

INTEROPERABILITY IN HETEROGENEOUS ENVIRONMENT: MULTIPROTOCOL OVER ATM (MPOA)

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ABSTRACT

Interoperability is a most challenging issue in today's network infrastructures (e.g. ATM and IP). Additionally, the issue of QoS is not addressed adequately in today's available heterogeneous platforms, because only the best-effort is possible.

For many years, ATM based Broadband-ISDN has generally been regarded as the ultimate networking technology, which can integrate voice, data, and video services and which is suitable for LANs and WANs, both private and public.

With the recent tremendous growth of the Internet, the future role of ATM seems to be less clear than it used to be. WWW based use of multimedia applications on the Internet is widespread. By offering not only typical data service but also real time voice and video applications (though with poor quality), the Internet is entering the typical target market of ATM at service level. Furthermore, the Internet Society is quite drastically loosening their policy of shared resources and free usage and starts investigation on how to introduce resource reservation and charging support in the Internet to provide better support for multimedia applications and service providers.

The discussions about whether IP or ATM is the better technology for an Integrated Services Network (ISN) are ongoing. A further important criterion to be fulfilled by ATM for the acceptance at the end-user's site is the difficult integration of existing networks like Token Ring, Ethernet, and FDDI. The first and simple solutions are Classical-IP (CLIP) from the Internet Engineering Task Force (IETF) and LAN Emulation (LANE) from the ATM-Forum, but this solutions ignore the advantages of ATM, because CLIP and LANE hides the QoS support of ATM and are unable to run protocols in native mode.

This paper will discuss the interoperability of different technologies like the Internet Protocol (IP) and the Asynchronous Transfer Mode (ATM) in a heterogeneous environment, because this are the most important protocols in the near future. Furthermore this paper will give an overview about available adaptations between IP and ATM (CLIP and LANE) and mainly the new developments of IP/ATM integrations with full Quality-of-Service (QoS) features like Multiprotocol over ATM (MPOA) and Multiprotocol Layer Switching (MPLS).

KEYWORDS:

INTERWORKING, ATM, IP, TCP, CLIP, LANE, MPOA, MPLS, QoS, ATM-FORUM, IETF.

1. IP-OVER-ATM DIFFICULTY

The completely different structures and characteristics of the two transmission modes of IP and ATM constitute a problem for the successful adaptation.

ATM has its own addressing structure and hierarchical routing functions, uses signaling to set-up and tear down virtual connections (VPC/VCC) with a specified traffic contract and QoS, and is universally scalable technology. Small packets, called cells (53 byte), are transported over pre-established connections. The QoS of ATM defines parameters like bandwidth, loss rates, delays, jitters, etc. These defined parameters are promised to the participant and must be kept. But there will be only exclusively point-to-point connections established.

On the other hand, TCP/IP is a connectionless network protocol designed to forward data packets on a hop-by-hop basis, network-to-network, independent of the underlying network. It defines a robust and flexible set of host and network behavior that enables adaptation to dynamic network conditions. TCP/IP is supported on almost every network device and is universally accepted as de-facto networking protocol. Its basic mechanisms have changed over the years and the stability as well as its ability to run on any platform have contributed to its widespread deployment.

For shared media LANs like Ethernet or Token-Ring, IP uses the Address Resolution Protocol (ARP) to resolve an IP address with the associated Medium Access Control (MAC). ARP uses the broadband support of the underlying shared media to accomplish this. MAC protocols also don't work for connection-orientated in the local network area and no acknowledgement mechanisms have therefore been implemented at the receiver site. Lost data packets must be requested high protocol layers such as TCP protocol mechanisms via the IP protocol.

Furthermore at local area network data will be transmitted on a physical medium, so the information is available for any attached station by access mechanisms. Broadcast functions are possible by sending from one station to the others and evaluating the data through all attached stations. Clear communication connections with other net participants are build-up by special

detail of the destination address. This characteristics are in strong contrast to the ATM mechanisms.

IP multicast enables one or more senders to send packets to multiple destinations by addressing them to a group address. Broadcast or multicast messages are exclusively practicable about many virtual connection paths which is created by signaling mechanisms with the help of assignment tables. But ATM does not still support multicast mechanisms by the user network interface (UNI) signaling protocol of version 4. Only point-to-multipoint is optional implemented. Furthermore, today's ATM switches use UNI 3.1 signaling yet, instead version 4.0.

On the other hand, TCP does lack some important capabilities. It is a data network protocol only. That means real-time data like audio and video can not be supported. An exception is the use of a very carefully controlled network configuration with more than sufficient bandwidth. The Multicast Backbone (MBONE) is an example of this and for the need for multicast support.

Additionally, IP and ATM have different addressing structures. Two addressing models exist: peer and separated. The peer model supports an algorithmic translation of the IP address to an ATM address and vice-versa. One address scheme to administer would be desirable, but it requires that a host perform this function, thus requiring a change in host behavior. There is also the issue of mobility and consistency across address hierarchy boundaries. The separated model keeps the IP and ATM address spaces separately. A dynamic mapping or association of an IP address with an ATM address is required.

Furthermore, IP has no knowledge of the underlying data link it is running on. For instance, IP packets are encapsulated in Ethernet frames when running on an Ethernet network. ATM uses AAL-5 or AAL-3/4 for data transmission. AAL-5 contains less overhead than AAL-3/4, but does not support multiplexing of cells from different AALs on the same VC. [3]

Additional problems appear to the different characteristics in the area of various transmission rates and incompatible packet or cell formats. Nowadays these difficulties can however be overcome by efficient routers how this is realize

at the edges of Ethernet and Token Ring to FDDI networks. But the address translation and the routing itself should consider as not non-trivial.

2. IP-OVER-ATM POSSIBILITIES

To adapt or integrate ATM to other protocols and traditional networks, four different solutions have been developed in the meantime:

- Classical-IP (CLIP)
- LAN-Emulation (LANE)
- Multiprotocol over ATM (MPOA)
- Multi-Label Protocol Switching (MPLS)

CLIP (RFC-1577) and ARP over ATM was the first implementation of IP-over-ATM (IPoATM). The CLIP model positions ATM as a replacement for the wires or LAN segment connecting two workstations on the same subnet. IP routers are still required to interconnect two or more IP subnets. Indeed the classical model purposely limits ATM to intra-subnet connectivity. The components and operation of CLIP and ARP over ATM are contained in a series of Request For Comments (RFCs) issued by the IETF Internetworking over NBMA (ION) working group. The RFC's (RFC-1577, RFC-1483, RFC-1626, RFC-1755) describe an encapsulation technique, ATMARP service, UNI signaling flows, and default MTU size. Without fully exploiting the capabilities of ATM, they have provided developers and vendors with initial and stable set of guidelines for developing IP over ATM.

LAN Emulation (LANE) is the second solution for IPoATM and can be best characterized as a service developed by the ATM Forum that will enable existing LAN applications to run over an ATM network. To do so this service must emulate the characteristics and behaviors of traditional Ethernet, Token Ring and FDDI networks. It must also support a connectionless service, because current LAN stations send data without first establishing a connection. Therefore it must support broadcast and multicast traffic such as the kind allowed over shared media LANs. It must enable the interconnection of traditional LANs with the emulated LAN and maintain the MAC address identity associated with each individual device attached to a LAN. And finally, it must protect the vast install basis of existing LAN applications and enable them to work unchanged over an ATM network. That became realize over

the OSI layer 2, why the LANE technology can be understood as a bridging technology.

Similar to CLIP and LANE, Multiprotocol over ATM (MPOA) is based on a client/server model. MPOA clients established VCCs with the MPOA server components to forward data packets or request information so that the client can establish a more direct path. MPOA will support various kinds of routable protocols (IP, IPX, AppleTalk, etc.) and integrate existing internetworking protocols (RFC-1577, RFC-1483, NHRP, MARS, RSVP) from the IETF and ATM Forum solutions (LANE, P-NNI) into a virtual router environment. But actually, MPOA support only IP and based on LANE, RFC-1483, NHRP, and MARS. MPOA is a service with layer 3 internetworking support for hosts attached to ELANs, ATM networks, and legacy LANs. So the real premise behind MPOA is to provide and deliver the function of a router and take advantage of the underlying ATM network as much as possible. MPOA works as a virtual router on the OSI layer 3.

A further technology arises on the market: MPLS. The technique is much simpler than the other solutions like LANE and MPOA, because MPLS use the fast and efficient switching technology from ATM and a simpler managing IP-based software for the control of the connections. Furthermore, MPLS provide a good scalability, higher functionality, and higher router performance, but is still under development. [1]

2.1 Classical-IP (CLIP)

RFC-1577 defines the CLIP and ARP over ATM. It was developed by the Internet Engineering Task Force (IETF) in 1993. Hosts on a subnet are still assigned an IP address and ATM physical layer address. When communicating with another host on the same subnet using ATM, it is necessary to resolve the destination IP address with the ATM address of the endpoint.

The characteristics can be summarized as the following points:

- Maximum Transmit Unit (MTU) size of 9180 byte is used as a default for all Virtual Channels (VCs) on a subnet.
- LLC/SNAP encapsulation of IP packets in AAL 5 cells as described in RFC-1483 is used.
- IP addresses are resolved to ATM addresses by use of an ATMARP service within the

Logical IP Subnet (LIS) via an additional server. The scope of the ATMARP service is limited to the LIS, just as the scope ARP is limited to a single subnet.

- A single LIS can support many hosts and routers with the same IP network and subnet mask. Communications between any two members of the LIS takes place over an ATM PVC or SVC.
- The traditional IP model is unchanged.

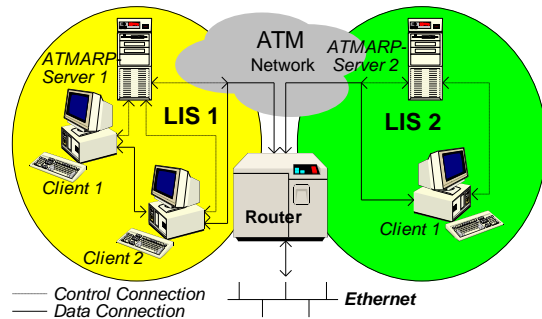


Figure 1: CLIP Architecture [1]

But by CLIP's simple structure there arise also several disadvantages. CLIP over ATM does not support multicast or broadcast, only IP will be adapted to ATM, high delay of the connections, and scalability is limited. Furthermore, CLIP does not provide QoS and direct coupling of different Logical IP Subnets (LIS). Only via a router the communication between different subnets is possible. That means, direct ATM connections can only be established inside a LIS, but not across LIS borders. Additional, all IP data flowing between two hosts shares the bandwidth of a single virtual connection (VC).

But CLIP is a stable standard, can use direct IPoATM, and establish PVC/SCV connections, and a higher packet encapsulation (9180 byte). The limit of the MTU is important for the effectiveness of IPoATM.

Very recently, RFC-1483 was defined for the encapsulation routed and/or bridged packets in ATM-AAL-5 cells. The first technique is called LLC/SNAP encapsulation and works with an additional LLC/SNAP header on each packet. This is necessary for the identification of the protocol within the payload field. The LLC/SNAP header consists of a 3 byte Logical Link Control (LLC), a 3 byte Organisational Unique Identifier (OUI), and a 2 byte Protocol Identifier (PID) field. With the PID field every protocol can be distinguished from others. Figure 1 shows the

LLC/SNAP encapsulation of an IP packet. The second technique described in RFC-1483 is called VC multiplexing and differs from LLC/SNAP solution in that the VC is terminated directly at a layer-3 endpoint. This means, the VC-multiplexed connection will carry one protocol only. In a multiprotocol environment, this scheme would use additional VCs. But for the use of IPoATM, the LLC/SNAP technique is the default method, because the UNI signaling required to initiate a LLC/SNAP encapsulated Switched Virtual Connection (SVC). This is defined in RFC-1755. The important advantage is that multiple protocols can share a VC thus limiting the numbers of VCs required in an IP and multi-protocol environment. On the other hand, it uses an additional 8 byte per AAL frame.

RFC-1483 Permanent Virtual Channels (PVCs) between two routers is an effective technique for ATM, having some of the advantages of higher bandwidth and supporting IP as well as other protocols. This is the reason, why RFC-1483 is also occurred for LANE and MPOA. [1, 3]

2.2 LAN-Emulation (LANE)

LANE is a further development of the IPoATM adaptation. But LANE has a more complex structure as CLIP, because the adaptation of different traditional networks like Ethernet, Fast-Ethernet, Token-Ring, FDDI, etc. is possible by LANE. Therefore not only IP is supported, other routable protocols such as IPX, APPN, DECnet, and AppleTalk can be included as well. Even non-routable protocols such as NetBIOS, LAT, and SNA can be supported.

LANE must enable the interconnection of traditional LANs with the emulated LAN (ELAN), which client stations directly attached to an ATM network. It must maintain the MAC address identity associated with each individual device attached to a LAN. Additional, it must protect the vast install base of existing LAN applications and enable them to work unchanged over an ATM network.

LANE is available in the version 1.0 and 2.0 and includes the following key requirements:

- Connectionless service is emulated over ATM.
- Broadcast/multicast traffic is supported over an emulated LAN using standard techniques such as transparent and source-route bridging.

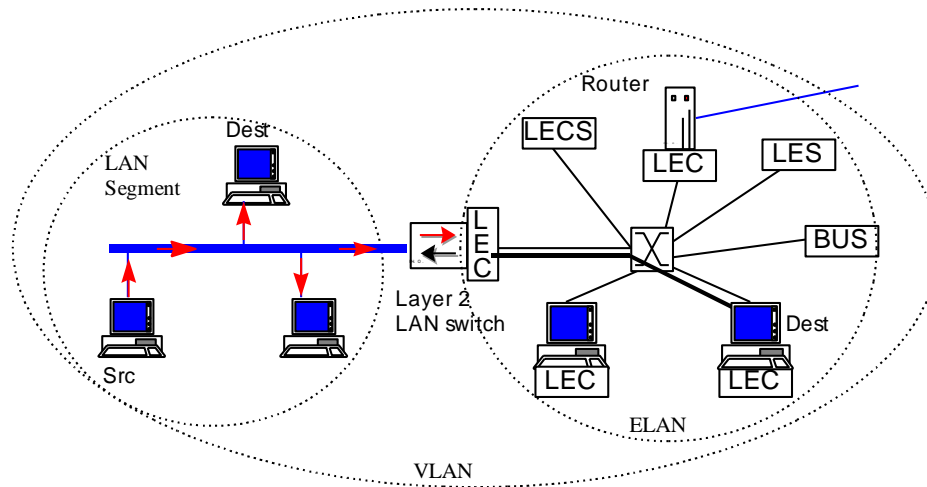


Figure 2: LAN-Emulation Architecture [4]

- MAC addresses are still used to identify emulated LAN clients. Similar to the ATMARP server approach, a server exists (LES) which maintains a table of MAC-to-ATM addresses.
- LAN applications can run unchanged over an emulated LAN.

LANE is a standard with a high functionality, because the complete MAC layer will emulate. Therefore, LANE defines protocols and operation for a collection of client functions as a single ELAN (Ethernet or Token-Ring). Furthermore, LANE specifies a set of services for each instance of an ELAN. The services provide configuration, address resolution (MAC-to-ATM), multicast/broadcast function. Membership in an ELAN is not based on physical location but rather on the association with a specific set of services. Therefore, LANE enables constructing and managing virtual LANs (VLANs).

The LANE architecture includes the following devices to fulfil the requirements:

- LAN Emulation Clients (LEC)
- LAN Emulation Server (LES)
- LAN Emulation Configuration Server (LECS)
- Broadcast and Unknown-Server (BUS)

The LANE components consist of a client (such as workstation), file-server, bridge, or router (LEC) and the LANE services itself (LES, LECS, and BUS). The LEC performs address resolution, data forwarding, and other control functions. The LEC presents a MAC-level interface to the higher layers and implements LANE User Network Interface (L-UNI) when communicating with other components in the ELAN.

The LES functions as a registry and address resolution server for the LECs attached to the ELAN. The LES provides a facility for LECs to register their MAC and ATM addresses. A LEC may also query a LES for resolution of a MAC to ATM address. The LES will either respond directly to the LEC or forward the query to other LECs that may be able to respond.

The LECS is used to initialize a LEC with information specific to the ELAN that the LEC will be joining. The LECS will provide a LEC with the ATM address of the LES. The LECS can provide this information to the LEC, based on the client's ATM address, MAC address, or some other pre-configured policy. The LECS enables a LEC to autoconfigure itself and provides some level of control as to who can join an ELAN.

The BUS handles data addressed to the MAC broadcast address, all multicast traffic, and unicast frames sent by a LEC before the ATM address of the destination has been resolved. All LECs maintain a connection to the BUS and are leave on a point-to-multipoint VC with the BUS as a root. This enables LECs to send data frames without first setting up a connection, thus maintaining the presence of a connectionless data-transfer service to the higher-layers service present in each LEC.

The server entities (LECS, LES, and BUS) can reside in a single physical device or can run in separate devices over an emulated LAN. An emulated LAN requires a single instance of a LES/BUS pair and supports only one type of emulated LAN: Token-Ring or Ethernet. In other words, a single LES/BUS can not support some clients that are emulating Token-Ring or Ethernet. The layer architecture of LANE defines

how and where the LANE entity is positioned and operates within a LAN client.

Figure 3 shows the LANE applications on the top, the functional layers with ATM at the bottom, and the LANE entity between these two layers. The Physical and ATM layer are common to any end user or switch implementing ATM. LANE makes use of standard AAL services to support signaling and data transfer. The functional layers interact through a set of specified interfaces between the different layers. LANE clients and server interact over the LANE User Network Interface (L-UNI). LANE server interacts with other server via the LANE Network-to-Network-Interface (L-NNI). But this interface has not been standardized yet.

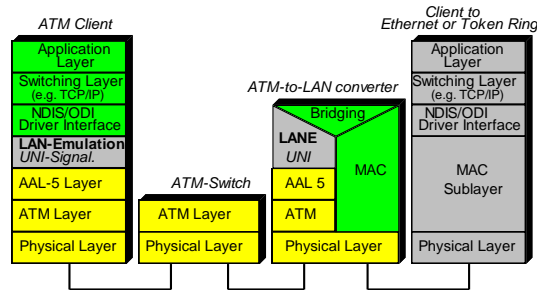


Figure 3: LANE Layer Architecture [1, 2]

In the Internet Protocol encapsulation, which is due to similar to the Classical-IP mechanism, the LLC/SNAP header has been used. The differences between both adaptations is the additional LANE packet with the receiver, transmitter address, and the LANE header field, which limited the packet size to 1500 byte. After that adaptation, the LANE packet will submit to the AAL-5 ATM layer.

Furthermore, LANE has not only advantages. Actually, the following disadvantages are obvious:

- Layer 2 emulation: high functionality.
- LANE address translation is very inefficient
- LANE is limited to one logical subnet (VLAN).
- Inter-VLAN traffic has to pass through routers even if direct ATM connectivity would be possible. These routers are likely to become bottlenecks.
- Maximum Transmission Unit (MTU) has a size of only 1500 byte (normal Ethernet packet size).
- Therefore, the payload size is smaller than at CLIP.

- MTU size must be the same in all participated networks (1500 byte).
- BUS limited LANE for multimedia applications.
- Traditional LAN driver boards limit also the bandwidth.
- Scalability is not efficient - only usable for small and medium networks.
- LANE has no recovery mechanisms for the server.
- QoS is not available.

From this limited point of view, new solutions must be found for better adaptations of IP or further protocols to ATM. The new version of LANE 2.0 includes more scalability, multiplexing ELANs, better throughput, and a more complete standardization. But also here are some points missing like the full QoS support and the L-NNI standardization. [2, 3]

2.3 Multiprotocol over ATM (MPOA)

Today many networks run a multitude of different protocols (e.g. IP, IPX, AppleTalk) and will continue to do so in the near future. Therefore these layer-3 internetworking protocols correctly imply the existence of multiple networks. Solutions exists for internetworking IP (RFC-1577, NHRP, MARS) over an ATM network, but LANE supports only multiple protocols via a single ELAN. A single ELAN is logically a flat network within there is no need to route data streams. However, if a network consists of multiple ELAN that need to be connected, and the ELANs represent different layer-3-subnets, than a router is needed.

Therefore, the ATM-Forum develops the MPOA specification. MPOA is a service, which support layer-3 internetworking for hosts attached to ELANs (running a LEC), hosts attached to ATM networks, and hosts attached to legacy LANs. MPOA provides and delivers the functions of a router and takes advantage of the underlying ATM network as much as possible. That means, MPOA works as a virtual router with real QoS features of ATM.

Figure 4 illustrates the idea of a virtual router. This router consolidates a number of different internetworking solutions over ATM. Therefore, the IETF specifications for intra- and inter-subnet address resolution protocols (ATMARP and NHRP), IP multicast support (MARS), resource

reservation (RSVP), and encapsulation solution for the multiple protocols (RFC-1483) will integrate into MPOA. Additionally, the ATM-Forum implements LANE and in the near future the Private-Network-to-Network-Interface (P-NNI) into the virtual router environment. Both organizations work strongly together for the set-up of a comprehensive internetworking solution.

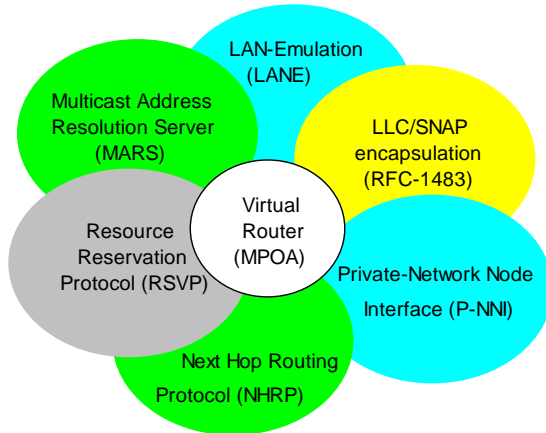


Figure 4: Virtual Router of MPOA [1]

Next Hop Routing Protocol (NHRP) allows the use of shortcuts for the transmission of IP packets over ATM. Therefore, it is possible to send IP packets directly to other devices in other subnets without hop-by-hop routing between all subnets. Multicast Address Resolution Server (MARS) makes the support of IP multicast possible. MARS works as a virtual multicast server and allows also direct connections to the destination address. However, the Resource Reservation Protocol (RSVP) works as a bandwidth reservation mechanism. Thus, the ATM characteristics (QoS) can be adapted to IP packets. The P-NNI protocol of the ATM-Forum is a solution for the efficient routing of ATM cells. A P-NNI extension exists which allows also an IP routing.

The functions of a virtual router are similar like a real router, because the router has to fulfil two key functions: path computation and packet forwarding. But this virtual router is distributed over the ATM network. The advantages of a virtual router can be summarized in the following points:

- Support multiple protocols effective over ATM networks
- Distribute the routing functions between route servers that run the routing protocol and

inexpensive, high-performance data forwarding devices

- Separate routing from switching functions
- Leverages performance and QoS capabilities of ATM network
- Enables direct connections between ELANs rather than passing through traditional routers
- Enables direct Virtual Channel Connections (VCC) between data forwarding devices
- Interworking with unified routers
- Enables subnet members to be distributed across entire ATM network rather than physically collocated to unified router port
- Scalability of the ATM network is efficient enough for all kind of network sizes.

MPOA based on a client/server architecture like CLIP and LANE. MPOA clients establish VCCs with the MPOA server components for forward data packets or request information so that the client can establish a more direct path.

The functions of MPOA will be provided by the MPOA architecture. It can be described by the following components:

- Edge Device
- ATM host
- Default Forwarder Functional Group (DFFG)
- IASG Co-ordination Function Group (ICFG)

The edge device is a physical device that forwards packets from legacy LAN to an ATM LAN, at any protocol. An edge device may use a destination's network address or MAC address to forward a packet. Additionally, a query of an MPOA server for information before forwarding a packet is possible. Edge devices can be described as bridges or multi-layer switches, which allow clients which are not MPOA-capable to work within a MPOA architecture. An edge device is also a MPOA client, which is called in a group Edge Device Functional Group (EDFG).

Another ATM client implementation that can query a MPOA server as well as forward packets at the network of MAC level is the ATM host. If there exist more than one ATM host it can be combined to a ATM Host Functional Group (AHFG).

Figure 5 shows the complex MPOA architecture which includes also the MPOA server

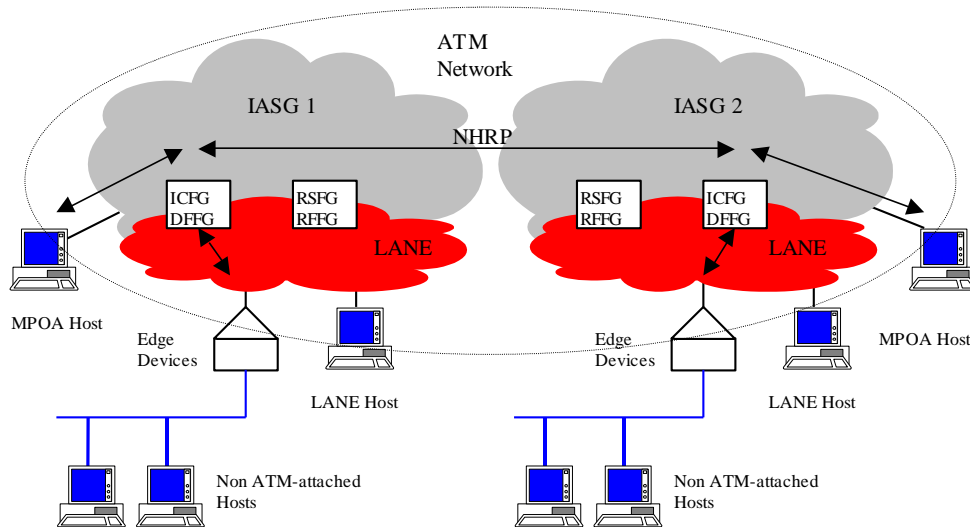


Figure 5: MPOA Architecture [4]

Internetwork Address Subgroup Co-ordination Functional Group (ICFG). The Internetwork Address Subgroup (IASG) is a collection of devices that share a common layer-3 address prefix. The ICFG is a MPOA server which supports the distribution of a single subnet range across multiple legacy ports on edge devices or ATM hosts. The ICFG is co-resident with the route server and one exists for each IASG that the route server is attached to. For instance, if the route server was supporting IP and IPX there would be two ICFGs, one for IP and one for IPX. Another MPOA server is the Default Forwarder Functional Group (DFFG), which allows to reduce the ATM connections to the ICFG. In addition, the call duration can be reduced. This would occur if IP packets of a transmitter can not be assigned to an ATM connection to the receiver. In this case, the DFFG takes the packets, why it does not appear a connection set-up delay. If the DFFG recognizes the receiver location, then the IP packets are transmitted further.

Besides the ICFG and DFFG servers, MPOA defines several other server types like Route Server Functional Group (RSFG), Remote Forwarder Functional Group (RFFG), and the Configuration Server Functional Group (CSFG). These servers are not shown in Figure 5, but complete the MPOA functionality.

CSFG commits the start configuration of the participated components. That means, CSFG assigned ATM addresses to the devices of the MPOA network. Additionally, the maximum packet size (MTU) and the supported protocols will be defined.

RFFG and RSFG are responsible for the communication between several virtual networks. RFFG includes the forwarding part of the virtual router with multicast functions between MPOA clients, which do not need an edge device. Thereby, the MARS attempt is realized and implemented in the ICFG. Before any multicast groups are sending or receiving, the MPOA clients have to ask the MARS.

However, RSFG realizes the routing part of the virtual router. Also traditional routers will be supported. Both router servers offer a multitude of functions to map subnets onto the ATM network layers. The router server can work as a standalone device or as additional functions inside a real router or switch. The router server includes address tables for the network layer and MAC addresses for ATM for the connection to ATM hosts and edge devices. Therefore, direct connections between two arbitrary devices are now possible.

MPOA has also some disadvantages like CLIP and LANE:

- MPOA is not a fully defined specification of the ATM-Forum. First the IETF protocols have to develop further, before the MPOA is a final standard. Currently MPOA is a very flat specification in version 1.0 with only IP support.
- The manufacturer will integrate different MPOA systems in their switches, because of the flat standard.
- The scalability is an extremely complex issue in a large network environment. Actually, it does not provide a stable MPOA network.

- The standardization of the IETF protocols NHRP, RSVP, and MARS is a difficult task, which needs more development. RSVP is still not integrate and NHRP, MARS are not final specify.
- The use of NHRP considers the use of shared VCC shortcuts without end-to-end QoS support.
- The full MPOA architecture will be probably available in 1999.

LANE and MPOA are two efforts of the ATM-Forum that will enable traditional LANs and internetworks to run on top and coexist with ATM switched-based networks. LANE enables a group of ATM-attached clients to emulate the functions and protocols of a traditional Token-Ring or Ethernet LAN. An ELAN can internetwork with traditional legacy LANs through a bridge function. MPOA will enable multiple protocols to be routed and bridged over an ATM network with some QoS features. MPOA can also internetwork with traditional router-based networks. For the final realization, MPOA needs some more time. [1, 4, 5]

2.4 Multi-Protocol Label Switching (MPLS)

The primary goal of the MPLS working group of the IETF is to standardize a base technology that integrates the label swapping forwarding paradigm with network layer routing. This base technology (label swapping) is expected to improve the price/performance of network layer routing, improve the scalability of the network layer, and provide greater flexibility in the delivery of (new) routing services (by allowing new routing services to be added without a change to the forwarding paradigm).

The initial MPLS effort will be focused on IPv4 and IPv6. However, the core technology will be extendible to multiple network layer protocols (e.g., IPX, AppleTalk, DECnet, CLNP). MPLS is not confined to any specific link layer technology, it can work with any media over which Network Layer packets can be passed between network layer entities. MPLS makes use of a routing approach whereby the normal mode of operation is that layer 3 routing (e.g., existing IP routing protocols and/or new IP routing protocols) is used by all nodes to determine the routed path.

MPLS provides a simple core set of mechanisms which can be applied in several ways to provide a rich functionality. The core effort includes:

- a) Semantics assigned to a stream label:
 - Labels are associated with specific streams of data.
- b) Forwarding Methods:
 - Forwarding is simplified by the use of short fixed length labels to identify streams.
 - Forwarding may require simple functions such as looking up a label in a table, swapping labels, and possibly decrementing and checking a TTL.
 - In some cases MPLS may make direct use of underlying layer 2 forwarding, such as is provided by ATM or Frame Relay equipment.
- c) Label Distribution Methods:
 - Allow nodes to determine which labels to use for specific streams.
 - This may use some sort of control exchange, and/or be piggybacked on a routing protocol.

In MPLS, the assignment of a particular packet to a particular stream is done just once, as the packet enters the network. The stream to which the packet is assigned is encoded with a short fixed length value known as a label. When a packet is forwarded to its next hop, the label is sent along with it; that is, the packets are labeled.

The fact that a packet is assigned to a stream just once, rather than at every hop, allows the use of sophisticated forwarding paradigms. A packet that enters the network at a particular router can be labeled differently than the same packet entering the network at a different router, and as a result forwarding decisions that depend on the ingress point (policy routing) can be easily made. In fact, the policy used to assign a packet to a stream need not have only the network layer header as input; it may use arbitrary information about the packet, and/or arbitrary policy information as input. Since this decouples forwarding from routing, it allows one to use MPLS to support a large variety of routing policies that are difficult or impossible to support with just conventional network layer forwarding. [5]

The MPLS working group will define the procedures and protocols used to assign significance to the forwarding labels and to distribute that information between cooperating MPLS forwarders. MPLS can be a simple integration from IP to ATM or other high speed

technologies. But nevertheless, MPLS is far away from a standard now.

3. CONCLUSIONS

The rapid and wide acceptance of ATM has stimulated enormous activity in the communication industry to standardise ATM interfaces. One of the principal objectives of this activity is to enable protocols and applications at the internetworking layer and above to operate effectively over an ATM transport network. Enabling existing protocols and applications to operate over ATM is generally viewed as one of the final, necessary steps to allow the benefits of ATM to be brought gradually into existing networks. Several industry projects address different pieces of the internetwork layer problem, including LANE under auspices of the ATM-Forum, CLIP defined in RFC-1577, NHRP, MARS, RFC-1483, and other projects under the auspices of the IETF. New approaches have addressed extensions for the High Performance Routing (HPR) protocol for ATM networks. These approaches have all taken a somewhat similar technical approach. The existing protocol stack is either left unchanged (e.g. LANE), or its modified in only minor ways (e.g. CLIP). These approaches have additionally required that any changes or additions can be made only to protocol stacks in systems that have a direct ATM interface, that no changes can be made to the protocol stack on LAN systems, and that ATM-attached and LAN systems must be fully interoperable. [6]

MPOA is the best solution to get the advantages from the underlying ATM technology. Other methods are not really able to provide the QoS needs. ATM in the core of a network is necessary to provide this QoS. The advantages of MPOA and the flexibility arise the hope that ATM with IP on the top will be the future network technology. But MPOA has already some disadvantages, because MPOA is a very complex technology and the work in the ATM Forum has only started and is far from being complete standard. That means, MPOA 1.0 exists, but the standardization is not deep enough for a common solution between the different manufacturers. Additional an end-to-end QoS can not be guaranteed, because by the use of the NHRP some connections between the same subnets have to shared the resources.

IP might be worth the complexity because it is so widely used, but it can be doubted if this holds true for other layer 3 protocols as well. Nevertheless, the MPOA model is a very promising technology which has also negative aspects like very complex software implementation (hard to handle), QoS can only be supported if other IETF protocols will be implemented into MPOA (e.g., NHRP, RSVP, and IPv6), and MPOA is actually not a stable standard, but maybe in the near future. We will have further tests with existing ATM equipment to check the flexibility, scalability, QoS, and effectiveness of such solutions.

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