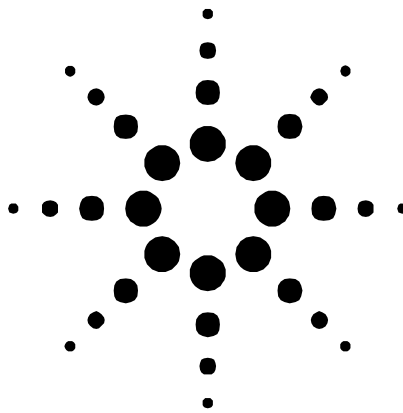




Operating LANs in an ATM Environment

Agilent Technologies Broadband Series Test System
Application Note



Introduction

It is a widely-held opinion that ATM's acceptance and success in the private network will depend in part on its ability to interwork with existing LAN protocols and networks. There is much research and development work being done in this area, and several technologies of increasing complexity are being developed to make ATM/LAN interworking a reality.

In this application note, two of the key technologies for integrating local area network data into ATM networks will be discussed. These technologies are currently under development or are being deployed in initial implementations. Consequently, several interoperability issues have been discovered. These issues, and techniques for testing implementations, will also be discussed.



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ATM Local Area Networks

There are several approaches for bringing ATM to the local area network. Perhaps the most straightforward is to use ATM as the physical media for existing LAN protocols and applications. End stations are connected to local ATM hub switches in a star topology as in Figure 1, and ATM virtual channels are used to transport data packets between stations.

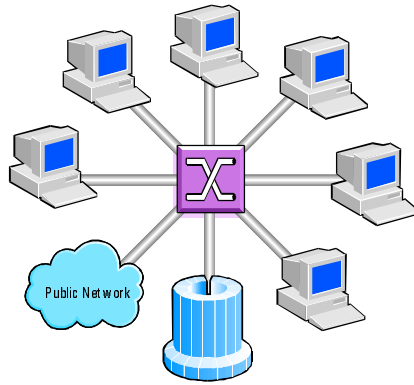


Figure 1: Stations connect to a local hub in a star configuration.

This method is used in RFC 1577, “Classical IP and ARP Over ATM”, a draft Internet standard developed by the IP Over ATM Working Group of the Internet Engineering Task Force (IETF). RFC 1577 shows how Internet Protocol (IP) and its associated Address Resolution Protocol (ARP) can be used as network protocols over native ATM interfaces.

Stations are organized into a Logical IP Subnet (LIS) with a single IP subnet number and address mask. Within each LIS, stations can send packets to any other station. A router must be used to send packets to IP addresses outside the LIS.

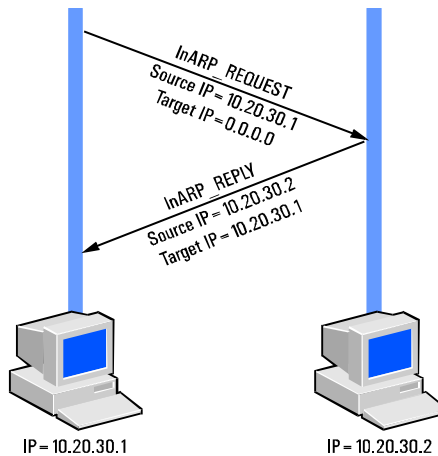


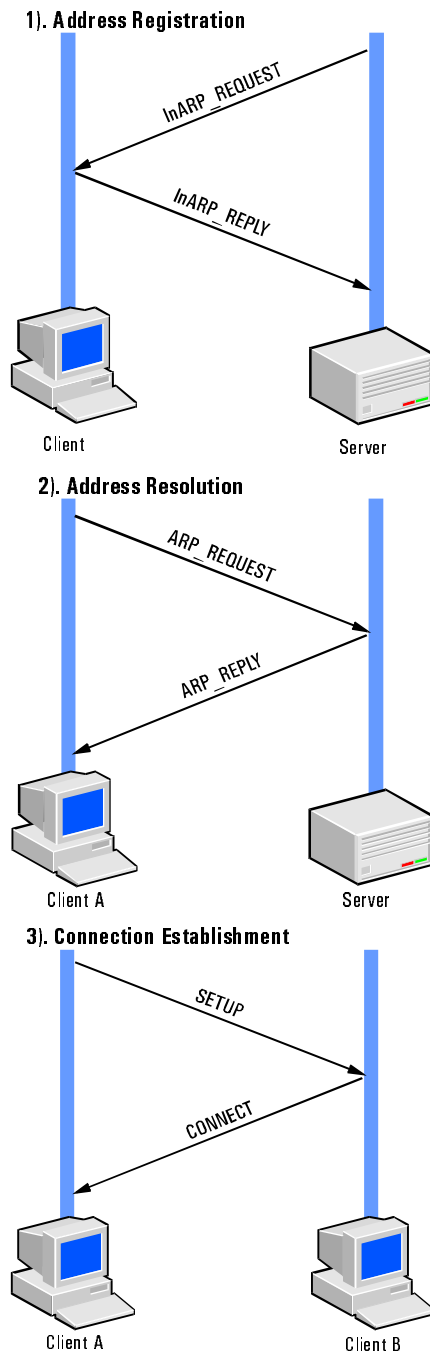
Figure 2: Inverse ATMARP used to identify IP addresses for connected stations.

ATM Address Resolution

ATM networks are connection-oriented, unlike most legacy LAN technologies which use connectionless data transfer. As we shall see, this means that a station must be able to find the ATM address of the destination station and create a virtual channel for data transmission.

In classical IP over ATM, this is accomplished using the ATMARP protocol. Traditional ARP is used to find a hardware MAC address for a given IP address. Similarly, Inverse ARP (InARP) is used to find the IP address for a specified hardware address. This model is extended for ATMARP (and InATMARP) to consider an ATM address as a hardware address.

In a Permanent Virtual Connection (PVC) environment, manual configuration is used to establish virtual channels between each pair of stations within the LIS. InATMARP is used by each station to determine which IP addresses it is connected to. A request message is sent with the IP address of the sending station; the corresponding reply contains the IP address of the receiver. Figure 2 shows the operation of InATMARP over PVCs.



In a Switched Virtual Connection (SVC) environment, UNI signalling is used to establish virtual channels on demand between IP stations. An ATMARP server is used to manage the table of ATM and IP address pairs for each station in the LIS. This server is located at a well-known ATM address that is manually configured for each client station in the LIS.

When a client establishes a connection to the ATMARP server, the server issues an InATMARP request to determine the IP address of the client. It uses the reply to construct and validate its address table. When the client needs to send a packet to an IP address for which it does not have the ATM address, it issues an ATMARP request to the server. The ATM address in the reply is then used in the signalling SETUP message to create the new virtual channel. Figure 3 illustrates these steps in establishing an SVC for IP data. The client does not always have to query the server, as it will likely have an open VC to the destination IP address, or it possibly has its own address table constructed from previous replies from the server.

Entries in the server's address table are invalidated if the connection has been closed for twenty minutes. Open connections are re-validated by issuing InATMARP requests on the virtual channel every twenty minutes.

Figure 3: Three steps in establishing an SVC for IP data.



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Packet Format

Two methods of packet encapsulation are used in classical IP over ATM. When IP and ATMARP packets are transmitted over a single virtual channel, the protocol must be identified by additional header fields in each packet. Alternatively, VC multiplexing can be used whereby a different virtual channel is used for each protocol type. This is also known as “null encapsulation”.

Packets are encapsulated using IEEE 802.2 LLC/SNAP as described in RFC 1483, “Multiprotocol Encapsulation over ATM Adaptation Layer 5”. This method prepends an eight byte header to each packet. The header is composed of a three byte Logical Link Control (LLC) field that identifies that a Sub-Network Attachment Point (SNAP) value follows. The SNAP field is composed of a three byte Organizationally Unique Identifier (OUI) and a two byte Protocol Identifier (PID) defined by the OUI. The OUI value 00-00-00 indicates that the PID is an EtherType. An EtherType value of 08-00 signifies that the following packet is IP; 08-06 denotes that the following packet is ARP. Figure 4 shows the encapsulation and segmentation from an IP packet to a sequence of ATM cells.

Testing Classical IP over ATM

Classical IP over ATM is a relatively simple protocol, but of course, implementations must be tested to ensure correct operation and interoperability between vendors. The encapsulation procedures can be verified by simply decoding the frames captured on the ATM link. The LLC/SNAP header should always be AA-AA-03-00-00-00-08-00 for IP packets.

Correct encoding of ATMARP packets is slightly more involved, since the packet format is a modification of

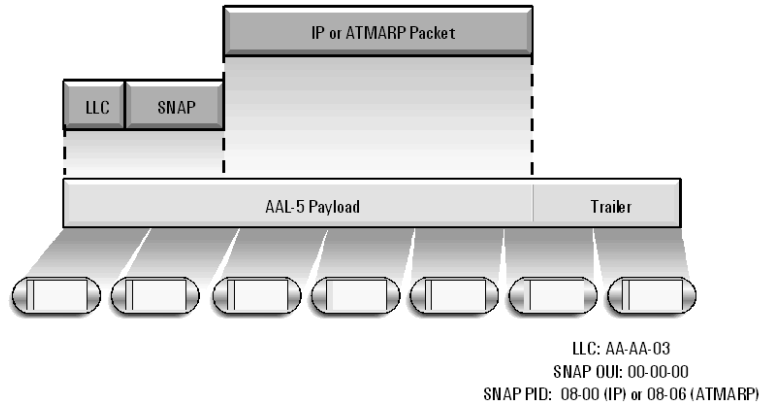


Figure 4: LLC/SNAP Encapsulation

traditional ARP. One point of differing interpretation is how unknown addresses are encoded. ATMARP packets have length fields for each source and target address component. A request message could encode the unknown target address field in one of two ways:

- zero length and missing address field
- correct length (e.g. four bytes for IP addresses, twenty bytes for ATM addresses) and a zero address (e.g. 0.0.0.0 for IP)

This issue arose at a recent RFC 1577 multi-vendor interoperability testing session conducted at the University of New Hampshire in February, 1995. Discussion among developers concluded that messages should be encoded using the latter method, but received messages using either encoding will be correctly interpreted. Since then, it has been proposed that RFC 1577 be updated so that the length field should be interpreted as the number of meaningful address octets in a fixed length buffer of twenty bytes or four bytes. This has significant interoperability consequences since current implementations use the length field, not the address length, to determine the buffer size.

Another interoperability issue that has surfaced is how the ARP_NAK reply should be encoded. This message is a new extension for ATMARP, indicating that the requested address could not be found. (In traditional ARP, the requesting station would wait for an ARP_REPLY from the destination address and time out if no reply is received.)

RFC 1577 states that the server simply returns a copy of the request message but with the op code changed from 1 (ARP_REQUEST) to 10 (ARP_NAK). This behavior is unlike a normal reply, where the source and target address fields are swapped. Some implementations have chosen to encode one reply message (with swapped addresses) and insert the appropriate op code for a successful or unsuccessful address look-up. This may cause problems for implementations that verify the ATMARP message fields according to the intent of RFC 1577.

Testing the ATMARP protocol behavior of a client or the server can best be accomplished by using a protocol tester to simulate one end of the connection. For example, the tester can be used to initiate a connection to the server and respond to the initial InARP_REQUEST. It can then send ARP_REQUESTs using different known or unknown IP addresses. The replies (ARP_REPLY or ARP_NAK) should correspond to the server's address table, which can usually be examined from a terminal attached to the device.

Performance Issues

An important consideration for RFC 1577 implementations is the end application performance.

“Performance” is a relative term, and depends upon such diverse factors as transmission rates (with or without congestion), protocol implementations, and system architecture.

TCP performance depends upon a term called the “bandwidth-delay product”. Simply put, capacity equals bandwidth times the round-trip delay.

For example, the capacity of a TCP pipe for a 10 Mb/s virtual channel with a round-trip delay of 15 ms is 18,750 bytes. The TCP window size corresponds to the amount of unacknowledged data that can be handled correctly, and should be at least this large to achieve maximum throughput.

The round-trip delay (also called round-trip time or RTT) can be measured over a connection by using the ping program. This familiar networking tool sends ICMP Echo packets to a destination IP address and examines the Echo Reply packets from that address. A departure timestamp, with microsecond precision, is inserted in the Echo packet and subtracted from the time the Echo Reply was received to compute the RTT. This technique takes into account the software processing time at each end.

Ping tests could also be used to crudely measure the connection setup time. The initial ping may take significantly longer than the remaining pings in an SVC environment, since the ATM address may need to be obtained from the ATMARP server, and the virtual channel must be established. In this case, more accurate connection setup delay measurements can be made by a protocol tester monitoring the line.



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TCP Over High Performance Networks

Returning to our discussion about the bandwidth-delay product, we can see that as the bandwidth increases, the window size must also increase to ensure maximum throughput. The TCP window size is constrained by a 16 bit field to 65,536 bytes. Therefore, the effective throughput is also limited unless the RTT can be reduced.

Even if we are able to use a larger window size, this means that we may have more unacknowledged data in the pipe. If a packet is lost, TCP will normally clear the unacknowledged packets as part of the recovery process. With a large window, a significant amount of retransmission may result. On an ATM network, a single cell loss will result in an AAL-5 packet loss and the effects magnify upwards through the protocol stack. One tool for measuring TCP performance is “tcp”. It operates as a TCP traffic source on a UNIX workstation host, and therefore measures the throughput an application might experience. A designer could fine-tune TCP’s configurable parameters to optimize the throughput.

A designer might also need to measure the application throughput when errors are introduced at the ATM level. A network impairment emulator can be inserted between IP hosts to introduce errors such as cell delay and cell loss as in Figure 5. This technique models what may happen when network elements become congested, for example. The results from “tcp” can be used at different impairment levels to quantify the quality of service necessary to satisfy the application requirements.

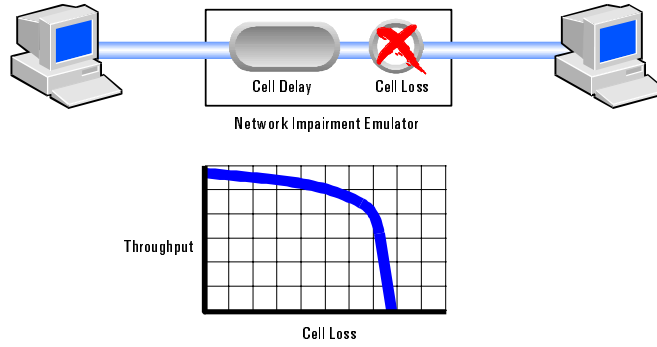


Figure 5: Characterize application performance for different network conditions

Some experiments have shown that there is a point at which network impairments cause TCP performance to fall rather dramatically. The initial near-linear correlation between cell loss and packet throughput reaches an asymptote after which the application becomes virtually unusable, despite a significant amount of cell data still being received correctly.

The Next Step

Classical IP over ATM is an efficient solution for packet data applications in a local area, but it does not support wide area networks well. Packets destined for IP addresses outside the LIS must be routed, imposing extra overhead and delay at each router.

This deficiency is being addressed within the IP over ATM Working Group, where the Next Hop Routing Protocol (NHRP) has been proposed to replace ATMARP. Address resolution requests that can not be resolved in the local LIS are passed on to additional servers in other LISs. Eventually, the destination ATM address is returned and a virtual channel can be created across the network. This approach solves the data delay problem, but can still result in significant setup delay.

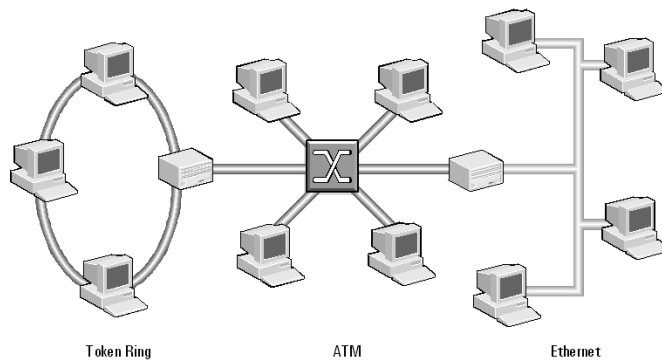


Figure 6: A small network with two emulated LANs

Some vendors are addressing TCP's limitations on high-speed networks by implementing new options described in RFC 1323, "TCP Extensions for High Performance". Additionally, algorithms for "Fast Retransmit" and "Fast Recovery" can alleviate the effects of packet loss with a large window.

LAN Emulation

While classic IP over ATM is useful for bringing ATM to the local area, it does not address existing legacy LAN technologies very well. Packets would need to be routed between different network types, and IP is the only supported protocol.

The ATM Forum recognized that interoperability with existing LAN networks and applications is important to ATM's market acceptance. The LAN Emulation Sub-Working Group was started to define a service that emulates the characteristics of existing LANs. This emulation takes place at the MAC (Media Access Control) layer, so that the ATM network effectively looks like a traditional LAN network to the application. A wide range of protocols (such as NetBIOS, IPX and AppleTalk) will operate over this interface.

The end result is that a single local area network can be composed of ATM segments and legacy LAN segments. At present, only Ethernet and Token Ring LANs can be emulated. Figure 6 shows a small network with two emulated LANs (ELANs).

The biggest difference between legacy LANs and ATM networks is that ATM is connection-oriented, whereas LANs use a shared media to connect its devices. LAN protocols typically broadcast connectionless packets to all stations on the LAN, to be received by the addressed destination(s) and ignored by others. An ATM emulation of this behavior requires the ability to broadcast packets to multiple destinations.

LAN Emulation Architecture

There are multiple components of the LAN Emulation architecture. Several LAN Emulation Clients (LECs) communicate with one LAN Emulation Service across the LAN Emulation User to Network Interface (LUNI). Each ATM end station is associated with an LEC. This includes the ATM interface to a bridge to a legacy LAN. The LEC is responsible for providing the MAC layer emulation to higher protocol layers.



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The LAN Emulation Service itself has three sub-components:

- *LAN Emulation Server (LES)*
The LES is responsible for address resolution from MAC addresses to ATM addresses.
- *Broadcast and Unknown Server (BUS)*
The BUS is used to forward frames from a LEC to broadcast addresses. It is also used by the LEC to send unicast frames to all clients before the destination address is known.
- *LAN Emulation Configuration Server (LECS)*
The LECS is used by the LEC for initial configuration of the LEC.

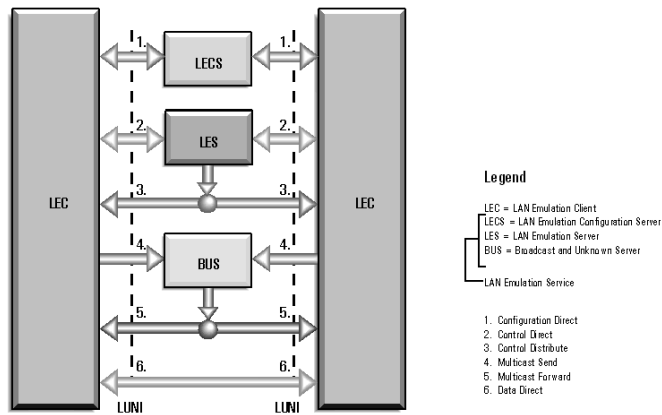


Figure 7: Set of connections present between LAN Emulation components

The system architecture allows these components to be distributed among multiple physical devices.

These three components communicate with each other by multiple virtual channels at the LUNI. Some of these VCs are unidirectional, and others may be implemented as point-to-multipoint VCs. Figure 7 shows the set of connections present between LAN Emulation components.

Packet Format

LAN emulation packets are encoded using a new frame format. The ATM Forum chose not to use the LLC/SNAP encapsulation method for IEEE 802.3 Ethernet or IEEE 802.5 Token Ring frames, as described in RFC 1483. Instead, a packet format was defined that shares an initial common header between control and data packets.

Data packets begin with a 16 bit field that identifies the sending LEC. This value must be less than 0xFF00, since that value is used to identify control packets. Ethernet data packets have a different header than token ring data packets. Token ring is a source-routed protocol, so routing information is also sent in the packet header. Additionally, the bit ordering of the 48 bit MAC addresses is different, since ethernet transmits the least significant bit first and token ring transmits the most significant bit first.

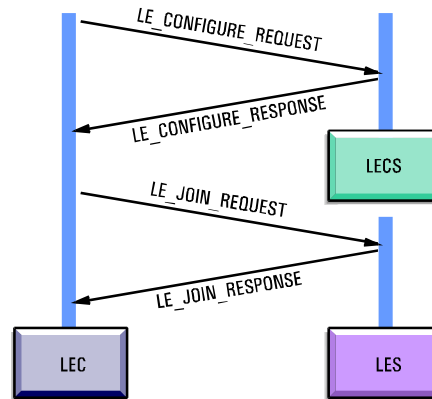


Figure 8: The initialization steps for a LEC to join an ELAN

The next step for the LEC is to establish the Control Direct connection to the LES. This SVC is used to send a request for the LEC to join the emulated LAN. If successful, the LES will return a unique LEC identifier (LECID) that will be included in future control and data packets sent by the LEC. The LES has the option of responding to the LEC on the Control Direct connection, or via a unidirectional point-to-multipoint Control Distribute connection to all the LECs. Figure 8 shows the initialization steps for a LEC to join an ELAN.

LAN Emulation Operation

LAN Emulation protocols are relatively complex, so we will examine each step of protocol operation.

Client Initialization

The LEC must be initialized before it can send data to other LECs.

Initialization begins when the LEC makes a connection to the LECS. It first tries to obtain the ATM address for the LECS with an ILMI request. If this fails, a well-known ATM address is used. The LEC then attempts to set up a bidirectional SVC to this address. If this fails, the LEC uses a PVC (VPI=0, VCI=17) as a last resort.

Once this Configuration Direct connection has been established, the LEC sends its ATM address in a configuration request message to the LECS. The LECS replies with the ATM address of the LES and the name and type (Ethernet or Token Ring) of the emulated LAN. Additional configuration parameters (such as timer and counter values) may also be returned.

Address Registration and Resolution

Each LEC must register the MAC address(es) it represents with the LES. The LES builds a table of ATM address—MAC address pairs that it uses to respond to address resolution requests made later by a LEC. This protocol is similar to ARP as described above.

One key difference is that the server may not respond to the request. It may decide to forward the request to the client that registered that MAC address, or it may forward the request to all clients over the point-to-multipoint Control Distribute connection. The LEC that represents the MAC address will respond to the requesting LEC with the corresponding ATM address.

Data Transfer

At this point, a Data Direct SVC can be set up between two LECs. The LAN emulation header is prepended to the MAC frame and the data packet is sent from client to client.



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Normally, each Data Direct connection is aged. If no packets are sent between the LECs for twenty minutes, the SVC is cleared normally. Of course, a new connection can be established between the LECs if it later becomes necessary.

Another alternative exists for sending data to a client. The BUS can be used to forward data to an unknown address prior receiving an ARP reply. Each LEC establishes a unidirectional Multicast Send connection to the BUS, which adds the LEC to a unidirectional point-to-multipoint Multicast Forward connection for return data. The LEC obtains the ATM address of the BUS by sending an ARP request to the LES using the broadcast MAC address (all ones).

When the LEC sends a packet to the BUS, it is forwarded back to all LECs. The destination address in the data packet determines which LEC will process the packet. Figure 9 illustrates the operation of the BUS.

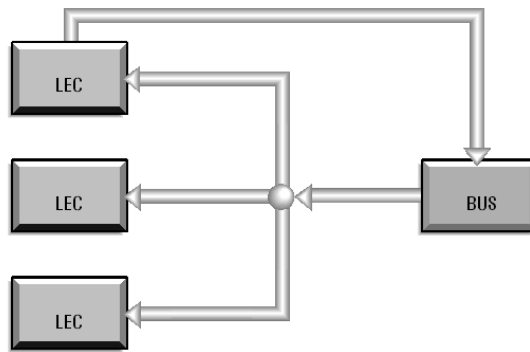


Figure 9: The operation of the BUS

Implementation Difficulties

LAN emulation is a hot topic for many manufacturers, but it encompasses a complex set of protocols. Consequently, there are liable to be many implementation hurdles to jump. It has been estimated that the software implementation of the LAN emulation servers takes about 50,000 lines of C code, and a LEC implementation is about 20,000 lines. As you can imagine, debugging these components can be a large task!

There are several possible points of failure in the protocol process. Care was taken to ensuring that the client and server states remain in synchronization, even when other systems (e.g. signalling) fail.

However, there could be unforeseen problems, such as race conditions between steps in the configuration process.

Testing Challenges

Testing LAN emulation components can be performed at several levels. Physical and ATM layer testing can be performed on a bridge device. For example, the latency across the bridge can be measured by capturing and timestamping an ethernet packet on one side of the bridge and correlating the timestamp to the captured packet on the ATM side. A common timebase between the two physical interfaces is required.

Protocol interoperability will be a big issue for LAN emulation, since many more manufacturers will be producing client devices than servers. For client manufacturers, operation against many server implementations is mandatory. In time, interoperability and conformance test suites will be defined for LAN Emulation. For now, development or quality testing groups will have to observe client-server communication manually for conformance to the specification.

Summary

This solution briefing presented an overview of two technologies designed to bring ATM into the local area. Some of the current problems and issues surrounding these technologies were examined, and some testing tools for exploring these issues were also described.

Acronym

ARP	Address Resolution Protocol	LLC	Logical Link Control
ATM	Asynchronous Transfer Mode	LUNI	LAN Emulation User to Network Interface
ATMARP	ATM Address Resolution Protocol	MAC	Medium Access Control
BUS	Broadcast and Unknown Server	NETBIOS	Network Basic Input/Output System
ELAN	Emulated Local Area Network	NHRP	Next Hop Routing Protocol
IEEE	Institute of Electrical and Electronic Engineers	OUI	Organizationally Unique Identifier
IETF	Internet Engineering Task Force	PID	Protocol Identifier Governing Connection Types
InARP	Inverse ARP	PVC	Permanent Virtual Connection
InATMARP	Inverse ATMARP	RFC	Request For Comment
IP	Internet Protocol	RTT	Round-Trip Time
IPX	Novell Internetwork Packet Exchange	SNAP	Sub-Network Attachment Point
LAN	Local Area Network	SVC	Switched Virtual Connection
LEC	LAN Emulation Clients	TCP	Transmission Control Protocol
LECS	LAN Emulation Configuration Server	UNI	User Network Interface
LES	LAN Emulation Server	VC	Virtual Channel
LIS	Logical IP Subnet		



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