LAN Emulation Over ATM

A Technology White Paper

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Executive Summary

This white paper is aimed at network designers and engineers who are looking at the deployment of ATM networking technology within or alongside an existing LAN infrastructure. The paper describes in detail how an ATM network can be made to emulate an existing Ethernet or Token Ring LAN. The benefit of this scheme is that it allows existing LAN applications to run over an ATM network with no modification, and it provides for straightforward interconnection of existing Ethernet and Token Ring LANs with an ATM network. The paper provides a comprehensive tutorial on the LAN Emulation scheme which is the subject of standardization by the ATM Forum, together with a discussion of the practical implications of the scheme and its application in real networks.

About the Author

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The Challenge of ATM Integration

ATM has emerged as probably the single most important step forward in networking of this decade. Barely ten years after the birth of the shared-media LAN technologies Ethernet and Token Ring, ATM offers a completely new way to network - with some compelling advantages.

ATM has been designed from the outset to carry voice, video and bursty data traffic on a single common protocol. And since ATM is based on point-to-point links like the phone system, it suffers none of the scalability and distance limitations of the shared-media LANs. This means that ATM can be used to build very large networks spanning both the local and the wide area, with one common protocol end-to-end. Finally, ATM lends itself to high speed and high capacity networking, and provides more than enough bandwidth to support all imaginable future networking needs.

ATM's power and universality explains why almost every area of the communications industry is supporting the development of the technology, and the standards that will ensure its interoperability. The membership of the ATM Forum includes representation from all the major LAN and WAN equipment vendors, as well as telecommunications service providers and cable TV companies.

It is clear that many organizations using networks today will want to take advantage of the new capabilities that ATM will offer. For some, ATM will mean the deployment of networked video and multimedia applications. For others, ATM will be simply a means to higher performance and lower costs in supporting the networked applications they use today. But in almost all cases, the ability successfully to weave ATM technology into the fabric of today's shared-media networks will be a critical issue.

LAN Emulation Over ATM sets out to address precisely this issue: how to integrate existing Ethernet and Token Ring LANs with ATM networks. The importance of LAN Emulation as a key enabling technology has been recognized by the ATM Forum, and much effort is being applied in the Forum to the development of the standards that will ensure interoperability of LAN Emulation schemes. Madge Networks has been at the forefront of this activity.

The purpose of this white paper is to describe the operation of LAN Emulation Over ATM, to explain how this technology allows today's LAN applications to operate over ATM networks, and to explore the architectural issues of integrated LAN and ATM networks.

Madge Networks is one of the principal architects of the LAN Emulation scheme which is the subject of standardization within the ATM Forum. The substantive design work on the LAN Emulation scheme was carried out by Cisco, Fore Systems, Madge and SynOptics. This White Paper draws on contributions made by Madge to the Forum, and may be regarded as an authoritative guide to the Forum's LAN Emulation scheme as of September 1994, when work on the standard was nearing completion.

The Need for LAN Emulation

The need for LAN Emulation Over ATM arises because the current generation of LAN applications are all architected around the services provided by shared-media LANs like Ethernet and Token Ring, and these services are not provided directly by ATM networks.

Almost all LAN-based network applications, including network operating systems, assume that the LAN is capable of:

- The delivery of datagrams to individual destinations according to a unique MAC address, without the necessity for any kind of connection set-up to that address.
- The delivery of broadcast datagrams to all stations on the LAN or a specified group of stations, by mean of a special kind of MAC destination address indicating broadcast or multicast.

ATM networks do not directly offer either of these services. ATM networks deliver data on Virtual Channel Connections (VCCs) which need to be set up between pairs of end stations before any data can be sent. And ATM networks require point-to-multipoint VCCs to be set up between groups of stations in order for broadcast or multicast data to be sent. So ATM networks are "connection-oriented", by contrast with LANs which offer "connectionless" data delivery.

LAN Emulation provides the "conversion layer" that masks the complexities of ATM connection set-up from the applications that expect connectionless data delivery. LAN Emulation also supports the transmission of the familiar Ethernet and Token Ring frame formats over ATM networks, so that network applications are able to operate over ATM without any modification whatsoever.

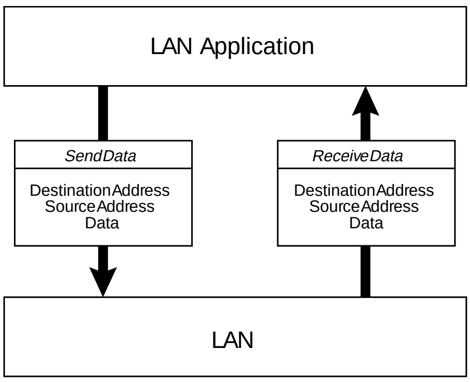

Figure 1: Services provided by a LAN to an application

Data Transmission in ATM Networks

ATM networks consist of end stations and switches, all connected together by physical point-to-point links. Switches have multiple ports supporting connections both to end stations and to other switches.

When a station wishes to communicate to another station, it must signal to the switch to which it is connected that it requires a Virtual Channel Connection (VCC) to that destination station. It does this by talking to the switch using a signalling protocol, which is analogous to telephone dialling. Just like a telephone network, the ATM switches co-operate to locate the required destination according to the ATM address specified by the calling station, and then set up the VCC.

Successful completion of this activity is signalled back to the calling station, including an identifying channel number known as the Virtual Channel Identifier (VCI). The calling station is then free to send data to the destination station. In an ATM network, data is sent in cells which are 48 bytes in length, with a 5 byte header. Cells are addressed by the VCI information in each cell header, which the ATM switches interpret in order to route them to the correct destination.

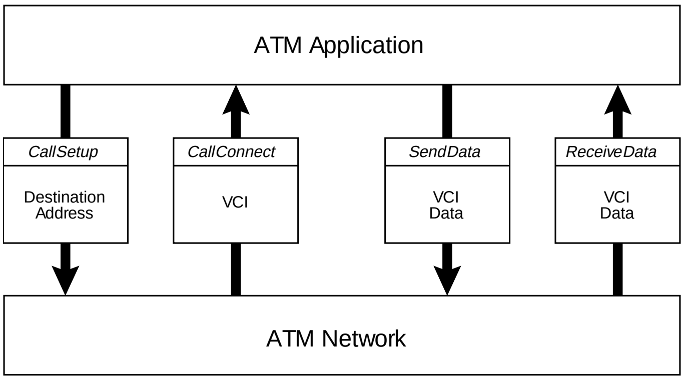

Figure 2: Services provided by an ATM network to an application (simplified)

LAN Emulation in End Stations

When a network application in an Ethernet or Token Ring end station wishes to send data on the LAN, it sends a frame to the network adapter via a standard software interface. The frame contains the MAC destination address, which may be a unique end station, or a broadcast or multicast address, and this is sufficient information for the network adapter to transmit the frame onto the LAN and for it to reach its destination.

This is the interface which must be emulated by an ATM adapter if we are to operate the application successfully over the ATM network with no modification.

Operating under this interface, the adapter must carry out the following steps in order to support the application in sending a frame across the network:

- For the specified MAC destination address, the adapter must determine whether a VCC already exists to that station to allow data to be transmitted. It does this by maintaining a table of mappings between MAC addresses and VCCs that it has already set up.

- If there is no known VCC corresponding to the MAC address, the adapter card has to set one up before it can transmit the data. It does this by means of a two-stage process. First, it carries out an address resolution process, which enables it to learn the ATM address of the end station that answers to the specified MAC address. Then it signals into the ATM network that it requires a VCC to be set up to that ATM address. Having successfully set up the VCC (which is known as a "Data Direct VCC"), it updates its table of MAC address mappings.

- Once the station has established on which VCC the frame is to be transmitted, it takes the frame in its entirety, appends a 2-byte LAN Emulation header to it, and segments it into 48-byte cell payloads. Each cell has a 5-byte header appended to it, containing the Virtual Channel Identifier of the relevant VCC. These cells can now be transmitted across the network.

- At the far end, the cells are received and re-assembled to re-create the original Ethernet or Token Ring data frame. This is then passed to the application running in the end station just as if it had been received from an Ethernet or Token Ring LAN.

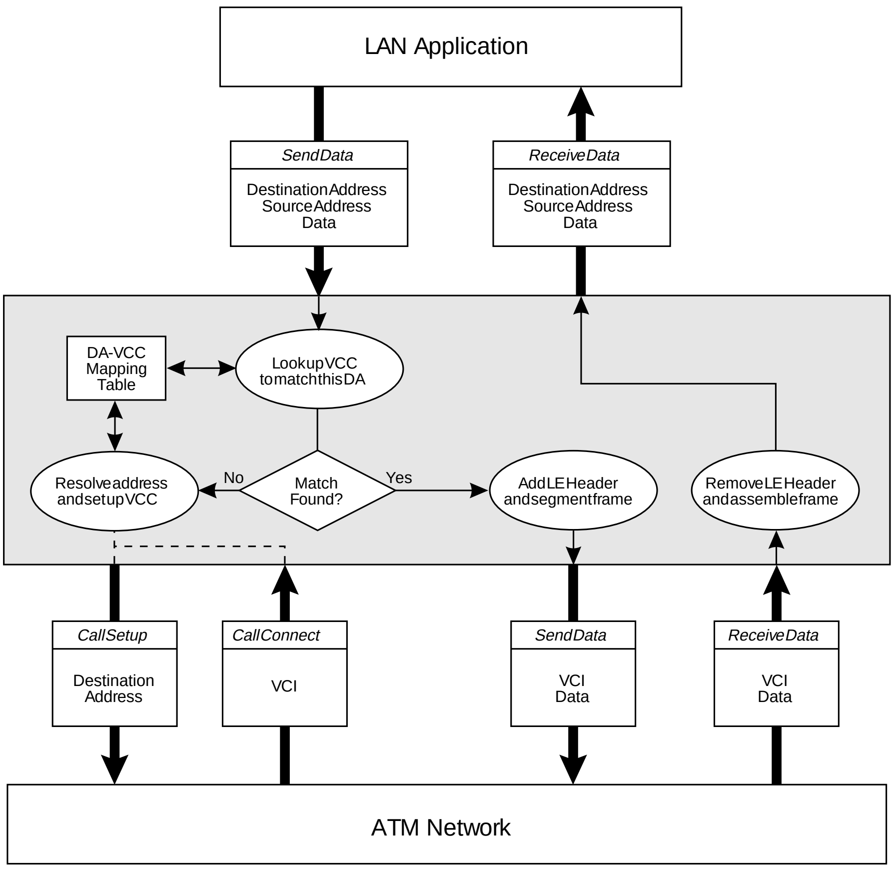

Figure 3: LAN Emulation Client Process as a "Conversion Layer"

At this point, it may be helpful to clarify the difference between a MAC address and an ATM address. Every station on an ATM network must have an ATM address. This is the address that must be specified when signalling into the ATM network to request a VCC to be set up to a particular destination. In addition, every station that wishes to participate in LAN Emulation must have a MAC address, which looks like an Ethernet or Token Ring address. This is the address by which the application knows that station by. The ATM address of a station and its emulated MAC address are not the same. Indeed, it is possible for an ATM station to emulate multiple Ethernet and Token Ring stations simultaneously, and this means it may have multiple MAC addresses.

LAN Emulation in Bridges and LAN Switches

We have described the operation of LAN Emulation from the point of view of an end station, such as a PC or a workstation, with the assumption that both end stations in the communications process are connected directly to the ATM network.

LAN Emulation can also be used in bridge or LAN switching devices to enable physical Ethernet or Token Ring LAN segments to interconnect with other such devices, or with end stations, across an ATM network. In this context, a bridge or a LAN switch can be thought of as a special kind of end station that represents a large number of different MAC addresses, which are the actual Ethernet or Token Ring stations that are connected to it.

Bridges and LAN switches provide connectivity between LAN segments of the same type. Typically, a bridge is a two-port device that connects two Ethernets or two Token Rings together, whereas a LAN switch is a multi-ported device for interconnecting LAN segments of the same type. For the purposes of discussion, we shall refer to both types of device collectively as "bridges".

As we have said, a bridge connects LANs of the same type. It operates by transferring frames from one LAN segment to the other according to the MAC destination address or source route information present in the frames. If we can make an ATM network emulate an Ethernet or Token Ring segment, then we can use a bridge to transfer frames from a physical Ethernet or Token Ring to an emulated one. This simply requires a bridge device that has an ATM interface which supports LAN Emulation.

Bridges apply logic to the transfer of frames according to one of two different mechanisms: transparent bridging or source route bridging. Transparent bridging is applicable to both Ethernet and Token Ring, but source route bridging is used only with Token Ring. In both cases, the mechanisms define the logical rules that a bridge uses to determine whether or not to forward a frame.

In a bridge with LAN Emulation, the bridge receives frames from the physical LAN segment(s) attached to it and applies normal rules of bridging logic to determine whether to forward it. If a frame is to be forwarded, then the bridge examines its MAC destination address and looks this up in a table of VCC mappings. From this point on, the process for sending that frame across the ATM network is identical to that described above for end stations.

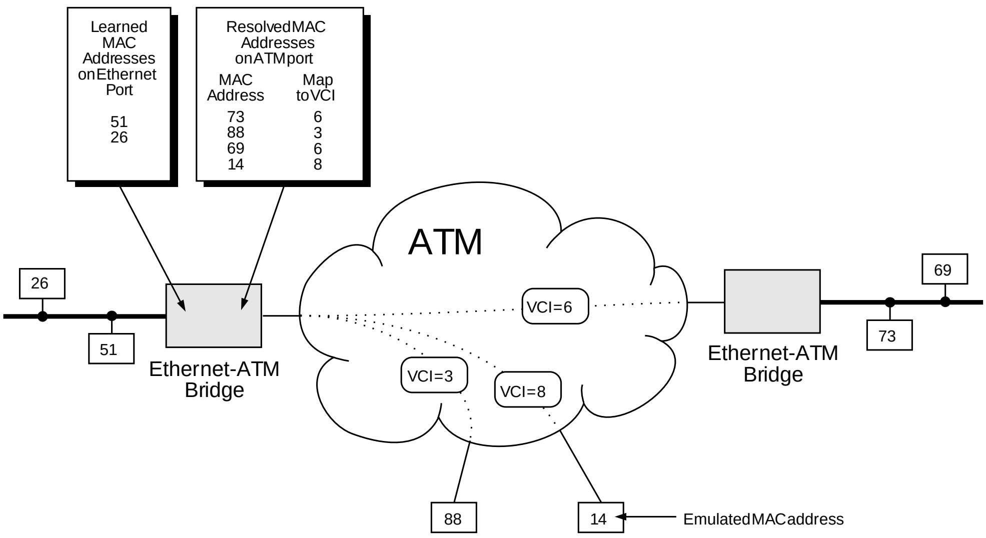

Figure 4: Transparent bridges in a LAN Emulation environment

The Address Resolution Process

One vitally important process that was not explained above is the process by which an end station or a bridge resolves a LAN MAC address to an ATM address so that it can set up a VCC to the relevant end station. This requires an additional process to be operating in the ATM network, which is known as the LAN Emulation Server (LES), and a protocol for communicating with the LES, which is known as the LAN Emulation Address Resolution Protocol (LE_ARP).

While we are defining acronyms, we should also identify any end station or bridge that implements LAN Emulation as a LAN Emulation Client (LEC). Strictly speaking, the LEC is a process that resides in an end station or in a bridge, which provides the entry point to the emulated LAN.

The LAN Emulation Server acts as a clearing house for address resolution requests. When a LAN Emulation Client needs to know the ATM address of another LEC that it knows the MAC address for, it sends a request to the LES using the LE_ARP protocol. If the LES knows what ATM address matches the requested MAC address, it responds to the LEC with this information. If it does not know, it forwards the request to all the other LECs that it knows about so that they can respond directly if they own this MAC address. Some of these LECs may be bridges, and they will respond to the LE_ARP request if the MAC address matches one that they know about on their attached LAN segments.

For this to work, it is necessary for each LEC to have a VCC set up to the LES on which to send LE_ARP requests, and on which to receive responses. This VCC, known as the "Control Direct VCC", is set up by each LEC when it joins the emulated LAN. The join process normally takes place when an end station or a bridge that implements LAN Emulation is started up, as part of its initialization. During the join process, a LEC will exchange information with the LES so that the LES can maintain a table of details of all the LECs currently active on the emulated LAN.

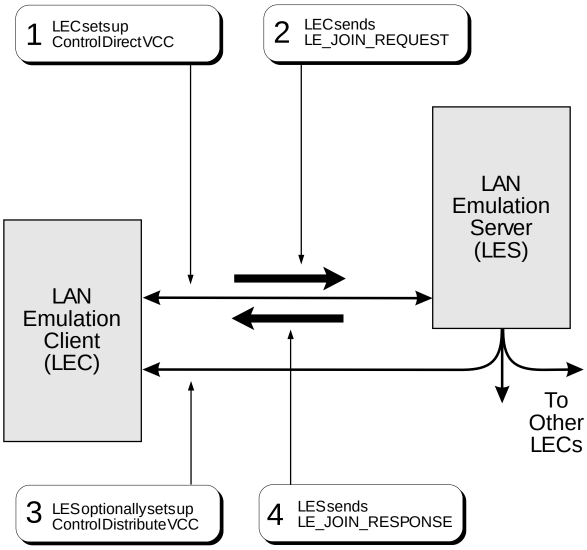

Figure 5: Connecting to the LES and Joining the Emulated LAN

One of the tasks that has to be performed by the LES is the forwarding of LE_ARP requests to multiple LAN Emulation Clients when it is not able to resolve the request based on its own data. This distribution could be carried out via the individual Control Direct VCCs that the LES maintains with each LEC. However, it is more efficient to handle this distribution via a point-to-multipoint VCC, and so the LES may choose to set up such a point-to-multipoint VCC to all LECs as they join. This is known as the "Control Distribute VCC".

In addition, during the join process the LES will issue to the LEC a 2-byte identity code that is unique for this LAN Emulation Client on this emulated LAN, known as the LECID. The LEC will use this value as the LAN Emulation header to be appended to all Ethernet or Token Ring frames before they are segmented into cells.

After joining the Emulated LAN, a LEC may choose to inform the LES about the MAC address or addresses that this LEC represents. This process is known as *registration*. If LECs register their MAC addresses with the LES, then when another LEC requests an address resolution to this MAC address, the LES can respond directly without needing to forward the address resolution request to all the LECs it knows about.

If the LEC is a transparent bridge, it may represent hundreds of MAC addresses, and this list of MAC addresses will change over time as stations on the Ethernet or Token Ring LANs come and go. This type of LEC is not permitted to register its MAC addresses with the LES, since it would require an unreasonable amount of traffic on the Control Direct VCCs to maintain the LES tables up to date. Instead, the LEC registers as a "Proxy", and the LES has to forward all LE_ARP requests to it so that it can respond directly to the LEC that is requesting.

There is an additional requirement of the joining process, to enable the network to deal with broadcast and multicast frames. We'll take a look at that next.

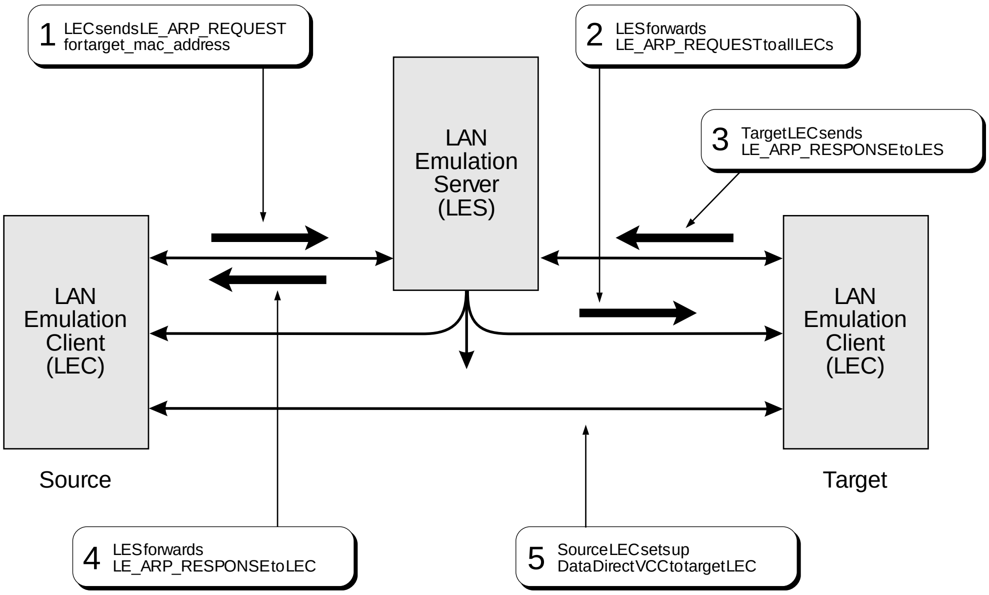

Figure 6: The Address Resolution Process

Forwarding of Broadcast and Multicast Frames

In discussing the LAN Emulation processes in end stations, we didn't cover the special case of broadcast and multicast frames. In fact, the process for dealing with these in the end station is just the same as for unicast frames: the MAC broadcast or multicast destination address is mapped to a VCC, and the frame is segmented into 48 byte cell payloads for transmission on this VCC.

However, the ATM network now has to take care of ensuring that the broadcast or multicast frame reaches all its intended destinations. It does this by means of an additional process in the ATM network known as the Broadcast and Unknown Server (BUS).

When a LEC registers with the LES, it immediately issues a LE_ARP request to find the ATM address that corresponds with the broadcast MAC address (hex FFFFFFFFFFFF). The LES responds to this LE_ARP request with the ATM address of the BUS. The end station then proceeds to set up a VCC to the BUS. This is known as the "Multicast Send VCC".

Once the LEC has established this connection to the BUS, the BUS sets up a return path to the LEC, where possible by adding the LEC to an existing point-to-multipoint VCC. This is known as the "Multicast Forward VCC". Alternatively, the BUS may establish a point-to-point VCC to the LEC.

Whenever the application in the end station requests the transmission of a broadcast or multicast frame, the LEC process in that end station uses this VCC to send the frame to the BUS. When the BUS receives a broadcast or multicast frame from a LEC, it copies the frame and forwards it to all the LECs that are registered with it, using the Multicast Forward VCC(s).

It should be noted that the BUS sends the broadcast and multicast frames to all the LECs that are registered with it, including the LEC that originated the broadcast. It is the responsibility of each LEC to discard any superfluous broadcast "echoes". It can do this by looking for a match between the LAN Emulation header on the frame and its own unique LEC identity (LECID).

Unknown Frames - Transparent Bridging

When one or more of the LECs on an emulated LAN are transparent bridges, there will be occasions when a valid MAC address cannot be located by the address resolution process. This can occur when the MAC address is that of an end station which lies the far side of a transparent bridge, and which has not yet transmitted any frames. The bridge will be unaware of the existence of this station, since the bridge can only learn about stations when they transmit.

If a LEC fails to resolve a MAC address by means of a LE_ARP request, it may forward the frame to the BUS using the Multicast Send VCC. The BUS will treat this frame as if it were a broadcast or multicast, and will forward it to all registered LECs. If these LECs are transparent bridges, their bridging logic dictates that such frames should be forwarded on all attached LAN segments. When the target station replies, the bridge on that segment will learn of its whereabouts, and the next time a LEC attempts an address resolution to this MAC address, the bridge will be able to respond.

This scheme for dealing with unknown MAC addresses carries with it the risk that a badly behaved station could conduct all of its communications via the BUS without ever resolving the MAC address and setting up a Data Direct VCC to the appropriate LEC. Because of this, the LAN Emulation scheme specifies an upper limit on the rate at which a LEC is permitted to send unknown frames to the BUS.

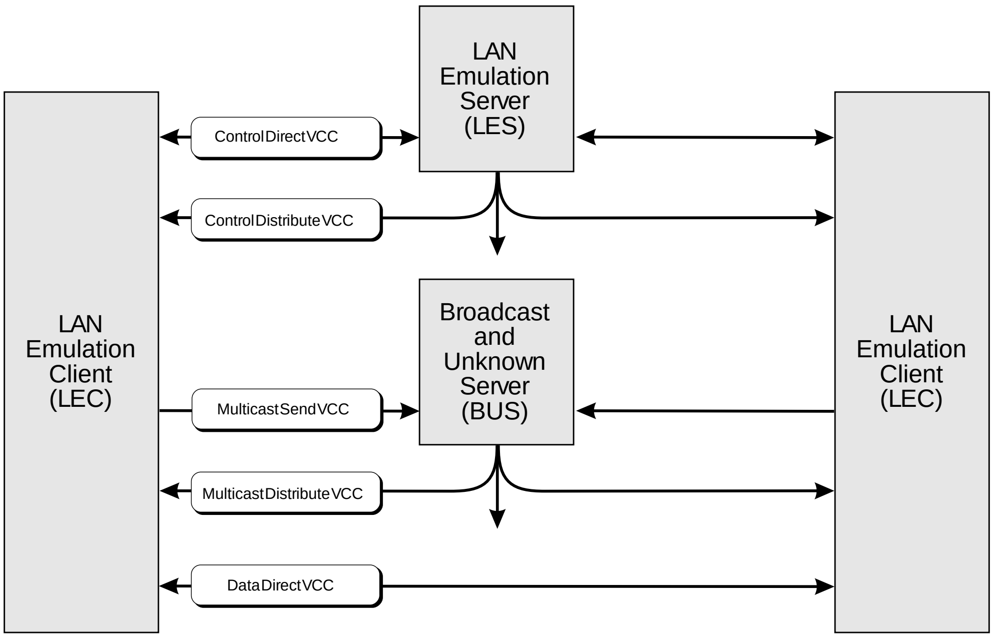

Figure 7: Virtual Channel Connections linking the processes of LAN Emulation

Source Routing on Emulated Token Ring

Source routing is the standard technique for bridging between Token Rings, and the LAN Emulation scheme fully supports source routing in emulated Token Ring on ATM.

In a source routed environment, a Token Ring frame contains a Routing Information (RI) field in addition to MAC source and destination addresses. The RI field contains a list of Route Descriptors (RD) which describe the sequence of ring numbers and bridge numbers that the frame must traverse from source to destination. The route is discovered by Token Ring end stations using a process that involves broadcast route explorer frames, which are handled in the LAN Emulation scheme just like any other broadcast frames.

When a LEC is operating as an emulated Token Ring station in a source routed environment, it has to operate a modified version of the address resolution process. Before issuing a LE_ARP request, it must establish whether the frame that is to be sent needs to traverse a source route bridge or not. It can determine this by examining the RI field in the frame. If there is no RI field present, or the RI field is less than 6 bytes long, or the final ring identified in the RI field corresponds to the emulated ring on which the LEC is located, then it can conclude that the frame is destined for another LEC on the same emulated ring and does not need to traverse a source route bridge. In this case it performs the standard LE_ARP request specifying the MAC address to be located.

If examination of the RI field indicates that the frame does need to traverse a source route bridge, then the LEC must perform a LE_ARP request specifying the Route Descriptor (bridge number, ring number) of the next hop specified in the RI field. This is because source route bridges, unlike transparent bridges, know nothing about the MAC addresses attached to them, but know only about bridge numbers and ring numbers.

The LES may be able to respond directly to a LE_ARP request for a Route Descriptor if the LEC processes in the source route bridges registered the RDs that they represent when they joined the emulated LAN. So in a source routed environment, the LES may contain tables of both MAC addresses and Route Descriptors, with corresponding ATM addresses, to enable it to respond to both kinds of LE_ARP request.

If the LES is not able to respond directly to a LE_ARP request for a Route Descriptor, it will forward the request to those LECs that are registered as Proxies. The appropriate source route bridge that recognizes the Route Descriptor in the LE_ARP request will then respond.

When a LEC receives a response to its Route Descriptor LE_ARP request, it requests the set-up of a Data Direct VCC to the relevant source route bridge, so that all subsequent frames with the same source routing information can be sent directly to the source route bridge on this VCC.

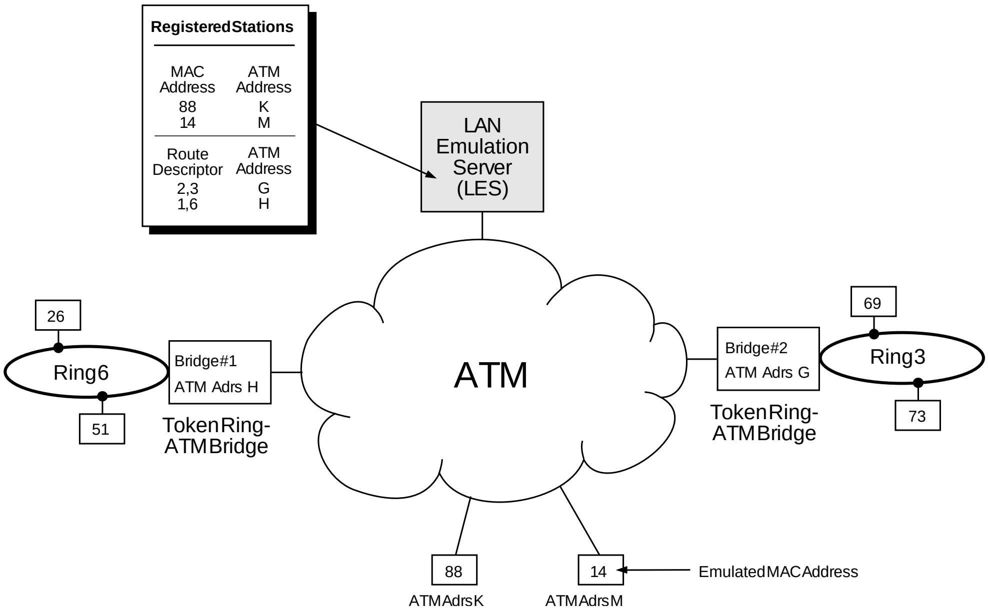

Figure 8: MAC Address and Route Descriptor registration in a Source Routed environment

The LAN Emulation Configuration Server

In describing the process by which LAN Emulation Clients register with a LAN Emulation Server, we did not explain how the LEC finds the ATM address of the LES so that it can set up the Control Direct VCC and execute the registration process. There may, in practice, be many instances of the LES in an ATM network, each one representing a single emulated Ethernet or Token Ring LAN segment. Therefore we need a mechanism for determining which LES each LEC can register with.

One possible way of handling this would be to configure the address of the appropriate LES into each of the LECs. However this scheme is a cumbersome and inflexible, and so LAN Emulation provides us with the option of defining a LAN Emulation Configuration Server (LECS) which can be queried by any LEC to obtain the ATM address of the LES it is to register with. The LECS itself may have a "well known" address, or its address may be configured into the SNMP management MIB for the ATM switch interface, which may be queried by the LEC.

A LEC wishing to locate a LES with which it can register sets up a Configuration Direct VCC with the LECS, and issues a configuration request specifying a range of parameters that may include the type of LAN emulated (i.e. Ethernet or Token Ring), the maximum packet size supported, the emulated MAC address of the LEC, and the name of the emulated LAN which the LEC wishes to join. The LECS uses this information to determine which LES it would be appropriate for this LEC to register with, and responds with the ATM address of the relevant LES.

The LAN Emulation scheme does not prescribe the logic that the LECS uses to determine which LES to offer to any requesting LEC. This allows the network administrator the freedom to define the rules of membership of any emulated LAN in the ATM network. At the simplest level, these rules may simply ensure that a LEC emulating a Token Ring station joins an emulated Token Ring, and not an emulated Ethernet. Made more sophisticated, the rules could be used to define and control the membership of multiple virtual LANs within the ATM network.

Complications: the Flush Message Protocol

Complications can arise in the use of the BUS to forward frames with MAC addresses that cannot be resolved, resulting in the possibility that frames may be delivered out of order. Since Token Ring and Ethernet LANs do not permit the delivery of frames out of order, applications designed to run over LANs do not always have robust mechanisms for dealing with out-of-order frames. Therefore LAN Emulation implements an additional optional protocol to deal with the effects of this complication.

It is possible for a LEC to send a unicast frame for forwarding by the BUS, having failed to resolve its MAC address, and then to succeed with the resolution of the MAC address the next time it has another frame to send to the same destination. In this circumstance, if the first frame gets delayed in the BUS for any reason, the second frame may arrive sooner by the Data Direct VCC that the LEC set up when it resolved the address.

The Flush Message Protocol is intended to eliminate the risk of out-of-order frame delivery. If a LEC has to change routes for any given MAC address (in this case, it is changing from the BUS to the Data Direct VCC), then before it sends data on the new route, it may send a Flush Request Message on the old route. It may then wait until it a has received a Flush Response Message from the destination LEC, indicating that there are no further data frames in transit over the old route, before it begins transmitting frames on the new route.

Fault Tolerance in LAN Emulation

As it stands, the LAN Emulation scheme does not specifically address the issue of fault tolerance. The scheme as described depends critically on the existence of the LECS, LES and BUS services, which in practice must be implemented on one or more processors attached to the network. These are clearly potential points of failure.

There are two approaches to making the network tolerant to failure of these LAN Emulation services. One is to provide back-up or standby services which would be invoked if the primary source of the services failed. The other is provide the services on a distributed basis, with multiple processors in the network providing LECS, LES and BUS services in parallel.

The simpler of the two approaches is to provide a back-up source of LAN Emulation services. One potential problem that must be overcome is that the scheme provides no explicit mechanisms for the LAN Emulation Clients to detect the failure of the LES or BUS. However, it should be possible for a LEC to deduce that a failure has occurred by observing the result of interactions between the LEC and the LES and BUS. For example, when a LEC sends a broadcast frame to the BUS, it should expect to hear the frame repeated on the Multicast Distribute VCC when the BUS performs its forwarding operation. If the broadcast "echo" is not heard within a reasonable time period, the LEC may reasonably deduce that the BUS has failed.

Even though the scheme does not describe how failure of the LES or BUS is to be detected, it does prescribe what should happen when such a failure occurs. The LAN Emulation Clients are to drop all the connections they have and revert to the LAN Emulation Configuration Server, effectively to re-start the process of joining the emulated LAN from the beginning. The LECS should therefore be implemented in such a way as to recognize that a failure of the LES or BUS has occurred, and in these circumstances it should respond to all requests to join the emulated LAN with the ATM addresses of the back-up LES and BUS services.

This leaves the LECS as the only single point of failure. This may not be too much of a problem as the failure of the LECS only has the effect of preventing new LECs from joining an emulated LAN. Provided that the network administrator can be made aware of the failure of the LECS, he probably has time to bring up a new LECS manually without the disruption being widely noticed. Alternatively, it may be possible to implement the LECS as a kind of distributed database, with its own built-in fault tolerance mechanisms.

The design of the LAN Emulation scheme does not preclude the implementation of fully distributed LECS, LES or BUS services, but equally the scheme does not describe how this may be accomplished. The implementation of distributed services is likely to require additional protocols between the distributed elements, and these protocols are not, as yet, defined.

Location of Emulated LAN Processes

We have described the processes involved in the implementation of LAN Emulation in a rather abstract way, without much reference to the items of hardware that make up real networks. Each of the processes we have described is implemented in software, so now we'll look briefly at where this software is likely to be located.

The LEC can be thought of as the entry point to the emulated LAN. LECs are always associated with a physical ATM interface. They may reside in end stations, like PCs or workstations, that are connected directly to the ATM network. In addition, LEC processes may reside in devices that connect the emulated LAN to other networks. Such devices include bridges, LAN switches and routers.

We have already discussed the implementation of the LEC process in bridges and LAN switches. These kinds of device provide a protocol-independent connection between physical Ethernet and Token Ring segments, and emulated Ethernets or Token Rings within the ATM network. LECs may also reside in ATM interfaces to routers. In this case, the router is treated as just another kind of end station that can connect to an ATM network. We will discuss the network architecture implications of bridges, LAN switches and routers later in this paper.

In a PC or workstation, the LEC process operates as software either in the host or running on a processor on the ATM adapter card. It operates underneath a standard LAN driver interface, such as Novell Open Datalink Interface (ODI) or Microsoft Network Datalink Interface Specification (NDIS). These interfaces support standard server and client network operating software for Ethernet and Token Ring networks. In practice, the LEC will typically be an integral part of the driver software for the ATM adapter card.

It is perfectly possible to have multiple instances of the LEC process associated with a single ATM adapter card, and indeed these LECs could be of different types. The practical application of this is in networks with a mix of Ethernet and Token Ring, where stations on both types of LAN want access to common servers. In this case, the network drivers for the ATM adapter card may implement both Ethernet and Token Ring LAN Emulation simultaneously, with two or more different emulated MAC addresses. Both ODI and NDIS permit a single card to present both Ethernet and Token Ring interface appearances, and from the point of view of the server software, there appears to be an Ethernet and a Token Ring card installed in the server.

The LES, BUS and LECS processes need to reside on hosts that are easily accessed by all the LECs. They may be located all on the same host, or on different hosts. In practice, they could be run on any kind of station that is attached to the ATM network, which might be a dedicated PC or workstation, or a server. They could, for example, be implemented as NetWare Loadable Modules (NLMs) and run on an existing or dedicated NetWare server.

Alternatively, the LES, BUS and LECS could be located on a processor that is integrated with an ATM switch. Many ATM switches are expected to be equipped with general purpose processors that can handle tasks such as routing and network management, and the LAN Emulation processes could therefore reside in the switch.

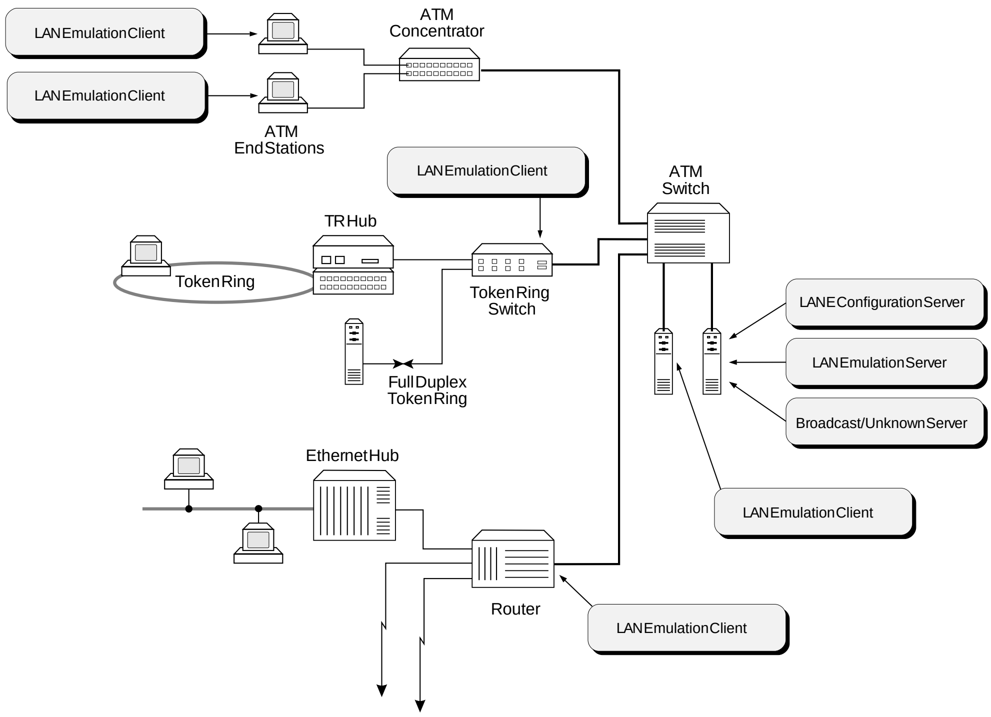

Figure 9: Location of LAN Emulation Processes in Integrated LAN-ATM Environment

Network Architectures with LAN Emulation

LAN Emulation Over ATM allows for the implementation of emulated Ethernet and Token Ring segments that far exceed the limitations which apply to real LAN segments in terms of physical reach, bandwidth and number of stations.

ATM imposes no limitations on physical distance. Using leased lines or public cell-switching services, it should be possible to construct emulated LANs that span the globe with a single emulated segment. ATM also imposes no practical limit on bandwidth or carrying capacity. Data traffic between end stations is carried on point-to-point Virtual Channel Connections, and the ATM links themselves can be run at speeds of 622 Mbps, or more if the need arises. And there is no theoretical limit on the number of stations that may be connected to an emulated LAN, although the maximum number of unique LEC identity codes that may be handled by one LES (65,279) might be regarded as a practical upper limit.

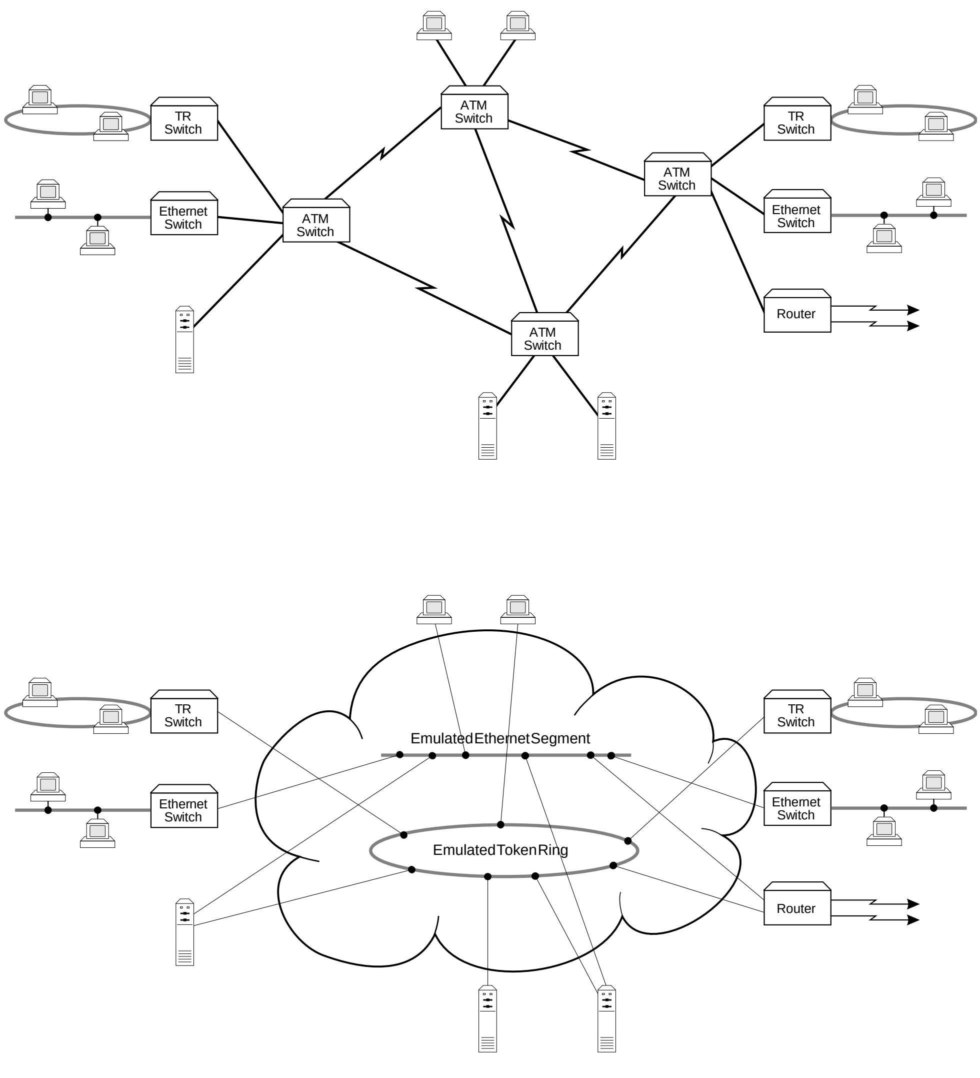

Figure 10: Physical and Logical Views of Integrated LAN-ATM Environment

LAN Emulation therefore raises the intriguing possibility that large enterprise networks could be built entirely around an ATM backbone that spans the wide area and campus backbone, with access from the desktop via physical Ethernets or Token Rings connected to the ATM network through bridges or LAN switches - and not a router in sight. The ATM network itself would consist of a mesh of point-to-point links with diverse routing, and the ATM switches would co-operate to loadshare and to route traffic around failed links. The emulated LAN segments that run over the ATM backbone would provide a robust transport between the LAN switches that connect to the physical LANs and to any servers or workstations that may be attached directly to the ATM backbone. And the very low end-to-end latency of ATM networks promises to put and end to the protocol timeout problems that plague router-based internetworks carrying SNA traffic.

Architecturally, this is a pleasingly elegant solution. From the point of view of migration towards ATM to the desktop, it has the desirable effect of eliminating the routers that will not be needed in a fully ATM world. And from the point of view of the installed base of Ethernet and Token Ring LANs, it provides a global LAN architecture that operates independently of Network Layer protocols.

However, there is one cloud on the horizon: broadcast traffic. Many LAN protocols are notoriously "chatty", sending a variety of broadcast messages on a regular basis. The more stations there are connected to a LAN segment, the greater the aggregate load of broadcast traffic on the LAN. Excessive broadcast traffic consumes bandwidth and increases running costs, and therefore control of broadcast traffic becomes essential. Routers are reasonably effective at limiting the propagation of this broadcast traffic, and in practice the need to control broadcast traffic may make it necessary to implement a number of emulated LAN segments in the ATM network and use routers to link these emulated LANs together.

However, routers do represent additional complexity in the network architecture, and there are gains to be made in reducing dependency on routing. Two areas of network technology development will assist this process. One is the effort that network operating system vendors are putting in to reduce the amount of broadcast traffic that is generated on LANs. For example, the emerging NetWare Link State Protocol from Novell generates far less broadcasts than the Routing Information Protocol that has been the traditional basis for NetWare. The other area of development is in techniques for intelligent broadcast filtering and broadcast response "spoofing", which can allow bridges and LAN switches to drastically reduce the amount of broadcasts they need to pass from protocols such as NetBIOS.

To sum up, it is clear that routers will play an important role in emulated LANs in the short to medium term, at least in environments that make use of routed protocols such as IP and IPX. But as organizations move increasingly towards end-to-end ATM, and as techniques for limiting broadcast traffic become more sophisticated, the role of routers in the network will be progressively diminished.

Conclusion

LAN Emulation Over ATM provides an effective solution to two of the key issues facing potential users of ATM: how to run existing network applications across the ATM network, and how to interconnect the installed base of Ethernet and Token Ring LANs with the ATM network.

However, it is clear that LAN Emulation Over ATM does not provide the best long term solution for networks that run ATM end-to-end. This is because LAN Emulation effectively prevents the user from taking advantage of some of ATM's most useful features, such as the ability to specify quality of service.

As ATM gains ground in the marketplace, we can expect to see the emergence of network operating system software and network applications that are written directly to "native" ATM interfaces. These will operate more efficiently than applications which run over a LAN Emulation interface, and will benefit from the ability to distinguish between different classes of traffic. There is, of course, no reason why these applications cannot share the ATM network with others that continue to make use of LAN Emulation.

Eventually, as end-to-end ATM networking becomes the dominant model, LAN Emulation Over ATM can be expected to fade away. But as long as network administrators have to support applications designed for Ethernet and Token Ring LANs, and as long as these kinds of LANs must be interconnected with ATM networks, LAN Emulation will continue to play an important role.

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