Abstract

There is increasing interest in deploying ATM technology in local or campus networks. ATM is an ideal technology to overcome many of the limitations of today's LAN technologies. This article focuses on the application of ATM in the LAN environment to interconnect high-end host computers and on the interworking of ATM-based LANs with legacy LANs.

In this article, the authors introduce ATM LAN requirements, followed by a discussion of possible ATM LAN architectures to support these requirements. The article then covers current standards and their relation to the possible architectures, and concludes with a discussion of current ATM LAN issues and directions.

ATM Local Area Networks: A Survey of Requirements, Architectures, and Standards

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Initially, asynchronous transfer mode (ATM) technology was primarily considered for applications in wide area networks. Interest in ATM came from the traditional telecommunications carriers and their suppliers. However, there has been an emerging interest in deploying ATM technology in the local or campus network. A typical ATM local area network (LAN) would use a mesh topology of ATM switches and standard ATM protocols. Motivation for ATM LANs can be summarized by the following observations and resulting technical challenges in the local and campus areas:

- Emerging applications, such as video distribution, computer imaging, and multimedia conferencing require very high bandwidths and multimedia capabilities.
- Performance of computers is increasing at a rapid pace, with some computers able to source/sink 100 Mb/s.
- Because of the short distances, high-bandwidth links are relatively inexpensive in the local and campus environments, and deploying them for LANs can be economically justified.
- Today's local and campus networks may not provide the required bandwidth and quality of service (QoS) to support future applications needs.
- Today's local and campus networks may not provide the scalability and bandwidth to support an ever increasing user population [1].

ATM is an ideal technology to meet the above challenges in the local area. ATM offers flexible bandwidth allocation at high speeds and a scalable architecture that is not limited by the technology. ATM is the first technology to support seamless integration across local, metropolitan, and wide area networks. While ATM offers many benefits in the LAN environment, ATM LANs must provide transparent interworking with existing LAN technologies to be successful.

In this article we focus on the application of ATM in the LAN environment to interconnect high-end host computers and on the interworking of ATM based LANs with legacy LANs. We first discuss ATM LAN requirements and ATM LAN architecture functions to support these requirements in the second and third sections, respectively. We then examine current standards and implementations, and their relation to the architectures. The article is concluded with a discussion of ATM LAN issues and directions.

ATM LAN Requirements

Most current LAN technologies offer connectionless, best-effort service to transfer variable-size data packets between host computers and peripherals on the local network. LAN technologies support point-to-point, multicast, and broadcast data transfer. Many current protocols, such as Transmission Control Protocol/Internet Protocol (TCP/IP) [2], Novell IPX [3], and Appletalk [3], rely on broadcast capability for address resolution, service advertising, and so on. Since current LAN technologies are connectionless, user applications and protocols are not required to establish a connection before submitting data for transmission over the LAN media [4]. In addition, applications and protocols are not required to specify traffic characteristics before transmitting data; data is simply submitted, and protocol mechanisms are used to recover from errors or lack of bandwidth.

The most common LAN technologies today are based on the IEEE 802 family of standards, as shown in Fig. 1. In this architecture the data link layer is divided into two sublayers, logical link control (LLC) and media access control (MAC). The LLC offers a common interface and services to the network layer, while the MAC sublayer and the physical layer implement the media-specific functions — token passing, carrier sense multiple access with collision detection (CSMA/CD), and so on. All stations on an 802-based LAN have a globally unique, 48-bit MAC layer address with a flat address space. Well-known group, multicast, and broadcast addresses are defined. Currently LANs are interconnected via bridging or routing functions to form larger LAN internetworks. Bridges operate at the MAC layer, while routers operate at the network layer, independent of the MAC.

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Routers are dependent on the network layer protocol(s) used in the LAN. Routers allow greater control and better management facilities, and may be used to construct larger networks than bridges [4].

Therefore, to be a replacement for and work with existing LAN technologies, ATM LANs must:

- Transparently support existing applications, protocols, and operating systems
- Provide connectionless service
- Support multicast and broadcast traffic and service
- Provide address resolution

As noted above, ATM LANs must not only interwork with and support existing LANs; they must also support new advanced applications and protocols that take advantage of ATM-based services: ATM-capable applications. The requirements to support ATM capable applications are generally different from traditional, data-oriented applications supported by LANs today. These future applications require connection-oriented services, higher bandwidth (5–150 Mb/s), QoS guarantees, maintenance of timing relationships, and so forth.

At the same time, network administrators require simplified network configuration and flexible assignment of network resources. Today's workplace is a dynamic environment with employees moving offices, changing work assignments, and changing workgroups. Faced with these changes, network administrators and users want flexibility while still maintaining their network connectivity. Moving and adding network nodes (e.g., workstations) and making other changes, such as address changes, in traditional legacy LANs require time-consuming and expensive activities. These needs led to the concept of the virtual LAN, where workers can be moved or workgroups changed with minimum effort. Users are not constrained to a subnetwork by the physical port to which they are attached, as in today's router-based networks. The distinction between a LAN, a metropolitan area network (MAN), and a wide area network (WAN) is becoming blurred and in theory is only a matter of geographic dispersion [5]. To ease this administrative burden, ATM LANs should support one or more virtual LANs or workgroups on the ATM network.

In summary, an ATM LAN must provide a way for existing LAN applications and protocols to operate over ATM between ATM-attached hosts, support interoperability with hosts attached to legacy LANs, support grouping hosts into virtual workgroups, and support future applications. Figure 2 [6] illustrates an ATM LAN with an interworking unit (IWU), which provides translation functions between legacy LANs and ATM (e.g., between Ethernet and ATM).

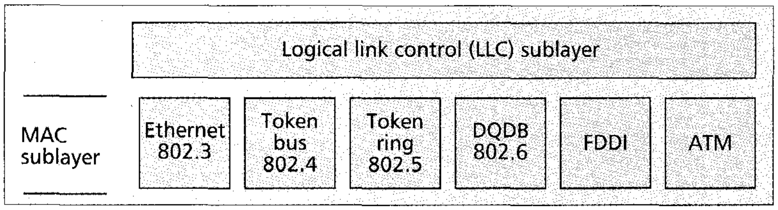


Figure 1. *IEEE 802 architecture.*

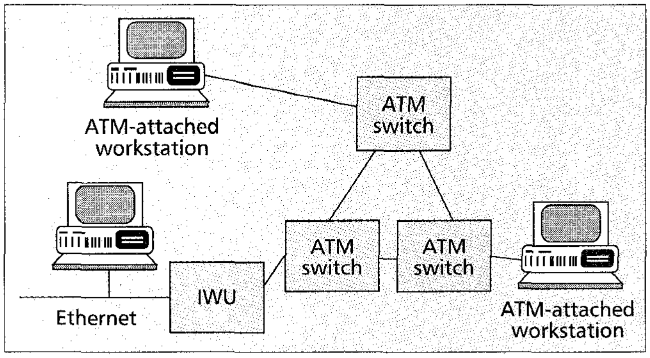


Figure 2. *An ATM LAN.*

ATM LAN Architecture Functions

To meet the requirements outlined above, ATM LAN architectures must support:

- Connectionless services for existing LAN protocols and applications
- Connection-oriented services for future applications
- Application programming interfaces (APIs) and protocol services that are transparent to existing LAN applications and protocols
- APIs for future applications that are specifically designed to take advantage of ATM
- Address resolution between ATM addresses, MAC addresses, and other higher-layer protocol addresses such as IP
- Broadcast and multicast services
- Virtual workgroups or LANs
- Interworking between hosts attached to legacy LANs and hosts attached directly to the ATM network

Connection-Oriented and Connectionless Services

ATM is connection-oriented, but does not directly support the connectionless service required in an ATM LAN. Inherently, therefore, ATM will support future applications that require or can utilize connection-oriented services. To provide connectionless services, the International Telecommunications Union (ITU) has defined two general approaches, direct and indirect [7], either of which can be used in ATM LANs to support connectionless services.

Direct Approach — As shown in Fig. 3, in the direct approach connectionless service functions (CLSFs) are located in the network [4]. The CLSFs can be implemented as adjuncts to the ATM switches or within the switches themselves. To send data, end nodes forward connectionless data packets over ATM virtual connections to a designated CLSF. End nodes

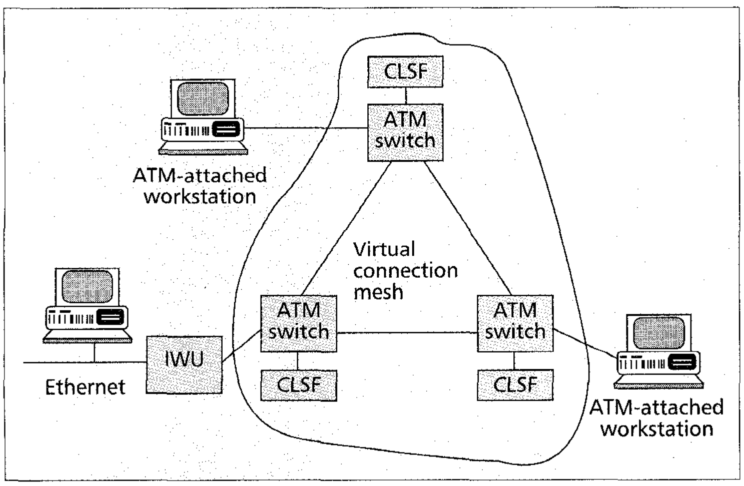
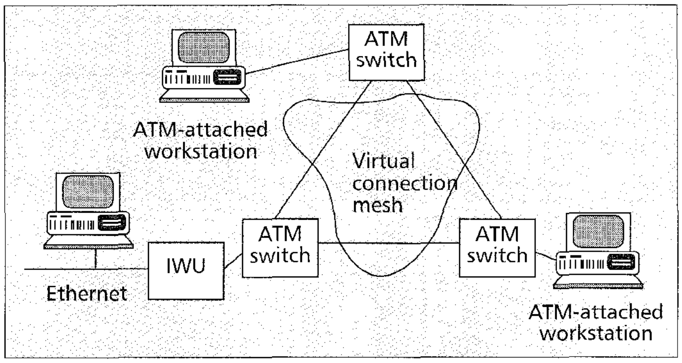


Figure 3. *Direct approach ATM LAN.*



■ **Figure 4.** *Indirect approach ATM LAN.*

may be IWUs, such as LAN hubs, bridges, or routers, or host computers with ATM interfaces. The CLSFs act as packet switches, forwarding data packets to destination end nodes or other CLSFs as required by the destination address of the packets. Within the network the CLSFs are connected over ATM virtual connections to form an overlay network of packet switches to the ATM network [4].

The direct approach has many advantages, including a reduced number of connections (only one connection to the connectionless server is required from end nodes such as host computers, bridges, routers, etc.), a reduced number of connections through the network (only connections between connectionless servers are required), and statistical gain. While these advantages may be important in the wide area, they are not as significant in the local area. The most significant disadvantage of the direct approach is the interjection of the connectionless server, a packet switch, in the network [7]. Depending on design and implementation, the connectionless server could be a performance bottleneck.

Indirect Approach — As shown in Fig. 4, in the indirect approach connectionless service is offered through the use of virtual circuits established between pairs of ATM-attached devices or end nodes. The end nodes support the connectionless service directly by forwarding data packets between the source end node and destination end node(s) over a separate ATM connection for each source and destination pair [7]. The indirect approach therefore creates a mesh-connected network between the end nodes over the ATM network. This approach can be based on permanent virtual circuits (PVCs), switched virtual circuits (SVCs), or a combination of both. The indirect approach based on a mesh of pre-provisioned PVCs is simple; however, the number of PVCs and maintenance of the PVCs is a concern and rapidly becomes unacceptable. For a network of N nodes the number of connections is $N \times (N - 1)$.

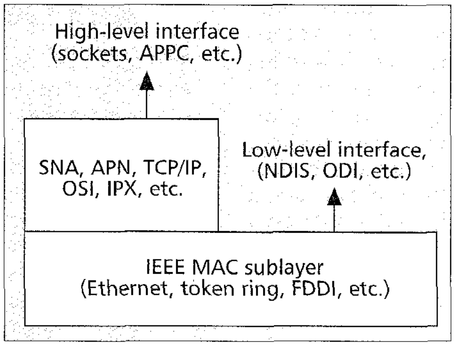
Since every node is not likely to need a connection to every other node all the time, the number of active connections can be reduced to only those needed in a specific instance with connections made between the nodes using SVCs. Since data transmission generally involves several packets, the connections can be set up and remain active until either it is clear that the data transmission is complete or a timer expires. This reduces the setup and release burden on the switches [4].

While connecting nodes on an ATM LAN through SVCs and/or PVCs has several advantages over the direct approach, including elimination of the connectionless server bottleneck, there are many technical challenges, including address resolution and rapid connection setup (to support the first packet in a transaction) that must be overcome. In addition, regardless of whether PVCs or SVCs are used, the indirect approach may suffer from poor utilization of network resources, specifically bandwidth.

Applications Programming Interfaces

ATM LANs must provide an API and protocol services that are transparent to existing applications and protocols, support interworking between hosts attached to legacy LANs and hosts attached directly to the ATM network, and support future ATM-capable applications. The protocol services must include LAN protocol data unit (PDU) framing for transport across ATM.

Two API types are of most interest in ATM LANs. The first, called "high-level" APIs, provide an interface at higher levels in the open systems interconnection (OSI) protocol model. The second type, located lower in the OSI model and called "low-level, " provides an interface at the MAC level [6–8]. Figure 5 illustrates both types of interfaces [8].



■ **Figure 5.** *ATM LAN programming interfaces.*

The low-level interface provides the same services as an IEEE MAC. In other words, the ATM LAN supports an ATM MAC sublayer that emulates the IEEE MAC sublayer shown in Fig. 6. Emulating the MAC sublayer provides direct compatibility with existing applications and protocol suites, and interoperability with existing LAN technologies, including bridges and routers. The ATM MAC sublayer generates the MAC PDU for the type of LAN supported (e.g., Ethernet) and any headers to support multiplexing. The ATM MAC sublayer will allow the installed LAN base to migrate to ATM LANs without major changes and supports interoperability with interworking devices such as bridges, routers, or hubs. These interworking devices, or units, can connect computers on an existing LAN media to the ATM LAN [4].

While an API at the MAC level is required to support existing protocols, a high-level interface has advantages. The high-level interface could exist all the way up the protocol model to the application layer, supporting ATM-capable applications [4]. A high-level interface is more efficient and may provide higher performance, since this solution avoids emulating the MAC sublayer. An interface at the network layer is an example of a high-level interface. The disadvantage of interfacing at the network layer is the number of network-layer protocols for which a direct interface would have to be defined. Higher-layer PDU encapsulation is supported in this method.

To support existing LANs and meet future application needs, both programming interfaces may coexist on an ATM LAN. In the future, the ATM virtual channel identifier (VCI) can be used as the demultiplexing identifier all the way up the protocol stack to the application process. This implies a radical departure from existing protocol stacks. Of course, this assumes an all ATM end-to-end connection [4].

Address Resolution

Today's LAN protocols take advantage of the inherent broadcast ability of existing LANs to support address resolution. Since ATM does not inherently support broadcast capability, an ATM LAN must have a means to support address resolution built on ATM connection-oriented services. As noted above, host computers or other networking devices attached to an IEEE 802 LAN are identified by their MAC address. If this node is now attached directly to an ATM LAN via an ATM interface or an IEEE 802 LAN that is connected through an IWU, the ATM-to-MAC-layer address must be resolved. In addition, if the high-level API is used, the higher-layer address (e.g., network layer) to ATM address must be resolved.

Address resolution can be supported through either a broadcast address resolution mechanism, similar to the IP Address Resolution Protocol (ARP), or a distributed address database [4]. In both solutions the sending host computer transmits an address resolution request. In a broadcast address resolution mechanism, for unicast addresses, the sending host broadcasts an address resolution request to all hosts on the local ATM LAN subnetwork and to all devices that interconnect subnetworks. All hosts check the destination MAC address in the request, and the owner of that MAC address responds with its ATM address. Group, multicast, and broadcast address resolution will require a special algorithm to resolve the addresses. Similar techniques would be used if the protocol interface were at higher layers.

In the address database solution, address resolution requests are handled by an address resolution server in the network. The server maintains a table of the MAC, or higher-layer protocol, address to ATM address mapping for each host on the ATM LAN, including hosts on legacy LAN segments attached to the ATM LAN through an IWU. Hosts that need to resolve an address to an ATM address send the request to the address resolution server. The address resolution server responds with the ATM address.

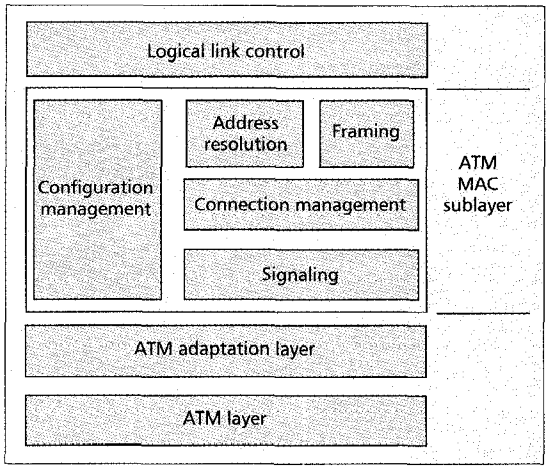


Figure 6. *ATM MAC sublayer.*

Broadcast and Multicast Services

Any frame sent on today's shared-medium LAN is received by all hosts, or other devices, on the LAN. The LAN is defined by the broadcast group membership. Group membership is easily defined by configuring the host with the groups to which it belongs [8]. Membership is usually defined by physical connections today. In a switched technology such as ATM, these capabilities are not easily supported. To support multicast and broadcast capability, cells received on an ATM interface must be replicated on all ATM interfaces within the multicast or broadcast group. Two types of multipoint connections have been defined in ATM that could be used to support multicast and broadcast capability: point-to-multipoint and multipoint-to-multipoint.

Like legacy LANs, any host on an ATM LAN may be a source or destination of multicast traffic. The most efficient way to support multicasting is through multipoint-to-multipoint connections. This method requires some form of multiplexing at the receiving end (e.g., the ATM adaptation layer, AAL, 3/4 multiplexing identification, MID) or the use of multiple virtual channel connections (VCCs). Since AAL 3/4 has experienced little support in the ATM LAN environment, its use for multicasting is unlikely. Another method is to use a token-passing scheme among the members of the broadcast group to arbitrate access to the multipoint-to-multipoint connection [8].

Multicasting can also be supported through point-to-multipoint connections in one of two ways. The first method uses a point-to-multipoint connection from every host to every other host in the multicast or broadcast group. This requires a point-to-multipoint connection from every host and continuous maintenance in every host of the group address. This could lead to significant management overhead. The second method is to incorporate a multicast/broadcast server in the ATM LAN. In this method each host sends multicast traffic over a point-to-point connection to the server. The server in turn sends the multicast to the members of the group over a single point-to-multipoint connection. Only the server has to maintain the addresses and connections for the group or groups. This is a much simpler approach.

Given the complexity of the other solutions and the current standards, the server-based point-to-multipoint method is the most appropriate choice for ATM LANs [8].

Virtual LANs

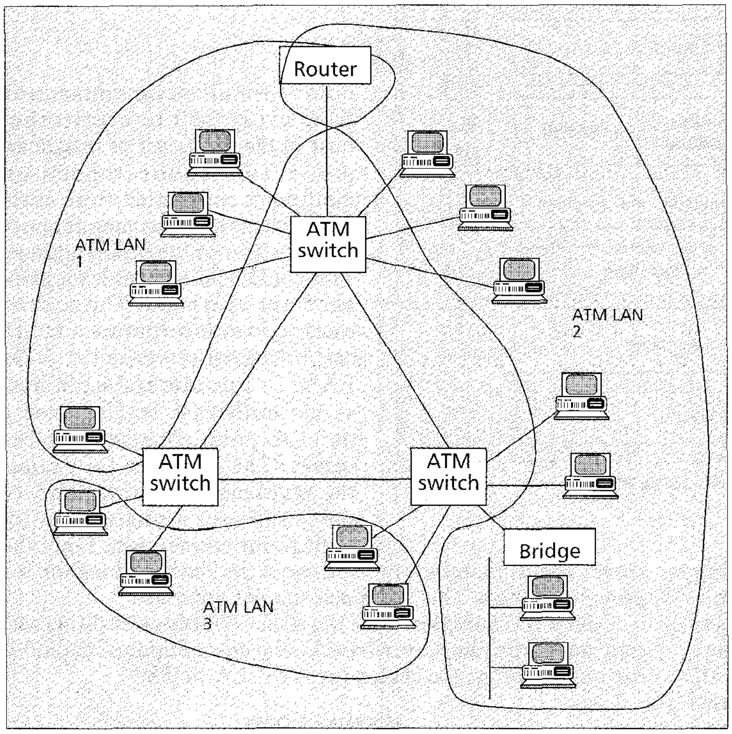
A virtual LAN is a group of network nodes, or hosts, that are not necessarily connected to the same physical LAN segment or located within the same geographic area. However, this group of nodes behaves like a traditional LAN with multicast and broadcast traffic received by all nodes on the virtual LAN. Virtual LANs can be supported either through the ATM MAC sublayer or by interfacing the higher-layer protocols directly to the AAL, the high-level interface, and forming virtual workgroups at the higher layers (e.g., at the network layer). Figure 7 [4] illustrates an ATM LAN supporting three virtual LANs. An ATM LAN can span several ATM switches. Network management or registration procedures can be used to enroll a host or an IWU in an ATM LAN. Registration in the virtual LAN could be by MAC or higher-layer address. If a host is moved from one switch port to another, the network can automatically reconnect the host to its appropriate ATM LAN based on its MAC or higher-layer address.

The router shown in Fig. 7 is a member of both ATM LANs 1 and 2 — virtual LANs — and is used to interconnect them. The router is a packet switch, and in this case is a potential bottleneck in the internetworking of these two ATM LANs. A more efficient means of supporting interconnection between virtual LANs is to allow hosts on different LANs to communicate directly over ATM virtual connections once the addresses have been resolved and the connections established. This may involve a two-step process, where the initial connection is made using the MAC sublayer, but switches to a high-level interface.

Legacy LAN Interworking

ATM LANs must also support interworking between hosts within the virtual LAN that are attached over an ATM interface and those attached to legacy LANs. As discussed above, this legacy LAN interoperability is supported by IWUs connecting the legacy LANs to the ATM network along with compatible interworking functions in the ATM-attached hosts. For example, an IWU may be an Ethernet switching hub with the additional necessary interworking functions.

The required interworking functions include:
- ATM layer functions
- AAL functions
- PDU framing or encapsulation



■ **Figure 7.** *Virtual LANs.*

- Legacy LAN, or MAC sublayer, to ATM address resolution and mapping as discussed above

The ATM layer and AAL functions are the same as those found in the ATM-attached hosts. These include normal ATM functions, such as cell framing, header error checking, and idle cell insertion, an agreed-upon AAL, such as AAL 5, associated functions such as segmentation and reassembly and framing, and other necessary user-network interface (UNI) functions, such as signaling.

PDU framing is the agreed-upon method for encapsulating data frames between the legacy LANs and the ATM-attached hosts. PDU framing can include encapsulation at the LAN MAC sublayer, which is equivalent to bridging, or encapsulation of the network-layer PDU, which is equivalent to routing. In either case, the IWU and the ATM-attached hosts must use the same PDU encapsulation format.

Industry Standards

With ATM LAN requirements and architecture functions as the foundation for ATM LANs, it is important to discuss standardization activities. To date, two organizations have developed ATM LAN specifications or recommendations, the ATM Forum and the Internet Engineering Task Force (IETF). The ATM Forum approach is documented in several Forum specifications [9]. The IETF work is documented in a series of Requests for Comments (RFCs).

ATM Forum LAN Emulation

The ATM Forum has produced several specifications related to ATM LANs. The ATM Forum LAN Emulation (LANE) is specified in [9–12]. The ATM Forum is currently developing the second version of the LANE specification [13, 14].

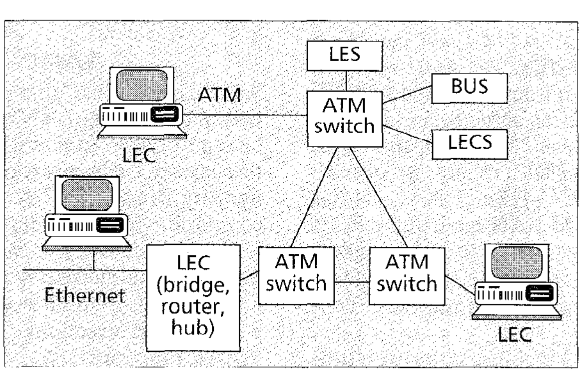
The ATM Forum LANE specification and its addendum define the operation of a single emulated LAN. LAN emulation is the combination of connectionless service, ATM MAC sublayer, address resolution, and multicast functions to support ATM-based LANs and interworking with existing LANs. The ATM Forum LANE specification defines an architecture framework and service interfaces, the system components and functions, framing formats, and protocols and procedures. Protocols and procedures are defined for initialization, making connections between the various system elements, address resolution, data transfer, and connection management for ATM LANs.

The ATM Forum LANE-defined emulated LAN is composed of LAN emulation clients (LECs) and a single LAN emulation server (LES), as shown in Fig. 8. The ATM Forum LANE also includes two other components, the broadcast and unknown server (BUS) and the LAN emulation configuration server (LECS).

Each LEC is part of an ATM end station (host computer, bridge, router, hub, etc.). The LEC represents a set of hosts identified by their MAC address. The LEC performs data forwarding, address resolution, and other control functions for the hosts it represents. Communication between the LECs and the LES, BUS, and LECS is through ATM VCCs. Multiple VCCs may be established between an LEC and the LES to improve efficiency. These VCCs may be PVCs, SVCs, or both. SVCs are established using ATM Forum-defined UNI signaling.

The LES may be implemented in a host computer or switch and may be distributed or centralized. The LES implements the control coordination functions for the emulated LAN and provides a facility for registering and resolving MAC addresses and/or route descriptors to ATM addresses. LECs register LAN destinations (MAC addresses) they represent with the LES and query the LES to resolve a MAC address and/or route descriptor to an ATM address. Once an address has been resolved the LEC caches the address for a specified time limit to support future connections to that destination and reduce address resolution requests. Through the LES, ATM Forum LANE supports the database server form of address resolution.

The BUS handles data sent by an LEC to the broadcast MAC address, all multicast addresses, and unicast packets sent by an LEC before the destination ATM address has been resolved and direct virtual connection established. The LECS is an optional component that implements the automatic configuration and assignment of LECs and the nodes they represent to an emulated LAN. The LECS supports the ability to assign an LEC in an emulated LAN based on either physical location or the identity of a LAN destination it is representing.



■ **Figure 8.** *ATM Forum emulated LAN.*

The ATM Forum LANE architecture uses a hybrid of the direct and indirect approaches to support connectionless service. Functions in the LEC, LES, and BUS use the direct connectionless service approach for broadcast and multicast traffic and packet routing of unicast traffic until a virtual connection is established. After a connection between LECs is established, the indirect approach for providing connectionless service is used. The traffic flows over a PVC or an SVC between two communicating LECs.

The hybrid approach of supporting connectionless service in ATM Forum LANE creates two possible paths between LECs, one via the BUS and another via a virtual connection after it is established. The LEC may send data along these two paths at different times. Depending on the time difference in sending packets along these two paths, BUS load, and network delays, the packets may be received out of sequence at the destination. To avoid packets being received out of sequence, ATM Forum LANE supports the flush message procedure. When using the flush procedure, the sender transmits a flush message over the path through the BUS before switching to the path over a virtual connection. The sender then holds or discards data until the flush message is acknowledged by the receiver. Once the flush message is acknowledged, the sender sends data along the virtual connection path. Instead of using the flush procedure, the sender could also ensure that all data sent through the BUS has been received by waiting a sufficient amount of time to account for network delays, and then send data over the virtual connection path.

The ATM Forum LANE architecture provides the low-level programming, or MAC sublayer, interface. The high-level interface is not supported. In the ATM Forum model the LECs communicate with each other and with the LES, LECS, and BUS through a well defined peer-to-peer interface — the LANE UNI (LUNI). The ATM Forum layered model defines the ATM MAC sublayer interfaces, or primitives, to higher-layer protocols and interfaces within the sublayer. The services provided by the ATM MAC sublayer to the higher layers are designed to include the essential primitives and parameter sets of common MAC driver interfaces in use today, such as the Network Driver Interface Specification (NDIS) and Open Data Link Interface (ODI). The other services and interfaces defined in the LANE model include the interfaces between the LANE layer and the AAL, connection management services to the higher layers, and layer management services.

The ATM Forum specification defines two types of VCCs, control and data VCCs. Control VCCs are used to transfer control and configuration data between the LEC, LES, and LECS. Data VCCs are used to transfer data between LECs and between an LEC and the BUS. The ATM Forum LANE uses AAL5 for all transmission of control and data frames. The ATM Forum specification defines the LAN PDU framing, or encapsulation, formats for IEEE 802.3, Ethernet, and IEEE 802.5, token ring. Figure 9 shows the ATM Forum AAL5 payload format for IEEE 802.3/Ethernet frames.

The ATM Forum LANE Client Management specification [11] defines the management information base (MIB) for configuration, fault, and performance management of LANE clients. The LANE Server Management specification [12] defines the MIB for the LES, BUS, and LECS. The LANE management specifications are based on the Simple Network Management Protocol (SNMP) version 2, but do not preclude the use of SNMP version 1.

The ATM Forum is currently developing version 2 of LANE over ATM. Two working documents are in draft form at this writing [13, 14].[1] The LANE version 2 LUNI specification supports connections to multiple emulated LANs over a single VCC from an LEC (LANE version 1 only supports connection to one emulated LAN) and supports enhanced multicast functions through a special multicast server (SMS), or point-to-multipoint VCCs between LECs. In the version 1 specification all multicast data is handled by the BUS. Additional updates in the version 2 LANE specification include a new packet format that adds a version 2 header to version 1 packet formats and expanded signaling of traffic descriptors.

LE header	Destination MAC address	Source MAC address	Type/ length	Information
2 octets	6 octets	6 octets	2 octets	50–100 octets

Figure 9. *ATM Forum LANE, IEEE 802.3/Ethernet data frame format.*

LLC AA-AA-03	OUI 00-00-00	Ethertype 08-00	IP PDU
3 octets	3 octets	2 octets	

OUI - organizationally unique identifier
Ethertype - identifies network-layer protocol

Figure 10. *IETF RFC-1483 LLC encapsulation, payload format for routed IP PDUs.*

The LANE version 2 LNNI (LANE network-network interface) specification defines the interfaces between an LEC and LANE service entities, and the protocols and procedures for interaction between LANE service entities.

In summary, the ATM Forum LANE uses a client-server architecture, a hybrid of the direct and indirect connectionless service approaches, an address resolution server, and a broadcast server. The ATM Forum LANE provides a low-level interface at the ATM MAC sublayer. Separate ATM Forum ATM LANs are interconnected through a router. Routers create a potential performance bottleneck.

IETF RFCs

The IETF has produced several RFCs defining the operation of data transmission protocols over ATM. While some of the IETF work supports multiple protocols, the majority of the RFCs define solutions for the TCP/IP protocol suite. The IETF RFCs do not define a specific ATM LAN architecture as in the ATM Forum LANE specification. Two of the most important and widely referenced initial IETF RFCs defining ATM LANs are RFC-1483 [15] and RFC-1577 [16]. Two additional RFCs that support the IETF definition of IP over ATM are RFC-1626 [17] and RFC-1755 [18].

RFC-1483 describes two LAN PDU encapsulation methods for carrying routed and bridged PDUs over AAL5. The first method allows multiple protocols to be multiplexed over a single virtual circuit. The protocol of a carried PDU is identified by prefixing the PDU with an IEEE 802.2 LLC header. This method is called "LLC encapsulation." For routed protocols, RFC-1483 defines LLC encapsulation payload formats for routed International Organization for Standardization (ISO) PDUs and routed non-ISO PDUs. Figure 10 shows the AAL 5 payload format for routed IP PDUs. For bridged protocols, RFC-1483 defines the LLC encapsulation payload format for Ethernet, token bus, token ring, fiber distributed data interface (FDDI), and IEEE 802.6 MAC protocols. Figure 11 shows the AAL 5 payload format for bridged IEEE 802.3/Ethernet PDUs.

The second encapsulation method defined in RFC-1483 multiplexes protocols by ATM VCCs. This method is called "VC-based multiplexing." For routed protocols the network-layer PDU is simply inserted into the payload of the AAL5 PDU. For bridged protocols, RFC-1483 defines the AAL5 payload format for Ethernet, token bus, token ring, FDDI, and IEEE 802.6 MAC protocols. Figure 12 shows the AAL 5

[1] *The LAN Emulation Version 2 specifications [13, 14] are drafts and are subject to change.*

LLC	OUI	PID	PAD	Destination MAC address	Source MAC address	Type/ length	Info	Ethernet FCS (optional)
AA-AA-03	00-00-00	00-00 or 00-07	00-00					
3 octets	3 octets	2 octets	2 octets	6 octets	6 octets	2 octets		4 octets

OUI - organizationally unique identifier
PID - protocol identifier

■ **Figure 11.** *RFC-1483 LLC encapsulation, payload format for bridged IEEE 802.3/Ethernet PDUs.*

payload format for bridged IEEE 802.3/Ethernet PDUs in the VC-based multiplexing method. Other than 00-00 in the first two octets and the optional frame check sequence (FCS), this frame format is the same as the ATM Forum LANE data frame format. 00-00 in the first two octets is one of the LE header options in the ATM Forum format. The FCS is not included in the ATM Forum data frame format.

RFC-1577 describes the initial application of "classical" IP within an ATM network as a logical IP subnetwork (LIS). ATM is a direct replacement for the LAN media and for IP links between routers. The goal of RFC-1577 is to allow compatible and interoperable implementations for transmitting IP and address resolution protocols over ATM AAL5. RFC-1577 defines the protocols and procedures for IP data transfer, address registration, and address resolution.

In the RFC-1577 IP subnetwork configuration, each LIS operates and communicates independent of other LISs on the same ATM network. The LIS is a virtual LAN. Hosts connected to ATM communicate directly with other hosts within the same LIS. Communication with hosts outside of the local LIS is provided by IP routers, just as IP subnetworks are connected today — the "classical model." In the RFC-1577 model a router may be connected to more than one LIS over the same physical interface. RFC-1577 uses RFC-1483 LLC encapsulation of routed protocols. It should be noted that RFC-1577 specifies a different encapsulation than the ATM Forum LANE specification.

RFC-1577 defines the ATM Address Resolution Protocol (ATMARP), based on IP ARP, and the Inverse ATMARP (InATMARP), based on IP Inverse ARP. Address resolution for ATM networks supporting PVCs and SVCs is defined. In a PVC-based network, the hosts must be configured with the PVCs. All hosts on an LIS use the InATMARP. In an SVC-based network, an ATMARP server within the LIS resolves IP-to-ATM addresses. The ATMARP server has authority for resolving ATMARP requests for all IP members in the LIS. The server depends on the LIS members to register with the server. Connection between the LIS member and the ATMARP server is a point-to-point VC. Once an LIS member registers with the ATMARP server, the server caches the addresses and uses this information to resolve address resolution requests from other hosts on the LIS. Once the destination ATM address is determined, an SVC is established. Hosts cache the addresses for a specified time. RFC-1577 does not address broadcast and multicast capability. Figure 13 illustrates an RFC-1577 ATM LAN.

RFC-1577 utilizes the indirect approach to support connectionless services and address resolution. PVCs or SVCs are used to connect two communicating network nodes. The direct approach using a connectionless server is not incorporated in these IETF RFCs.

RFC-1626 [17] defines the default maximum transmission unit (MTU) size for IP over AAL5. RFC-1755 [18] defines the ATM call control signaling exchanges to support classical IP-over-ATM implementations described in RFC-1577. RFC-1755 describes the information elements in the signaling message to support IP. RFC-1755 uses ATM Forum UNI signaling.

An update to RFCs 1577 and 1626 is currently in progress. This Internet draft[2] [19]:

- Incorporates the text of RFC-1626
- Clarifies several points from RFC-1577, including packet formats and ARP server configurations
- Defines the operation of address resolution in more detail
- Defines specific management capability via an MIB.

The IETF has also developed several Internet draft documents related to IP networking over ATM. These working documents enhance and supplement the foundation laid by the RFCs mentioned above. The IETF Internet drafts of interest at the time of this writing include [20, 21].

IPMC describes a mechanism to support the multicast needs of layer 3 protocols in general, and describes its application to IP multicasting in particular. ATM-based IP hosts and routers use a multicast address resolution server (MARS) to support multicast over the ATM Forum's UNI 3.0/3.1 point-to-multipoint connection service. Clusters of end nodes share a MARS and use it to track and disseminate information identifying the nodes listed as receivers for given multicast groups. This allows end nodes to establish and manage point-to-multipoint VCs when transmitting to the group. The MARS is an extended analog of the ATM ARP server introduced in RFC-1577 [20]. The IP multicast work is extended in [21] to include IP broadcast transmission.

In summary, the IETF RFCs utilize the indirect approach to support connectionless service, RFC-1483 defines protocol framing for both the low-level interface, using bridged PDU framing formats, and the high-level interface, using routed network-layer framing formats. RFC-1577 specifies routed PDU framing for classical IP-over-ATM. Interconnection between IETF-defined ATM LANs is supported through routers.

Current Issues and Directions

Today's ATM LAN architectures utilize both the indirect and direct approaches as defined by the ITU broadband integrated services digital network (B-ISDN) recommendations. These systems use the direct approach for some functions, such as broadcast packets and packets with unknown destination addresses, and the indirect approach for known destinations. There is also commonality in the means of protocol encapsulation across the industry standards.

While ATM LAN standards development and product availability have converged on similar fundamental architectures, there are a number of issues and concerns associated with ATM LANs. Current LAN emulation architectures (ATM Forum LANE and IETF RFC-1577) suffer from two primary limitations. First, current ATM LAN emulation architectures are bridged networks; therefore, they suffer from the same scalability issues as other bridged networks. Second, current ATM LAN emulation architectures require that connections between nodes on different LISs be through a router like a legacy LAN. Routers create potential performance bottlenecks. To address these issues, both the ATM Forum and IETF are developing next-generation specifications.

Since late 1994 the ATM Forum has been developing the Multiprotocol over ATM (MPOA) specifications [22].[3]

[2] *Internet draft documents represent works in progress. Internet drafts are only valid for six months, and may be updated, replaced, or made obsolete by other documents at any time.*

[3] *The MPOA specification [22] is a draft and is subject to change.*

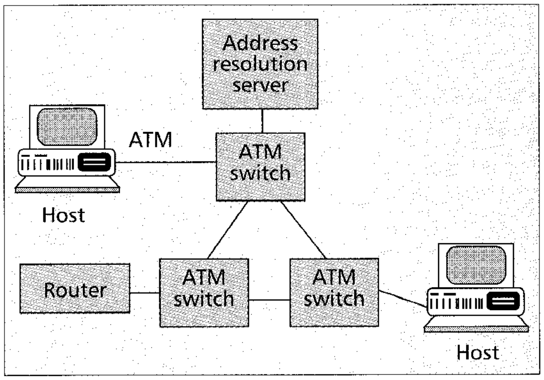
00-00	Destination MAC address	Source MAC address	Type/ length	Information	Ethernet FCS (optional)
2 octets	6 octets	6 octets	2 octets	50–100 octets	4 octets

■ **Figure 12.** *RFC-1483 VC-based multiplexing, payload format for bridged IEEE 802.3/Ethernet PDUs.*

MPOA is the next generation of network-layer routing over ATM. The fundamental purpose of MPOA is to provide end-to-end network-layer connectivity across an ATM fabric, including the case where some network-layer hosts are attached directly to the ATM fabric, some to legacy LANs (subnetwork) technologies, and some are using ATM Forum LANE.

MPOA overcomes some of the scalability limitations of the LANE architecture and standard by supporting connections between nodes on different subnets, or emulated LANs, over the ATM fabric instead of requiring that connections between nodes on different emulated LANs pass through a router. The router presents a potential scalability and performance limitation, especially for nodes connected directly to the ATM network. Using MPOA, nodes attached to an ATM network fabric, but on different internetwork address subgroups (IASGs), can be connected at the network layer using ATM virtual connections. As defined in the MPOA draft an IASG is a range of internetwork- (network)-layer addresses summarized in an internetwork-layer protocol. An IASG may be composed of more than one LANE emulated LAN. In MPOA terminology, this connection, at the network layer, across ATM is called a "shortcut connection." This type of connection eliminates the need to connect nodes on different emulated LANs through routers.

While MPOA might seem to supersede LANE, MPOA works in cooperation with LANE to support emulated LANs within an IASG. In addition, MPOA is adopting and integrating IETF protocols such as the Next Hop Resolution Protocol (NHRP) and RFC-1483. NHRP, with extensions, is used in MPOA for address resolution when establishing shortcut connections. In MPOA, nodes on separate IASGs — subnets or the traditional LAN — can be connected through ATM virtual connections using the indirect approach. This functionality overcomes one of the major limitations on scalability and performance in LANE.



■ **Figure 13.** *RFC-1577 ATM LAN.*

Like the ATM Forum, the IETF is addressing the limitations of current ATM LAN architectures. One example is NHRP [23], which can be considered a generalization of classical IP and ARP over ATM, defined in RFC-1577. First, NHRP avoids the need to go through extra hops of routers when the source and destination belong to different LISs. RFC-1577 specifies that when this is the case, the source station must forward data packets to a router that is a member of multiple LISs, even though the source and destination nodes may be on the same logical nonbroadcast multiple access (NBMA) network, such as ATM. If the source and destination stations belong to the same logical NBMA network, NHRP provides the source node with an inter-LIS address resolution mechanism at the end of which both nodes can exchange packets without having to use the services of intermediate routers. This feature is also referred to as "shortcut" routing. If the destination station is not part of the logical NBMA network, NHRP provides the source with the NBMA address of the egress router toward the destination [23].

While both of the primary limitations of ATM LANE are addressed by the aforementioned architectures that support shortcut connections, such as the ATM Forum MPOA activities and IETF activities such as NHRP, these new architectures also raise a number of technical issues of their own. First, as noted in [5], shortcut connections across LIS boundaries raise issues with the coordination of routing and addressing between the ATM and network layers. Although several routing and address models have been proposed to solve this issue, including the "classical" model (e.g., LANE with routers), the NHRP model, the "conventional" model, the peer model, and the integrated model [5], none of these is without its own issues or clearly superior to the others. The ATM Forum chose another model, the overlay model, for MPOA. The overlay model maps a network-layer address to ATM addresses. The most common issues with each of these models is the potential for routing loops with subsequent limitations on network topologies that can be supported.

Second, in architectures that support shortcut connections (between nodes attached to the ATM network, but on different LISs) when is it most efficient to do so, rather than continuing to use the "classical" connection through a server (router, BUS, etc.)? This switchover requires careful consideration of many factors, including:

- Packets already traversing the path through the router or server (ATM Forum LANE includes mechanisms to manage this situation)
- The criteria used to decide when a shortcut connection is activated
- How long the shortcut connection is maintained in the route cache

In addition to the technical issues noted above, early adopters of ATM LANs must be aware of implementation concerns as well. Two such issues are network design and interoperability. Efficient network design and sizing is a concern. Design rules defining the number of PVCs required, number of SVC setup and releases per second, number of host computers per route, address, or broadcast server, and so on are needed. These rules must be based on the protocols, applications, traffic patterns, mix of attached hosts, and so forth in operation on the network.

Today, interoperability between ATM LAN products from several suppliers is possible (and practical) and has been demonstrated; thus, network designers and operators must account for differences in suppliers' choices and implementation of standards. The encapsulation options defined in RFC-1483 and ATM Forum LANE are a good example. If one supplier chooses to support RFC-1483 LLC encapsulated bridged PDUs in their network interface card or IWU and another supplier chooses ATM Forum LANE data frame formats, the two will not interoperate.

Currently, research groups within the School of Electrical and Computer Engineering at the Georgia Institute of Technology operate ATM networks to support research activities investigating QoS issues, network-layer protocols over ATM, and ATM over wireless media. These networks utilize equipment from multiple suppliers, including Cisco Systems, Fore Systems, Hitachi, and Newbridge Networks.

Conclusion

Significant progress has been made toward making ATM LANs a reality. Architectures and standards that support existing applications and protocols as well as interworking with existing LAN media have been defined, and ATM LAN products are available. Support for and interworking with existing applications, protocols, and LAN media is provided through LAN emulation — a low-level programming interface, an ATM MAC sublayer, and connectionless services. Support for new ATM-capable applications is provided by the high-level interface, direct host attachment to the ATM network, and ATM-based services with guaranteed service quality. Through continuing efforts such as MPOA and NHRP, the standards bodies and private manufacturers are striving to overcome limitations of the current architectures. Also, the standards bodies are working to overcome issues related to shortcut connections of network-layer protocols over ATM, and coordination of routing information between the ATM fabric and the network layer.

Even though ATM LANs are still in their infancy, they hold promise to solve many of the limitations of today's LANs, bring higher bandwidth and flexible service to the desktop, and support higher-bandwidth LAN backbones while supporting interworking with existing LAN technology, applications, and protocols. ATM LANs also support the new business model of geographically dispersed teams and the resultant blurring of boundaries between the LAN, MAN, and WAN. It is not a question of whether ATM LANs will enjoy widescale deployment, but when.

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