multipoint	From an SMS to its LECs

Unicast traffic from a sending LEC is initially forwarded to a receiving LEC via the BUS. When a Data Direct VCC has been established between the two LECs, the unicast traffic is then forwarded via the direct path. During the switchover from the initial to the direct path, it is possible for frames to be delivered out of order. To prevent this possibility, LANE requires an LEC to either implement the Flush protocol, or for the sending LEC to delay transmission at some latency cost.

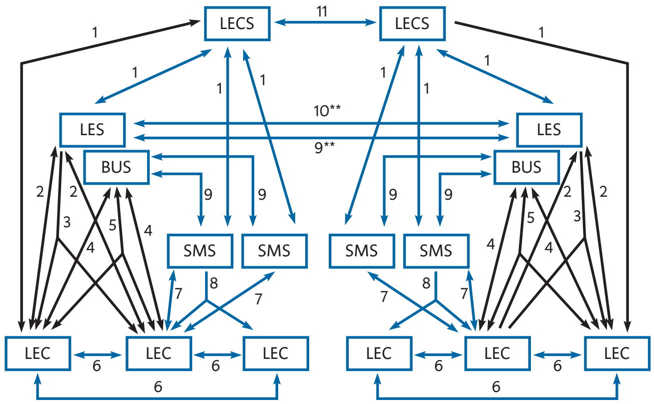
The forwarding of multicast traffic from an LEC depends on the availability of an SMS:

- If an SMS is not available, the LEC establishes the Default Multicast Send VCC to the BUS that, in turn, will add the LEC as a leaf to its Default Multicast Forward VCC. The BUS is then used for the forwarding of multicast traffic.
- If an SMS is available, the LEC can establish, in addition to the Default Multicast Send VCC to the BUS, a Selective Multicast Send VCC to the SMS. In this case, the BUS will add the LEC as a leaf to its Default Multicast Forward VCC and the SMS will add the LEC as a leaf to its Selective Multicast Forward VCC. The BUS is then used initially to forward multicast traffic until the multicast destination is resolved to an ATM address, at which time the SMS is used. The SMS also synchronizes its LAN-ATM multicast address database with its LES using SCSP across Cache Synchronization VCCs.

Figure 4 shows the additional connections required by LANE v2.

This multitude of control and coordination connections, as well as the exchange of control frames, consumes memory, processing power, and bandwidth, just so that a Data Direct VCC can finally be established for persistent communication between two end systems. The complexity can be seen in Figure 5.

Figure 5: Complexity of ATM LAN Emulation.



1 Configuration Direct VCC
2 Control Direct VCC
3 Control Distribute VCC
4 Default Multicast Send VCC
5 Default Multicast Forward VCC
6 Data Direct VCC

7 Selective Multicast VCC
8 Selective Multicast Forward VCC
9 Cache Sync-only VCC
10 Control Coordinate-only VCC
11 LECS Sync VCC

** may be combined into one dual function VCC between two neighbor LESs

AAL-5 Encapsulation

In addition to the complexity of connections and protocols, the data carried over LANE uses ATM Adaptation Layer-5 (AAL-5) encapsulation, which adds overhead to the Ethernet frame. The Ethernet frame is stripped of its Frame Check Sequence (FCS); the remaining fields are copied to the payload portion of the CPCS-PDU, and a 2-byte LANE header (LEH) is added to the front, with an 8-byte trailer at the end. Up to 47 pad bytes may be added, to produce a CPCS-PDU that is a multiple of 48, the size of an ATM cell payload.

The CPCS-PDU also has to be segmented into 53-byte ATM cells before being transmitted onto the network. At the receiving end, the 53-byte ATM cells have to be decapsulated and reassembled into the original Ethernet frame.

Figure 6 shows the CPCS-PDU that is used to transport Ethernet frames over LANE.

Gigabit Ethernet LAN

In contrast, a Gigabit Ethernet LAN backbone does not have the complexity and overhead of control functions, data encapsulation and decapsulation, segmentation and reassembly, and control and data connections required by an ATM backbone.

As originally intended, at least for initial deployment in the LAN environment, Gigabit Ethernet uses full-duplex transmission between switches, or between a switch and a server in a server farm — in other words, in the LAN backbone. Full-duplex Gigabit Ethernet is much simpler, and does not suffer from the complexities and deficiencies of half-duplex Gigabit Ethernet, which uses the CSMA/CD protocol, Carrier Extension, and frame bursting.

Frame Format (Full-Duplex)

Full-duplex Gigabit Ethernet uses the same frame format as Ethernet and Fast Ethernet, with a minimum frame length of 64 bytes and a maximum of 1518 bytes (including the FCS but excluding the Preamble/SFD). If the data portion is less than 46 bytes, pad bytes are added to produce a minimum frame size of 64 bytes.

Figure 7 shows the same frame format for Ethernet, Fast Ethernet and full-duplex Gigabit Ethernet that enables the seamless integration of Gigabit Ethernet campus backbones with the Ethernet and Fast Ethernet desktops and servers they interconnect.

Figure 6: AAL-5 CPCS-PDU.

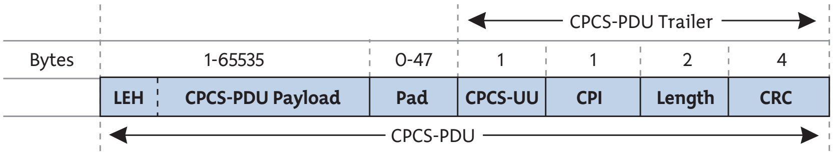


Figure 7: Full-Duplex Gigabit Ethernet Frame Format (no Carrier Extension).

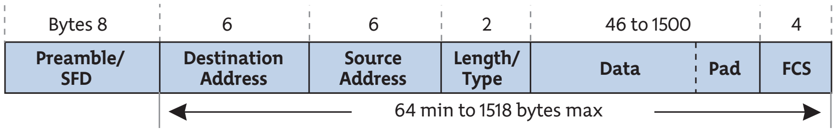
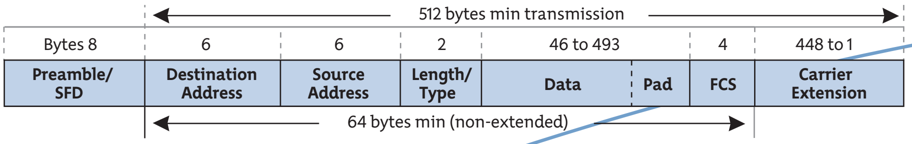


Figure 8: Half-Duplex Gigabit Ethernet Frame Format (with Carrier Extension).



Frame Format (Half-Duplex)

Because of the greatly increased speed of propagation and the need to support practical network distances, half-duplex Gigabit Ethernet requires the use of the Carrier Extension. The Carrier Extension provides a minimum transmission length of 512 bytes. This allows collisions to be detected without increasing the minimum frame length of 64 bytes; thus, no changes are required to higher layer software, such as network interface card (NIC) drivers and protocol stacks.

With half-duplex transmission, if the data portion is less than 46 bytes, pad bytes are added in the Pad field to increase the minimum (non-extended) frame to 64 bytes. In addition, bytes are added in the Carrier Extension field so that a minimum of 512 bytes for transmission is generated. For example, with 46 bytes of data, no bytes are needed in the Pad field, and 448 bytes are added to the Carrier Extension field. On the other hand, with 494 or more (up to 1500) bytes of data, no pad or Carrier Extension is needed.

"Goodput" Efficiency

With full-duplex Gigabit Ethernet, the good throughput ("goodput") in a predominantly 64-byte frame size environment, where no Carrier Extension is needed, is calculated as follows (where SFD=start frame delimiter, and IFG=interframe gap):

$$\frac{\text{64 bytes (frame)}}{[\text{64 bytes (frame)} + \text{8 bytes (SFD)} + \text{12 bytes (IFG)}]} = \text{76 \% approx.}$$

This goodput translates to a forwarding rate of 1.488 million packets per second (Mpps), known as the wirespeed rate.

With Carrier Extension, the resulting goodput is very much reduced:

$$\frac{\text{64 bytes (frame)}}{[\text{512 bytes (frame with CE)} + \text{8 bytes (SFD)} + \text{12 bytes (IFG)}]} = \text{12 \% approx.}$$

In ATM and Gigabit Ethernet comparisons, this 12 percent figure is sometimes quoted as evidence of Gigabit Ethernet's inefficiency.

However, this calculation is only applicable to half-duplex (as opposed to full-duplex) Gigabit Ethernet. In the backbone and server-farm connections, the vast majority (if not all) of the Gigabit Ethernet deployed will be full-duplex.

Mapping Ethernet Frames into ATM LANE Cells

As mentioned previously, using ATM LAN Emulation as the campus backbone for Ethernet desktops require AAL-5 encapsulation and subsequent segmentation and reassembly.

Figure 9 shows a maximum-sized 1518-byte Ethernet frame mapped into a CPCS-PDU and segmented into 32 53-byte ATM cells, using AAL-5; this translates into a goodput efficiency of:

$$\frac{\text{1514 bytes (frame without FCS)}}{[\text{32 ATM cells} \times \text{53 bytes per ATM cell}]} = \text{89 \% approx.}$$

For a minimum size 64-byte Ethernet frame, two ATM cells will be required; this translates into a goodput efficiency of:

$$\frac{\text{60 bytes (frame without FCS)}}{[\text{2 ATM cells} \times \text{53 bytes per ATM cell}]} = \text{57 \% approx.}$$

Figure 9: Mapping Ethernet Frame into ATM Cells.

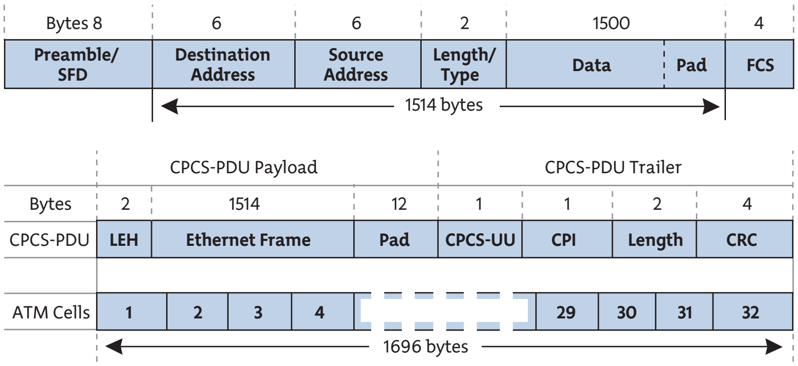
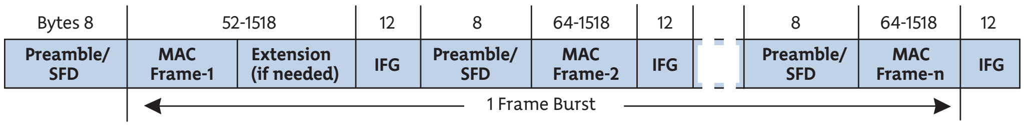


Figure 10: Frame Bursting.



Frame Bursting

The Carrier Extension is an overhead, especially if short frames are the predominant traffic size. To enhance goodput, half-duplex Gigabit Ethernet allows frame bursting. Frame bursting allows an end station to send multiple frames in one access (that is, without contending for channel access for each frame) up to the burstLength parameter. If a frame is being transmitted when the burst Length threshold is exceeded, the sender is allowed to complete the transmission. Thus, the maximum duration of a frame burst is 9710 bytes; this is the burst Length (8192 bytes) plus the max Frame Size (1518 bytes). Only the first frame is extended if required. Each frame is spaced from the previous by a 96-bit interframe gap. Both sender and receiver must be able to process frame bursting.

CSMA/CD Protocol

Full-duplex Gigabit Ethernet does not use or need the CSMA/CD protocol. Because of the dedicated, simultaneous, and separate send and receive channels, it is very much simplified without the need for carrier sensing, collision detection, backoff and retry, carrier extension, and frame bursting.

Flow Control and Congestion Management

In both ATM or Gigabit Ethernet, flow control and congestion management are necessary to ensure that the network elements, individually and collectively, are able to meet QoS objectives required by applications using that network. Sustained congestion in a switch, whether ATM or Gigabit Ethernet, will eventually result in frames being discarded. Various techniques are employed to minimize or prevent buffer overflows, especially under transient overload conditions. The difference between ATM and Gigabit Ethernet is in the availability, reach, and complexity (functionality and granularity) of these techniques.

ATM Traffic and Congestion Management

In an ATM network, the means employed to manage traffic flow and congestion are based on the traffic contract: the ATM Service Category and the traffic descriptor parameters agreed upon for a connection. These means may include:

- **Connection Admission Control (CAC):** accepting or rejecting connections being requested at the call setup stage, depending upon availability of network resources (this is the first point of control and takes into account connections already established).
- **Traffic Policing:** monitoring and controlling the stream of cells entering the network for connections accepted, and marking out-of-profile traffic for possible discard using Usage Parameter Control (UPC) and the Generic Cell Rate Algorithm (GCRA).
- **Backpressure**: exerting on the source to decrease cell transmission rate when congestion appears likely or imminent.
- **Congestion Notification:** notifying the source and intervening nodes of current or impending congestion by setting the Explicit Forward Congestion Indication (EFCI) bit in the cell header (Payload Type Indicator) or using Relative Rate (RR) or Explicit Rate (ER) bits in Resource Management (RM) cells to provide feedback both in the forward and backward directions, so that remedial action can be taken.
- **Cell Discard:** employing various discard strategies to avoid or relieve congestion:
  - **Selective Cell Discard:** dropping cells that are non-compliant with traffic contracts or have their Cell Loss Priority (CLP) bit marked for possible discard if necessary

  - **Early Packet Discard (EPD):** dropping all the cells belonging to a frame that is queued, but for which transmission has not been started
  - **Partial Packet Discard (PPD):** dropping all the cells belonging to a frame that is being transmitted (a more drastic action than EPD)
  - **Random Early Detection (RED):** dropping all the cells of randomly selected frames (from different sources) when traffic arrival algorithms indicate impending congestion (thus avoiding congestion), and preventing waves of synchronized re-transmission precipitating congestion collapse. A further refinement is offered using Weighted RED (WRED).
- **Traffic Shaping:** modifying the stream of cells leaving a switch (to enter or transit a network) so as to ensure conformance with contracted profiles and services. Shaping may include reducing the Peak Cell Rate, limiting the duration of bursting traffic, and spacing cells more uniformly to reduce the Cell Delay Variation.

Gigabit Ethernet Flow Control

For half-duplex operation, Gigabit Ethernet uses the CSMA/CD protocol to provide implicit flow control by "backpressuring" the sender from transmitting in two simple ways:

- Forcing collisions with the incoming traffic, which forces the sender to back off and retry as a result of the collision, in conformance with the CSMA/CD protocol.
- Asserting carrier sense to provide a "channel busy" signal, which prevents the sender from accessing the medium to transmit, again in conformance with the protocol.

With full-duplex operation, Gigabit Ethernet uses explicit flow control to throttle the sender. The IEEE 802.3x Task Force defined a MAC Control architecture, which adds an optional MAC Control sub-layer above the MAC sub-layer, and uses MAC Control frames to control the flow. To date, only one MAC Control frame has been defined; this is for the PAUSE operation.

A switch or an end station can send a PAUSE frame to stop a sender from transmitting data frames for a specified length of time. Upon expiration of the period indicated, the sender may resume transmission. The sender may also resume transmission when it receives a PAUSE frame with a zero time specified, indicating the waiting period has been cancelled. On the other hand, the waiting period may be extended if the sender receives a PAUSE frame with a longer period than previously received.

Using this simple start-stop mechanism, Gigabit Ethernet prevents frame discards when input buffers are temporarily depleted by transient overloads. It is only effective when used on a single full-duplex link between two switches, or between a switch and an end station (server). Because of its simplicity, the PAUSE function does not provide flow control across multiple links, or from end-to-end across (or through) intervening switches. It also requires both ends of a link (the sending and receiving partners) to be MAC Control-capable.

Bandwidth Scalability

Advances in computing technology have fueled the explosion of visually and aurally exciting applications for e-commerce, whether Internet, intranet or extranet. These applications require exponential increases in bandwidth. As a business grows, increases in bandwidth are also required to meet the greater number of users without degrading performance. Therefore, bandwidth scalability in the network infrastructure is critical to supporting incremental or quantum increases in bandwidth capacity, which is frequently required by many businesses.

ATM and Gigabit Ethernet both provide bandwidth scalability. Whereas ATM's bandwidth scalability is more granular and extends from the desktop and over the MAN/WAN, Gigabit Ethernet has focused on scalability in campus networking from the desktop to the MAN/WAN edge. Therefore, Gigabit Ethernet provides quantum leaps in bandwidth from 10 Mbps, through 100 Mbps, 1000 Mbps (1 Gbps), and even 10,000 Mbps (10 Gbps) without a corresponding quantum leap in costs.

ATM Bandwidth

ATM is scalable from 1.544 Mbps through to 2.4 Gbps and even higher speeds. Approved ATM Forum specifications for the physical layer include the following bandwidths:

- 1.544 Mbps DS1
- 2.048 Mbps E1
- 25.6 Mbps over shielded and unshielded twisted pair copper cabling (the bandwidth that was originally envisioned for ATM to the desktop)
- 34.368 Mbps E3
- 44.736 Mbps DS3
- 100 Mbps over multimode fiber cabling
- 155.52 Mbps SONET/SDH over UTP and single and multimode fiber cabling
- 622.08 Mbps SONET/SDH over single and multimode fiber cabling
- 622.08 Mbps and 2.4 Gbps cell-based physical layer (without any frame structure).

Work is also in progress (as of October 1999) on 1 Gbps cell-based physical layer, 2.4 Gbps SONET/SDH, and 10 Gbps SONET/SDH interfaces.

Inverse Multiplexing over ATM

In addition, the ATM Forum's Inverse Multiplexing over ATM (IMA) standard allows several lower-speed DS1/E1 physical links to be grouped together as a single higher speed logical link, over which cells from an ATM cell stream are individually multiplexed. The original cell stream is recovered in correct sequence from the multiple physical links at the receiving end. Loss and recovery of individual links in an IMA group are transparent to the users. This capability allows users to:

- Interconnect ATM campus networks over the WAN, where ATM WAN facilities are not available by using existing DS1/E1 facilities
- Incrementally subscribe to more DS1/E1 physical links as needed
- Protect against single link failures when interconnecting ATM campus networks across the WAN
- Use multiple DS1/E1 links that are typically lower cost than a single DS3/E3 (or higher speed) ATM WAN link for normal operation or as backup links.

Gigabit Ethernet Bandwidth

Ethernet is scalable from the traditional 10 Mbps Ethernet, through 100 Mbps Fast Ethernet, and 1000 Mbps Gigabit Ethernet. Now that the Gigabit Ethernet standards have been completed, the next evolutionary step is 10 Gbps Ethernet. The IEEE P802.3 Higher Speed Study Group has been created to work on 10 Gbps Ethernet, with Project Authorization Request and formation of a Task Force targeted for November 1999 and a standard expected by 2002.

Bandwidth scalability is also possible through link aggregation (that is, grouping multiple Gigabit Ethernet links together to provide greater bandwidth and resiliency. Work in this area of standardization is proceeding through the IEEE 802.3ad Link Aggregation Task Force (see the Trunking and Link Aggregation section of this paper).

Distance Scalability

Distance scalability is important because of the need to extend the network across widely dispersed campuses, and within large multi-storied buildings, while making use of existing UTP-5 copper cabling and common single and multimode fiber cabling, and without the need for additional devices such as repeaters, extenders, and amplifiers.

Both ATM and Gigabit Ethernet (IEEE 802.3ab) can operate easily within the limit of 100 meters from a wiring closet switch to the desktop using UTP-5 copper cabling. Longer distances are typically achieved using multimode (50/125 or 62.5/125 μm) or single mode (9-10/125 μm) fiber cabling.

Figure 11: Ethernet and Fast Ethernet Supported Distances.

	Ethernet 10BASE-T	Ethernet 10BASE-FL	Ethernet 100BASE-TX	Ethernet 100BASE-FX
IEEE Standard	802.3	802.3	802.3u	802.3u
Data Rate	10 Mbps	10 Mbps	100 Mbps	100 Mbps
Multimode Fiber distance	N/A	2 km	N/A	412 m (half duplex) 2 km (full duplex)
Singlemode Fiber distance	N/A	25 km	N/A	20 km
Cat 5 UTP distance	100 m	N/A	100 m	N/A
STP/Coax distance	500 m	N/A	100 m	N/A

Gigabit Ethernet Distances

Figure 11 shows the maximum distances supported by Ethernet and Fast Ethernet, using various media.

IEEE 802.3z Gigabit Ethernet – Fiber Cabling

IEEE 802.3u-1995 (Fast Ethernet) extended the operating speed of CSMA/CD networks to 100 Mbps over both UTP-5 copper and fiber cabling.

The IEEE P802.3z Gigabit Ethernet Task Force was formed in July 1996 to develop a Gigabit Ethernet standard. This work was completed in July 1998 when the IEEE Standards Board approved the IEEE 802.3z-1998 standard.

The IEEE 802.3z standard specifies the operation of Gigabit Ethernet over existing single and multimode fiber cabling. It also supports short (up to 25m) copper jumper cables for interconnecting switches, routers, or other devices (servers) in a single computer room or wiring closet. Collectively, the three designations — 1000BASE-SX, 1000BASE-LX and 1000BASE-CX — are referred to as 1000BASE-X.

Figure 12 shows the maximum distances supported by Gigabit Ethernet, using various media.

1000BASE-X Gigabit Ethernet is capable of auto-negotiation for half- and full-duplex operation. For full-duplex operation, auto-negotiation of flow control includes both the direction and symmetry of operation — symmetrical and asymmetrical.

IEEE 802.3ab Gigabit Ethernet — Copper Cabling

For Gigabit Ethernet over copper cabling, an IEEE Task Force started developing a specification in 1997. A very stable draft specification, with no significant technical changes, had been available since July 1998. This specification, known as IEEE 802.3ab, is now approved (as of June 1999) as an IEEE standard by the IEEE Standards Board.

The IEEE 802.3ab standard specifies the operation of Gigabit Ethernet over distances up to 100m using 4-pair 100 ohm Category 5 balanced unshielded twisted pair copper cabling. This standard is also known as the 1000BASE-T specification; it allows deployment of Gigabit Ethernet in the wiring closets, and even to the desktops if needed, without change to the UTP-5 copper cabling that is installed in many buildings today.

Trunking and Link Aggregation

Trunking provides switch-to-switch connectivity for ATM and Gigabit Ethernet. Link Aggregation allows multiple parallel links between switches, or between a switch and a server, to provide greater resiliency and bandwidth. While switch-to-switch connectivity for ATM is well-defined through the NNI and PNNI specifications, several vendor-specific

Figure 12: Gigabit Ethernet Supported Distances.

	1000BASE-SX	1000BASE-LX	1000BASE-CX	1000BASE-T
IEEE Standard	802.3z	802.3z	802.3z	802.3ab
Data Rate	1000 Mbps	1000 Mbps	1000 Mbps	1000 Mbps
Optical Wavelength (nominal)	850 nm (shortwave)	1300 nm (longwave)	N/A	N/A
Multimode Fiber (50 (m) distance	525 m	550 m	N/A	N/A
Multimode Fiber (62.5 (m) distance	260 m	550 m	N/A	N/A
Singlemode Fiber (10 (m) distance	N/A	3 km	N/A	N/A
UTP-5 100 ohm distance	N/A	N/A	N/A	100m
STP 150 ohm distance	N/A	N/A	25 m	N/A
Number of Wire Pairs/Fiber	2 fiber	2 fiber	2 pairs	4 pairs
Connector Type	Duplex SC	Duplex SC	Fibre Channel-2 or DB-9	RJ-45

Note: distances are for full duplex, the expected mode of operation in most cases.

protocols are used for Gigabit Ethernet, with standards-based connectivity to be provided once the IEEE 802.3ad Link Aggregation standard is complete.

Nortel Networks is actively involved in this standards effort, while providing highly resilient and higher bandwidth Multi-Link Trunking (MLT) and Gigabit LinkSafe technology in the interim.

ATM PNNI

ATM trunking is provided through NNI (Network Node Interface or Network-to-Network Interface) using the Private NNI (PNNI) v1.0 protocols, an ATM Forum specification approved in March 1996.

To provide resiliency, load distribution and balancing, and scalability in bandwidth, multiple PNNI links may be installed between a pair of ATM switches. Depending on the implementation, these parallel links may be treated for Connection Admission Control (CAC) procedures as a single logical aggregated link. The individual links within a set of paralleled links may be any combination of the supported ATM speeds. As more bandwidth is needed, more PNNI links may be added between switches as necessary without concern for the possibility of loops in the traffic path.

By using source routing to establish a path (VCC) between any source and destination end systems, PNNI automatically eliminates the forming of loops. The end-to-end path, computed at the ingress ATM switch using Generic Connection Admission Control (GCAC) procedures, is specified by a list of ATM nodes known as a Designated Transit List (DTL). Computation based on default parameters will result in the shortest path meeting the requirements, although preference may be given to certain paths by assigning lower Administrative Weight to preferred links. This DTL is then validated by local CAC procedures at each ATM node in the list. If an intervening node finds the path is invalid, maybe as a result of topology or link state changes in the meantime, that node is able to automatically “crank” the list back to the ingress switch for recomputation of a new path. An ATM switch may perform path computation as a background task before calls are received (to reduce latency during call setups), or when a call request is received (for real-time optimized path at the cost of some setup delay), or both (for certain QoS categories), depending on user configuration.

PNNI also provides performance scalability when routing traffic through an ATM network, using the hierarchical structure of ATM addresses. An individual ATM end system in a PNNI peer group can be reached using the summary address for that peer group, similar to using the network and subnet ID portions of an IP address. A node whose address does not match the summary address (the non-matching address is known as a foreign address) can be explicitly set to be reachable and advertised.

A Peer Group Leader (PGL) may represent the nodes in the peer group at a higher level. These PGLs are logical group nodes (LGNs) that form higher-level peer groups, which allow even shorter summary addresses. These higher-level peer groups can be represented in even higher peer groups, thus forming a hierarchy. By using this multi-level hierarchical routing, less address, topology, and link state information needs to be advertised across an ATM network, allowing scalability as the number of nodes grow.

However, this rich functionality comes with a price. PNNI requires memory, processing power, and bandwidth from the ATM switches for maintaining state information, topology and link state update exchanges, and path computation. PNNI also results in greater complexity in hardware design, software algorithms, switch configuration, deployment, and operational support, and ultimately much higher costs.

ATM UNI Uplinks versus NNI Risers

PNNI provides many benefits with regard to resiliency and scalability when connecting ATM switches in the campus backbone. However, these advantages are not available in most ATM installations where the LAN switches in the wiring closets are connected to the backbone switches using ATM UNI uplinks. In such connections, the end stations attached to the LAN switch are associated, directly or indirectly (through VLANs), with specific proxy LECs located in the uplinks. An end station cannot be associated with more than one proxy LEC active in separate uplinks at any one time. Hence, no redundant path is available if the proxy LEC (meaning uplink or uplink path) representing the end stations should fail.

While it is possible to have one uplink active and another on standby, connected to the backbone via a different path and ready to take over in case of failure, very few ATM installations have implemented this design for reasons of cost, complexity, and lack of this capability from the switch vendor.

One solution is provided by the Nortel Networks Centillion* 50/100 and System 5000BH/BHC LAN-ATM Switches. These switches provide Token-Ring and Ethernet end station connectivity on the one (desktop) side and "NNI riser uplinks" to the core ATM switches on the other (backbone) side. Because these "NNI risers" are PNNI uplinks, the LAN-to-ATM connectivity enjoys all the benefits of PNNI.

Gigabit Ethernet Link Aggregation

With Gigabit Ethernet, multiple physical links may be installed between two switches, or between a switch and a server, to provide greater bandwidth and resiliency. Typically, the IEEE 802.1d Spanning Tree Protocol (STP) is used to prevent loops forming between these parallel links, by blocking certain ports and forwarding on others so that there is only one path between any pair of source-destination end stations. In doing so, STP incurs some performance penalty when converging to a new spanning tree structure after a network topology change.

Although most switches are plug-and-play, with default STP parameters, erroneous configuration of these parameters can lead to looping, which is difficult to resolve. In addition, by blocking certain ports, STP will allow only one link of several parallel links between a pair of switches to carry traffic. Hence, scalability of bandwidth between switches cannot be increased by adding more parallel links as required, although resiliency is thus improved.

To overcome the deficiencies of STP, various vendor-specific capabilities are offered to increase the resiliency, load distribution and balancing, and scalability in bandwidth, for parallel links between Gigabit Ethernet switches.

For example, the Nortel Networks Passport Campus Solution offers Multi-Link Trunking and Gigabit Ethernet LinkSafe:

Multi-Link Trunking (MLT) that allows up to four physical connections between two Passport 1000 Routing Switches, or a BayStack* 450 Ethernet Switch and an Passport 1000 Routing Switch, to be grouped together as a single logical link with much greater resiliency and bandwidth than is possible with several individual connections.

Each MLT group may be made up of Ethernet, Fast Ethernet or Gigabit Ethernet physical interfaces; all links within a group must be of the same media type (copper or fiber), have the same speed and half- or full-duplex settings, and belong to the same Spanning Tree group, although they need not be from the same interface module within a switch. Loads are automatically balanced across the MLT links, based on source and destination MAC addresses (bridged traffic), or source and destination IP addresses (routed traffic). Up to eight MLT groups may be configured in an Passport 1000 Routing Switch.

Gigabit Ethernet LinkSafe that provides two Gigabit Ethernet ports on an Passport 1000 Routing Switch interface module to connect to another similar module on another switch, with one port active and the other on standby, ready to take over automatically should the active port or link fails. LinkSafe is used for riser and backbone connections, with each link routed through separate physical paths to provide a high degree of resiliency protection against a port or link failure.

An important capability is that virtual LANs (VLANs) distributed across multiple switches can be interconnected, with or without IEEE 802.1Q VLAN Tagging, using MLT and Gigabit Ethernet trunks.

With MLT and Gigabit Ethernet LinkSafe redundant trunking and link aggregation, the BayStack 450 Ethernet Switch and Passport 1000 Routing Switch provide a solution that is comparable to ATM PNNI in its resilience and incremental scalability, and is superior in its simplicity.

IEEE P802.3ad Link Aggregation

In recognition of the need for open standards and interoperability, Nortel Networks actively leads in the IEEE P802.3ad Link Aggregation Task Force, authorized by the IEEE 802.3 Trunking Study Group in June 1998, to define a link aggregation standard for use on switch-to-switch and switch-to-server parallel connections. This standard is currently targeted for availability in early 2000.

The IEEE P802.3ad Link Aggregation is an important full-duplex, point-to-point technology for the core LAN infrastructure and provides several benefits:

- Greater bandwidth capacity, allowing parallel links between two switches, or a switch and a server, to be aggregated together as a single logical pipe with multi-Gigabit capacity (if necessary); traffic is automatically distributed and balanced over this pipe for high performance.
- Incremental bandwidth scalability, allowing more links to be added between two switches, or a switch and a server, only when needed for greater performance, from a minimal initial hardware investment, and with minimal disruption to the network.
- Greater resiliency and fault-tolerance, where traffic is automatically reassigned to remaining operative links, thus maintaining communication if individual links between two switches, or a switch and a server, fail.
- Flexible and simple migration vehicle, where Ethernet and Fast Ethernet switches at the LAN edges can have multiple lower-speed links aggregated to provide higher-bandwidth transport into the Gigabit Ethernet core.

A brief description of the IEEE P802.3ad Link Aggregation standard (which may change as it is still fairly early in the standards process) follows.

A physical connection between two switches, or a switch and a server, is known as a link segment. Individual link segments of the same medium type and speed may make up a Link Aggregation Group (LAG), with a link segment belonging to only one LAG at any one time. Each LAG is associated with a single MAC address.

Frames that belong logically together (for example, to an application being used at a given instance, flowing in sequence between a pair of end stations) are treated as a conversation (similar to the concept of a “flow”). Individual conversations are aggregated together to form an Aggregated Conversation, according to user-specified Conversation Aggregation Rules, which may specify aggregation, for example, on the basis of source/destination address pairs, VLAN ID, IP subnet, or protocol type. Frames that are part of a given conversation are transmitted on a single link segment within a LAG to ensure in-sequence delivery.

A Link Aggregation Control Protocol is used to exchange link configuration, capability, and state information between adjacent switches, with the objective of forming LAGs dynamically. A Flush protocol, similar to that in ATM LAN Emulation, is used to flush frames in transit when links are added or removed from a LAG.

Among the objectives of the IEEE P802.3ad standard are automatic configuration, low protocol overheads, rapid and deterministic convergence when link states change, and accommodation of aggregation-unaware links.

Technology Complexity and Cost

Two of the most critical criteria in the technology decision are the complexity and cost of that technology. In both aspects, simple and inexpensive Gigabit Ethernet wins hands down over complex and expensive ATM — at least in enterprise networks.

ATM is fairly complex because it is a connection-oriented technology that has to emulate the operation of connectionless LANs. As a result, additional physical and logical components, connections, and protocols have to be added, with the attendant need for understanding, configuration, and operational support. Unlike Gigabit Ethernet (which is largely plug-and-play), there is a steep learning curve associated with ATM, in product development as well as product usage. ATM also suffers from a greater number of interoperability and compatibility issues than does Gigabit Ethernet, because of the different options vendors implement in their ATM products. Although interoperability testing does improve the situation, it also adds time and cost to ATM product development.

Because of the greater complexity, the result is also greater costs in:

- Education and training
- Implementation and deployment
- Problem determination and resolution
- Ongoing operational support
- Test and analysis equipment, and other management tools.

Integration of Layer 3 and Above Functions

Both ATM and Gigabit Ethernet provide the underlying internetwork over which IP packets are transported. Although initially a Layer 2 technology, ATM functionality is creeping upwards in the OSI Reference Model. ATM Private Network Node Interface (PNNI) provides signaling and OSPF-like best route determination when setting up the path from a source to a destination end system. Multiprotocol Over ATM (MPOA) allows short-cut routes to be established between two communicating ATM end systems located in different IP subnets, completely bypassing intervening routers along the path.

In contrast, Gigabit Ethernet is strictly a Layer 2 technology, with much of the other needed functionality added above it. To a large extent, this separation of functions is an advantage because changes to one function do not disrupt another if there is clear modularity of functions. This decoupling was a key motivation in the original development of the 7-layer OSI Reference Model. In fact, the complexity of ATM may be due to the rich functionality all provided “in one hit,” unlike the relative simplicity of Gigabit Ethernet, where higher layer functionality is kept separate from, and added “one at a time” to, the basic Physical and Data Link functions.

MPOA and NHRP

A traditional router provides two basic Layer 3 functions: determining the best possible path to a destination using routing control protocols such as RIP and OSPF (this is known as the routing function), and then forwarding the frames over that path (this is known as the forwarding function).

Multi-Protocol Over ATM (MPOA) enhances Layer 3 functionality over ATM in three ways:

- MPOA uses a Virtual Router model to provide greater performance scalability by allowing the typically centralized routing control function to be divorced from the data frame forwarding function, and distributing the data forwarding function to access switches on the periphery of the network. This "separation of powers" allows routing capability and forwarding capability to be distributed to where each is most effective, and allows each to be scaled when needed without interference from the other.
- MPOA enables paths (known as short-cut VCCs) to be directly established between a source and its destination, without the hop-by-hop, frame-by-frame processing and forwarding that is necessary in traditional router networks. Intervening routers, which are potentially performance bottlenecks, are completely bypassed, thereby enhancing forwarding performance.
- MPOA uses fewer resources in the form of VCCs. When traditional routers are used in an ATM network, one Data Direct VCC (DDVCC) must be established between a source end station and its gateway router, one DDVCC between a destination end station and its gateways router, and several DDVCCs between intervening routers along the path. With MPOA, only one DDVCC is needed between the source and destination end stations.

Gigabit Ethernet can also leverage a similar capability for IP traffic using the Next Hop Resolution Protocol (NHRP). In fact, MPOA uses NHRP as part of the process to resolve MPOA destination addresses. MPOA Resolution Requests are converted to NHRP Resolution Requests by the ingress MPOA server before forwarding the requests towards the intended destination. NHRP Resolution Responses received by the ingress MPOA server are converted to MPOA Resolution Responses before being forwarded to the requesting source. Just as MPOA shortcuts can be established for ATM networks, NHRP shortcuts can also be established to provide the performance enhancement in a frame switched network.

Gateway Redundancy

For routing between subnets in an ATM or Gigabit Ethernet network, end stations typically are configured with the static IP address of a Layer 3 default gateway router. Being a single point of failure, sometimes with catastrophic consequences, various techniques have been deployed to ensure that an alternate backs this default gateway when it fails.

With ATM, redundant and distributed Layer 3 gateways are currently vendor-specific. Even if a standard should emerge, it is likely that more logical components, protocols, and connections will need to be implemented to provide redundant and/or distributed gateway functionality.

Virtual Router Redundancy Protocol

For Gigabit Ethernet, an IETF RFC 2338 Virtual Router Redundancy Protocol (VRRP) is available for deploying interoperable and highly resilient default gateway routers. VRRP allows a group of routers to provide redundant and distributed gateway functions to end stations through the mechanism of a virtual IP address — the address that is configured in end stations as the default gateway router.

At any one time, the virtual IP address is mapped to a physical router, known as the Master. Should the Master fail, another router within the group is elected as the new Master with the same virtual IP address. The new Master automatically takes over as the new default gateway, without requiring configuration changes in the end stations. In addition, each router may be Master for a set of end stations in one subnet while providing backup functions for another, thus distributing the load across multiple routers.

LAN Integration

The requirements of the LAN are very different from those of the WAN. In the LAN, bandwidth is practically "free" once installed, as there are no ongoing usage costs. As long as sufficient bandwidth capacity is provisioned (or even over-provisioned) to meet the demand, there may not be a need for complex techniques to control bandwidth usage. If sufficient bandwidth exists to meet all demand, then complex traffic management and congestion control schemes may not be needed at all. For the user, other issues assume greater importance; these include ease of integration, manageability, flexibility (moves, adds and changes), simplicity, scalability, and performance.

Seamless Integration

ATM has often been touted as the technology that provides seamless integration from the desktop, over the campus and enterprise, right through to the WAN and across the world. The same technology and protocols are used throughout. Deployment and on-going operational support are much easier because of the opportunity to "learn once, do many." One important assumption in this scenario is that ATM would be widely deployed at the desktops. This assumption does not meet with reality.

ATM deployment at the desktop is almost negligible, while Ethernet and Fast Ethernet are very widely installed in millions of desktop workstations and servers. In fact, many PC vendors include Ethernet, Fast Ethernet, and (increasingly) Gigabit Ethernet NIC cards on the motherboards of their workstation or server offerings. Given this huge installed base and the common technology that it evolved from, Gigabit Ethernet provides seamless integration from the desktops to the campus and enterprise backbone networks.

If ATM were to be deployed as the campus backbone for all the Ethernet desktops, then there would be a need for frame-to-cell and cell-to-frame conversion — the Segmentation and Reassembly (SAR) overhead.

With Gigabit Ethernet in the campus backbone and Ethernet to the desktops, no cell-to-frame or frame-to-cell conversion is needed. Not even frame-to-frame conversion is required from one form of Ethernet to another! Hence, Gigabit Ethernet provides a more seamless integration in the LAN environment.

Broadcast and Multicast

Broadcasts and multicasts are very natural means to send traffic from one source to multiple recipients in a connectionless LAN. Gigabit Ethernet is designed for just such an environment. The higher-layer IP multicast address is easily mapped to a hardware MAC address. Using Internet Group Management Protocol (IGMP), receiving end stations report group membership to (and respond to queries from) a multicast router, so as to receive multicast traffic from networks beyond the local attachment. Source end stations need not belong to a multicast group in order to send to members of that group.

By contrast, broadcasts and multicasts in an ATM LAN present a few challenges because of the connection-oriented nature of ATM.

In each emulated LAN (ELAN), ATM needs the services of a LAN Emulation Server (LES) and a Broadcast and Unknown Server (BUS) to translate from MAC addresses to ATM addresses. These additional components require additional resources and complexity needed to signal, set up, maintain, and tear down Control Direct, Control Distribute, Multicast Send, and Multicast Forward VCCs. Complexity is further increased because an ELAN can only have a single LES/BUS, which must be backed up by another LES/BUS to eliminate any single points of failure. Communication between active and backup LES/BUS nodes requires more virtual connections and protocols for synchronization, failure detection, and takeover (SCSP and LNNI).

With all broadcast traffic going through the BUS, the BUS poses a potential bottleneck.

For IP multicasting in a LANE network, ATM needs the services of the BUS and, if available (with LUNI v2), an SMS. For IP multicasting in a Classical IP ATM network, ATM needs the services of a Multicast Address Resolution Server (MARS), a Multicast Connection Server (MCS), and the Cluster Control VCCs. These components require additional resources and complexity for connection signaling, setting up, maintenance and tearing down.

With UNI 3.0/3.1, the source must first resolve the target multicast address to the ATM addresses of the group members, and then construct a point-to-multipoint tree, with the source itself as the root to the multiple destinations before multicast traffic may be distributed. With UNI 4.0, end stations may join as leaves to a point-to-multipoint distribution tree, with or without intervention from the root. Issues of interoperability between the different UNI versions are raised in either case.

Multi-LAN Integration

As a backbone technology, ATM can interconnect physical LAN segments using Ethernet, Fast Ethernet, Gigabit Ethernet, and Token Ring. These are the main MAC layer protocols in use on campus networks today. Using ATM as the common uplink technology and with translational bridging functionality, the Ethernet and Token-Ring LANs can interoperate relatively easily.

With Gigabit Ethernet, interoperation between Ethernet and Token-Ring LANs requires translational bridges that transform the frame format of one type to the other.

MAN/WAN Integration

It is relatively easy to interconnect ATM campus backbones across the MAN or WAN. Most ATM switches are offered with DS1/E1, DS3/E3, SONET OC-3c/SDH STM-1 and SONET OC-12c/SDH STM-4 ATM interfaces that connect directly to the ATM MAN or WAN facilities. Some switches are offered with DS1/E1 Circuit Emulation, DS1/E1 Inverse Multiplexing over ATM, and Frame Relay Network and Service Interworking capabilities that connect to the existing non-ATM MAN or WAN facilities. All these interfaces allow ATM campus switches direct connections to the MAN or WAN, without the need for additional devices at the LAN-WAN edge.

At this time, many Gigabit Ethernet switches do not offer MAN/WAN interfaces. Connecting Gigabit Ethernet campus networks across the MAN or WAN typically requires the use of additional devices to access MAN/WAN facilities, such as Frame Relay, leased lines, and even ATM networks. These interconnect devices are typically routers or other multiservice switches that add to the total complexity and cost. With the rapid acceptance of Gigabit Ethernet as the campus backbone of choice, however, many vendors are now offering MAN/WAN interfaces such as ATM SONET OC-3c/SDH STM-1, SONET OC-12c/SDH STM-4, and Packet-over-SONET/SDH in their Gigabit Ethernet switches.

While an ATM LAN does offer seamless integration with the ATM MAN or WAN through direct connectivity, the MAN/WAN for the most part will continue to be heterogeneous, and not homogeneous ATM. This is due to the installed non-ATM equipment, geographical coverage, and time needed to change. This situation will persist more so than in the LAN where there is a greater control by the enterprise and, therefore, greater ease of convergence. Even in the LAN, the convergence is towards Ethernet and not ATM as the underlying technology. Technologies other than ATM will be needed for interconnecting between locations, and even over entire regions, because of difficult geographical terrain or uneconomic reach. Thus, there will continue to be a need for technology conversion from the LAN to the WAN, except where ATM has been implemented.

Another development — the widespread deployment of fiber optic technology — may enable the LAN to be extended over the WAN using the seemingly boundless optical bandwidth for LAN traffic. This means that Gigabit Ethernet campuses can be extended across the WAN just as easily, perhaps even more easily and with less cost, than ATM over the WAN. Among the possibilities are access to Dark Fiber with long-haul extended distance Gigabit Ethernet (50 km or more), Packet-over-SONET/SDH and IP over Optical Dense Wave Division Multiplexing.

One simple yet powerful way for extending high performance Gigabit Ethernet campus networks across the WAN, especially in the metropolitan area, is the use of Packet-over-SONET/SDH (POS, also known as IP over SONET/SDH). SONET is emerging as a competitive service to ATM over the MAN/WAN. With POS, IP packets are directly encapsulated into SONET frames, thereby eliminating the additional overhead of the ATM layer (see column "C" in Figure 13).

To extend this a step further, IP packets can be transported over raw fiber without the overhead of SONET/SDH framing; this is called IP over Optical (see column "D" in Figure 13). Optical Networking can transport very high volumes of data, voice and video traffic over different light wavelengths.

The pattern of traffic has also been rapidly changing, with more than 80 percent of the network traffic expected to traverse the MAN/WAN, versus only 20 percent remaining on the local campus. Given the changing pattern of traffic, and the emergence of IP as the dominant network protocol, the total elimination of layers of communication for IP over the MAN/WAN means reduced bandwidth usage costs and greater application performance for the users.

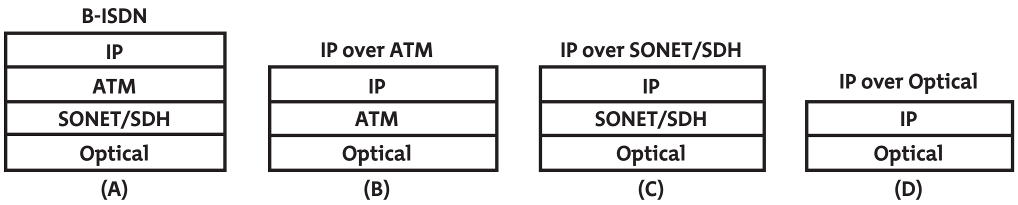
While all these technologies are evolving, businesses seek to minimize risks by investing in the lower-cost Gigabit Ethernet, rather than the higher-cost ATM.

Management Aspects

Because businesses need to be increasingly dynamic to respond to opportunities and challenges, the campus networking environment is constantly in a state of flux. There are continual moves, adds, and changes; users and workstations form and re-form workgroups; road warriors take the battle to the streets, and highly mobile users work from homes and hotels to increase productivity.

With all these constant changes, manageability of the campus network is a very important selection criterion. The more homogeneous and simpler the network elements are, the easier they are to manage. Given the ubiquity of Ethernet and Fast Ethernet, Gigabit Ethernet presents a more seamless integration with existing network elements than ATM. Therefore, Gigabit Ethernet is easier to manage. Gigabit Ethernet is also easier to manage because of its innate simplicity and the wealth of experience and tools available with its predecessor technologies.

Figure 13: Interconnection Technologies over the MAN/WAN.



By contrast, ATM is significantly different from the predominant Ethernet desktops it interconnects. Because of this difference and its relative newness, there are few tools and skills available to manage ATM network elements. ATM is also more difficult to manage because of the complexity of logical components and connections, and the multitude of protocols needed to make ATM workable. On top of the physical network topology lie a number of logical layers, such as PNNI, LUNI, LNNI, MPOA, QoS, signaling, SVCs, PVCs, and soft PVCs. Logical components are more difficult to troubleshoot than physical elements when problems do occur.

Standards and Interoperability

Like all technologies, ATM and Gigabit Ethernet standards and functions mature and stabilize over time. Evolved from a common technology, frame-based Gigabit Ethernet backbones interoperate seamlessly with the millions of connectionless, frame-based Ethernet and Fast Ethernet desktops and servers in today's enterprise campus networks. By contrast, connection-oriented, cell-based ATM backbones need additional functions and capabilities that require standardization, and can easily lead to interoperability issues.

ATM Standards

Although relatively new, ATM standards have been in development since 1984 as part of B-ISDN, designed to support private and public networks. Since the formation of the ATM Forum in 1991, many ATM specifications were completed, especially between 1993 and 1996.

Because of the fast pace of development efforts during this period, a stable environment was felt to be needed for consolidation, implementation and interoperability. In April 1996, the Anchorage Accord agreed on a collection of some 60 ATM Forum specifications that provided a basis for stable implementation. Besides designating a set of foundational and expanded feature specifications, the Accord also established criteria to ensure interoperability of ATM products and services between current and future specifications. This Accord provided the assurance needed for the adoption of ATM and a checkpoint for further standards development. As of July 1999, there are more than 40 ATM Forum specifications in various stages of development.

To promote interoperability, the ATM Consortium was formed in October 1993, one of several consortiums at the University of New Hampshire InterOperability Lab (IOL). The ATM Consortium is a grouping of ATM product vendors interested in testing interoperability and conformance of their ATM products in a cooperative atmosphere, without adverse competitive publicity.

Gigabit Ethernet Standards

By contrast, Gigabit Ethernet has evolved from the tried and trusted Ethernet and Fast Ethernet technologies, which have been in use for more than 20 years. Being relatively simple compared to ATM, much of the development was completed within a relatively short time. The Gigabit Ethernet Alliance, a group of networking vendors including Nortel Networks, promotes the development, demonstration, and interoperability of Gigabit Ethernet standards. Since its formation in 1996, the Alliance has been very successful in helping to introduce the IEEE 802.3z 1000BASE-X, and the IEEE 802.3ab 1000BASE-T Gigabit Ethernet standards.

Similar to the ATM Consortium, the Gigabit Ethernet Consortium was formed in April 1997 at the University of New Hampshire InterOperability Lab as a cooperative effort among Gigabit Ethernet product vendors. The objective of the Gigabit Ethernet Consortium is the ongoing testing of Gigabit Ethernet products and software from both an interoperability and conformance perspective.

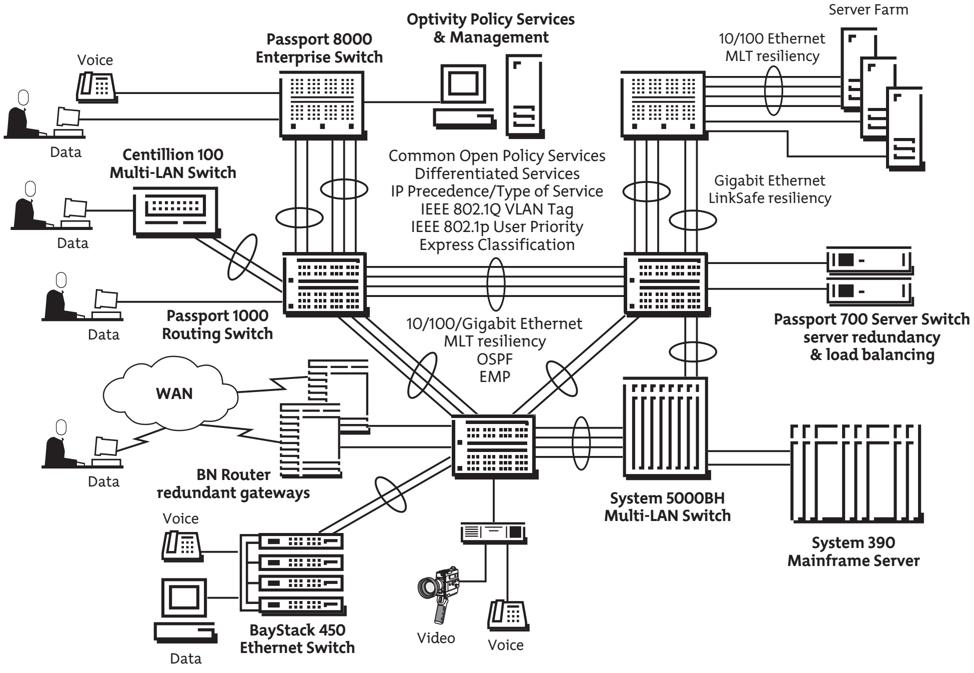
Passport Campus Solution

In response to the market requirements and demand for Ethernet, Fast Ethernet, and Gigabit Ethernet, Nortel Networks offers the Passport Campus Solution as the best-of-breed technology for campus access and backbone LANs. The Passport Campus Solution (see Figure 14) comprises the Passport 8000 Enterprise Switch, with its edge switching and routing capabilities, the Passport 1000 Routing Switch family, Passport 700 Server Switch family, and BayStack 450 Stackable Switch, complemented by Optivity Policy Services for policy-enabled networking.

The following highlights key features of the Passport 8000 Enterprise Switch, the winner of the Best Network Hardware award from the 1999 Annual SI Impact Awards, sponsored by IDG's Solutions Integrator magazine:

- High port density, scalability and performance
- Switch capacity of 50 Gbps, scalable to 256 Gbps
- Aggregate throughput of 3 million packets per second
- Less than 9 microseconds of latency
- Up to 372 Ethernet 10/100BASE-T auto-sensing, auto-negotiating ports
- Up to 160 Fast Ethernet 100BASE-FX ports
- Up to 64 Gigabit Ethernet 1000BASE-SX or -LX ports
- Wirespeed switching for Ethernet, Fast Ethernet and Gigabit Ethernet
- High resiliency through Gigabit LinkSafe and Multi-Link Trunking
- High availability through fully distributed switching and management architectures, redundant and load-sharing power supplies and cooling fans, and ability to hot-swap all modules
- Rich functionality through support of:
- Port- and protocol-based VLANs for broadcast containment, logical workgroups, and easy moves, adds and changes
- IEEE 802.1Q VLAN Tagging for carrying traffic from multiple VLANs over a single trunk
- IEEE 802.1p traffic prioritization for key business applications
- IGMP, broadcast and multicast rate limiting for efficient broadcast containment
- Spanning Tree Protocol FastStart for faster network convergence and recovery
- Remote Network Monitoring (RMON), port mirroring, and Remote Traffic Monitoring (RTM) for network management and problem determination.

Figure 14: Passport Campus Solution and Optivity Policy Services.



For users with investments in Centillion 50/100 and System 5000BH LAN-ATM Switches, evolution to a Gigabit Ethernet environment will be possible once Gigabit Ethernet switch modules are offered in the future.

Information on the other award-winning members of the Passport Campus Solution is available on Nortel Networks website: http://www.nortelnetworks.com

Conclusion and Recommendation

In enterprise networks, either ATM or Gigabit Ethernet may be deployed in the campus backbone. The key difference is in the complexity and much higher cost of ATM, versus the simplicity and much lower cost of Gigabit Ethernet. While it may be argued that ATM is richer in functionality, pure technical consideration is only one of the decision criteria, albeit a very important one.

Of utmost importance is functionality that meets today's immediate needs at a price that is realistic. There is no point in paying for more functionality and complexity than is necessary, that may or may not be needed, and may even be obsolete in the future. The rate of technology change and competitive pressures demand that the solution be available today, before the next paradigm shift, and before new solutions introduce another set of completely new challenges.

Gigabit Ethernet provides a pragmatic, viable, and relatively inexpensive (and therefore, lower risk) campus backbone solution that meets today's needs and integrates seamlessly with the omnipresence of connectionless, frame-based Ethernet and Fast Ethernet LANs. Enhanced by routing switch technology such as the Nortel Networks Passport 8000 Enterprise Switches, and policy-enabled networking capabilities in the Nortel Networks Optivity Policy Services, Gigabit Ethernet provides enterprise businesses with the bandwidth, functionality, scalability, and performance they need, at a much lower cost than ATM.

By contrast, ATM provides a campus backbone solution that has the disadvantages of undue complexity, unused functionality, and much higher cost of ownership in the enterprise LAN. Much of the complexity results from the multitude of additional components, protocols, control, and data connections required by connection-oriented, cell-based ATM to emulate broadcast-centric, connectionless, frame-based LANs. While Quality of Service (QoS) is an increasingly important requirement in enterprise networks, there are other solutions to the problem that are simpler, incremental, and less expensive.

For these reasons, Nortel Networks recommends Gigabit Ethernet as the technology of choice for most campus backbone LANs. ATM was, and continues to be, a good option where its unique and complex functionality can be exploited, in deployment, for example, in the metropolitan and wide area network. This recommendation is supported by many market research surveys that show users overwhelmingly favor Gigabit Ethernet over ATM, including surveys such as *User Plans for High Performance LANs* by Infonetics Research Inc. (March 1999), and *Hub and Switch 5-Year Forecast* by the Dell'Oro Group (July 1999).

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