NIG-G3: IP and ATM Integration.

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1 Executive Summary

The performance limits of the current Internet make the integration of IP with ATM a hotly debated issue in the networking arena, leading to various competing approaches and products. Legitimate technical and market issues are, however, often intertwined with biased views and hype, with vendors competing in the standards arena as well as on the markets. Together with the speed of technical evolution, this causes confusion for purchasers of networking equipment who, usually preferring a single vendor for their networks, run the risk of remaining locked into solutions that will not scale with the evolving needs and that will not fully inter-operate with other networks, even using the IP protocol.

It is important to note that the term "Internet" refers indeed to a specific network. In the following, we will refer more generally to the TCP/IP family of protocols, in order to encompass all types of IP networks such as intranets, extranets and the Internet. We will cover both IP version 4 (IPv4) and IP version 6 (IPv6). Unless Ipv6 is explicitly stated, IPv4 should be assumed.

IP and ATM integration refers here to the support of IP over (or within) ATM. From our point of view, integration is a particular case of coexistence. Another particular case is IP and ATM interworking, which means the interoperation between applications or between complete protocol stacks, based on one side on the IP technology, and on the other side on the ATM technology. For instance, interworking between IETF IP based videoconferencing and ATM based videoconferencing.

In this paper, we are not dealing with any interworking scenario. Interworking scenarios do not happen very often and are very difficult to realize. In fact, additional non-trivial aspects like interworking at the user plane, mapping of addresses, and several other issues strictly dependent upon the involved technologies, have to be considered in this case.

The scope of this paper will thus be restricted to IP and ATM integration, and three levels of integration have been identified:

- Level 1: use of IP over an intermediate layer over ATM (e.g. IP over LAN Emulation over ATM),
- Level 2: use of IP directly over ATM (e.g. Classical IP, MARS, NHRP and MPOA),
- Level 3: IP merged with ATM (e.g. MPLS).

In the integration scenarios considered in this paper, the applications always use a common layer to communicate and, in the specific cases under investigation, this common layer is the IP layer. Therefore we use the term "applications" to refer to IP applications.

The present paper is derived from a so-called “Guideline”, NIG-G3, produced by participants of the ACTS “Chain” NIG: Global Network Interoperability (particularly projects CONVAIR, DIANA, EXPERT, IthACI, MULTICUBE and PETERPAN). ACTS (Advanced Communications Technologies and Services) represents the major telecommunications R&D focus of the European Union's 4th research framework Programme.

ACTS uses "Chains" of related projects as a primary vehicle for concertation, both within ACTS itself, and from ACTS towards groups investigating issues of major importance addressed by the communications sector at large. The Network Inter-operability (NI) Chain Group considers all issues of inter-operability between different types of networks.

The current paper focuses on technology, and gives neither commercial, nor time-dependent information. It does not necessarily represent the views of the whole ACTS community or of any single organization participating in the Programme.

2 Purpose

This paper aims at helping technology strategists to evaluate the competing IP/ATM architectures and technologies, helping to clarify, from an unbiased point of view, the state-of-the art. Technology strategists will be informed of the potential opportunities and threats, and will be guided towards appropriate solutions, based on stable integration criteria and realistic evolution scenarios. They will be given an appreciation of the cost/benefits of the new technologies and will be advised on the upgradability and compatibility of various scenarios.

3 Scenarios and Questions

This paper is organized in a set of scenarios and questions that apply to the different aspects of IP and ATM integration.

Several existing scenarios of the modalities for IP and ATM integration have been identified which are described briefly, in this paper. These scenarios are divided into two classes:

- Basic scenarios
- Combination scenarios

Each basic scenario corresponds to the deployment of a particular stand-alone technology. Many basic scenarios are building blocks for combination scenarios. Combination scenarios are obtained by the composition of some basic technologies. Since most of the IP and ATM interworking technologies are still research activities, only a few relevant combinations of basic scenarios have been considered.

On the other side, a set of fundamental and relevant questions for the target recipients has been identified. These questions have to be considered in the context of each particular scenario. For each of these questions, one or more responses have been provided. Assessments on each particular technology have not been given since they generally reflect an opinion, which does not necessarily answer to the questions of the target user.

4 Basic and Combination Scenarios

4.1 Basic scenarios

Nine basic scenarios have been identified according to the three levels identified previously.

- **Level 1: use of IP over an intermediate layer over ATM:**

  B.1: Use of IP over virtual (or emulated) LANs over ATM.

- **Level 2: use of IP directly over ATM:**

  B.2: Trunking of IP systems (host and/or routers), over ATM (best effort).
  B.3: Classical IP (CLIP) over ATM to emulate a virtual unicast IP subnetwork over ATM.
  B.4: MARS to emulate a virtual multicast and broadcast IP subnetwork over ATM.
  B.5: NHRP to provide unicast IP shortcuts between devices over ATM.
  B.6: MPOA to provide shortcuts for bridged IP traffic between two LAN based devices over ATM.
  B.7: RSVP over ATM to associate IP and ATM resource reservations.
  B.8: Differentiated Services over ATM to associate various services classes (resources) to IP flows.

- **Level 3: IP merged with ATM:**

  B.9: MPLS to provide IP flow forwarding at the ATM level.

4.2 Combination Scenarios

The following combination scenarios have been identified:

C.1: combination of B.3 and B.4 to provide an unicast, multicast and broadcast virtual IP subnetwork:
C.2: combination of B.4 and B.5 to provide unicast shortcuts with a full IP subnetwork emulation:
C.3: combination of B.2 and B.7 to provide trunking with resource reservation:
C.4: combination of B.2 and B.8 to provide trunking with service classes (Differentiated Services):

5 Fundamental Questions

Since all the scenarios correspond to recent technologies (some are more experimental than others) it has been considered important to formulate a set of questions aimed at evaluating which of the outlined scenarios are best suited for application in current networking environments. Furthermore, since this paper is devoted especially to technology strategists, this set of questions has been tailored for such an audience:

Q.1: “What is the state of the art in this scenario?”
Q.2: “What opportunities/threats are there for my business using this scenario?”
Q.3: “Will this scenario allow my company to best progress our business?”
Q.4: “What are the cost/benefits of this scenario?”
Q.5: “When should I use this scenario?”
Q.6: “Should I use another scenario?”
Q.7: “Will the next generation be compatible/interwork with my existing equipment?”

Q.8: "What impact (if any) would the next generation Internet Protocol (IPv6) have on this scenario?"

6 Answers

6.1 Scenario B.1: IP over virtual (or emulated) LANs over ATM

LAN Emulation (LANE) [LANE1, LANE2] allows to emulate virtual Ethernet and Token Ring LANs over ATM. Stations belonging to an Emulated LAN (ELAN) may be located anywhere on the ATM backbone. Traffic between two stations (host or bridges) will be transferred over a direct ATM SVC. Traffic between two ELANs or with a legacy LAN will be sent through an IEEE 802.1d transparent bridge. This scenario consists of the use of IP over these ELANs, in the same way as IP is used over a legacy LAN. In that case, ATM is transparent to IP. Nevertheless, any application, aware of the fact that IP is running over LANE may ask to open a direct ATM SVC with a given QOS.

LANE has been standardized by The ATM Forum in two versions. Version 2 is divided in two parts: LUNI and LNNI. The LNNI allows some redundancy at the level of servers used to support LANE. The use of IP over LANE is mainly achieved by using the same legacy standards as those used for IP over legacy LANs.

This scenario allows the continued use of well-known and proven multi-protocol technology, while taking advantage of the ATM capabilities. Any two LANE end systems, located in the same ELAN, are able to communicate directly by using ATM SVCs with any chosen QOS. This scenario is not restricted to IP and allows to quickly create or modify a topology of bridged LANs without having to physically change, a potentially very complex wiring infrastructure.

LANE should be considered either as a transition step to an ATM based network, or as a mixed scenario between legacy LAN and ATM based devices. The transition scenario enables the introduction of ATM as a backbone technology without considerably modifying the existing LAN configuration. It allows to build a two-level infrastructure, an access network based on legacy LANs (directly) interconnected through an ATM backbone.

Direct benefits may be achieved in a dynamic campus or building style environment, where it would facilitate the configuration and management of bridged LANs. It is a transition scenario and no changes are required on existing LAN devices, except on the bridges connected to ATM. Investments are protected while enabling the introduction of ATM based devices able to talk with legacy devices without using a router. In a WAN environment, the cost of communication between clients and servers will probably prohibit the use of this scenario. However, using several synchronized servers at different locations (feature of LANE Version 2) may reduce this cost.

Other scenarios could be used, such as B3 or later, if one is more interested in supporting IP over ATM. For example, the MPOA scenario could be used to improve the IP forwarding over the ATM backbone, while maintaining the support of legacy access LANs.

LANE Version 2 is backward compatible with version 1; and a version 2 server should be able to support version 1 and 2 clients.

As LANE is inherently multi-protocol (through the emulation of a regular Ethernet or Token Ring), the transition to IPv6 should be trivial, although it is not expected that there will be any specific benefits in the use of IPv6.

6.2 Scenario B.2: trunking of IP systems (host and/or routers), over ATM (best effort)

IP hosts/routers are interconnected by ATM SVCs or PVCs. No address resolution mechanism is supported. Mapping between IP and ATM addresses is configured statically (either manually or by SNMP or by BOOTP/DHCP). The IP traffic is encapsulated over ATM. Any number of ATM connections may be supported between the same two IP systems with any ATM QOS.

This is the first and simplest solution used to interconnect IP systems over ATM [RFC1483, 1755, 2331]. The end systems are unaware of the presence of ATM and this mechanism does not impact on the IP subnet configuration and architecture.

This scenario should be considered as a transition step between the use of private or leased lines and the use of ATM. It allows introducing ATM as a backbone technology without modifying considerably the existing configuration.

It could be useful whenever there is a need to have a near-leased line capability between two sites of an organization or between two companies working together. It is even an interesting solution for providing fast access towards an Internet Service Provider (ISP).

The cost/benefit should be considered mainly in the context of a sensible evolution strategy. A direct benefit may be achieved if the cost of ATM connections is less than the cost of leased lines. However, the additional cost of the ATM edge equipment that must be purchased in order to access ATM services must also be considered.

It is the typical scenario of public ATM services. Currently, public network operators offer non-switched ATM services, which rely upon this scenario. It is typical to simulate a point-to-point connection or leased line between two IP systems.
Other scenarios could be used (such as B.3) if a dynamic address resolution is needed; or scenario C.3 or C.4 to support some class or quality of service.

It is irrelevant to this scenario whether IPv4 or IPv6 is being transported. However, such systems will probably have been upgraded to more sophisticated ones, by the time that IPv6 is widespread.

6.3 Scenario B.3: use of Classical IP (CLIP) over ATM

CLIP emulates a virtual IP subnet over ATM, also known as a Logical IP Subnet (LIS). It supports unicast communication inside a LIS, by enabling IP systems (host/router) to establish a direct ATM SVC with any QOS. IP systems belonging to the same LIS may be located at different places on the ATM network and will communicate together directly via ATM. Multicasting and broadcasting are not supported. Any number of ATM SVCs may be supported at the same time between the same two IP systems and may be opened with any ATM QOS.

This is the first and oldest approach for IP integration over ATM. Two versions of signalling protocols have been defined, [RFC1577] and [RFC2225] which are independent of any QOS concerns.

This scenario allows to take advantage of ATM capabilities for IP forwarding, in a multi-protocol environment, while maintaining the usual way of configuring IP networks.

This scenario should only be considered if no multicast and broadcast facilities have to be provided at the IP level. In this case, it is a very light way to emulate an IP subnet over ATM. It is implemented easily and quickly, and may be useful in environments where the resources dedicated to network level support are limited.

A direct benefit of this scenario comes from the ability to dynamically configure and manage LISs comprising devices located potentially anywhere over an ATM network. Closed User Groups may be easily achieved in this way. In a WAN environment, the cost of communication between clients and servers may be a concern, but this is less than with LANE or MARS.

Other scenarios could be used. For example, scenario C.1 which uses MARS to support intra-LIS multicasting and broadcasting, in addition to unicasting, or scenario B.5 (NHRP) in order to establish shortcuts between LISs, as a total replacement of this scenario.

CLIP version 2 is backward compatible with version 1, except that a version 1 client should not wait for a server query to register. Version 2 also supports redundant servers.

Under IPv4, address resolution depends on the operation of an auxiliary protocol operating at the 'link layer' – this began with Ethernet ARP. The ARP protocol was then applied to IPv4 over ATM (Classical IP). However, IPv6 opted for a non-specific link layer approach with the Neighbor Discovery protocol that replaced ARP. However, this new protocol requires that the link technology underlying a given IP interface is capable of native multicasting. Clearly, without the facilities of a MARS, the CLIP approach is not capable of supporting IPv6.

6.4 Scenario B.4: use of MARS

This scenario is similar to B.2 but MARS emulates multicasting and broadcasting. It could also emulate unicasting but this is not considered for standardization at the moment.

This scenario is based on the series of RFCs defining the Multicast architecture on ATM: the first one is MARS [RFC2022] which has been detailed in [RFC2149]. While the first one has a 'proposed standard' status, which means that it is a reference standard solution, the second one is at 'informational status' which means that it does not play the role of a reference but only that of a possible suggested solution. In any case it leads to the development of multi-vendor solutions based on this specification.

MARS opens the integration of IP and ATM to applications based on multicasting (e.g. conferencing) allowing the implementation of this architecture at the network layer to increase performance and flexibility. MARS complements CLIP by providing multicast and broadcast services and is easily integrated with CLIP.

MARS is supported by most commercial products. This scenario enables the setting up of an Enterprise Network based fully on ATM. ATM can be introduced easily into the local area (LAN) without losing important functionalities required on the LAN, such as multicasting and broadcasting. It becomes very important in the case of LAN Operating Systems (e.g. based on Microsoft or Novell) that use broadcasting and multicasting heavily. This solution makes it easy to build Enterprise Networks distributed over a wide area without losing the advantages of the local area (e.g. NFS).

Multicasting can be implemented by a single server (MCS) working as a proxy or directly accessing the features provided by ATM. In both cases, the behavior is quite similar to the CLIP architecture.

MARS could be used in all cases when multicast communications are required. It allows the implementation of one-to-many or many-to-many communications, without increasing the complexity of single network elements.

Another solution, applicable only in the case of one single LIS has been defined in [RFC2337]. It allows the definition of a Multicast architecture, restricted to the same LIS. This method seems to be easier to implement but is limited to the first CLIP version and it cannot take advantage from the integration with NHRP. This solution is an experimental solution proposed by CISCO to extent Multicasting among routers within the LIS. It is limited for several reasons: it is related to a special multicast routing protocol known as PIM-SM (Protocol Independent Multicast in Sparse Mode); it is limited to routers belonging to the same LIS; and it does not represent a standard solution.

This scenario is based on the UNI 3.0/3.1 features and the introduction of a new logical network element (MCS) that makes it easy to be integrated with existing equipment. To better exploit these features, upgrades are needed, but these are limited to the installation of new software releases.

6.5 Scenario B.5: use of NHRP

NHRP allows to setup direct connections between host members of different Virtual LANs, when a direct ATM connection is available.

NHRP allows a source (a host or router) to determine the IP and ATM addresses of the most suitable "next hop" towards a destination. This next hop may be the destination itself if it is directly connected to the ATM network, or an egress router, which is the “nearest” to the destination. Once these addresses have been found, one or more direct ATM SVCs may be established to this next hop with any ATM QOS.

The NHRP protocol was proposed as a standard by IETF in April 98 [RFC2332, 2335]. The applicability of this protocol to the routing of IP datagrams over networks such as ATM is discussed in [RFC2333].

This scenario is the natural and simplest evolution of scenario B.3. According to [RFC2336] the role of ATMARP can be improved by NHRP in order to open shortcuts between hosts belonging to different subnets.

NHRP is interesting especially for private networks, which are widely spread. NHRP alone is not a solution for QOS. In order to guarantee QOS to applications, RSVP over ATM, or NHRP with RSVP over ATM must be used.

6.6 Scenario B.6: use of MPOA

MPOA allows inter-subnet internetwork layer protocol communication over ATM without requiring routers in the data path. MPOA detects traffic going through LANE based IP routers and bypasses these routers at the edge of the ATM network, by establishing unicast shortcuts between MPOA Edge devices, acting as bridges on ingress and egress ELANs. Unicast shortcuts inside the ATM network are provided by NHRP. Any number of ATM connections can be opened between two MPOA Edge Devices, with any QOS.

MPOA version 1.0 has been standardized by the ATM Forum [MPOA] in July 1997.

This scenario combines the advantages of LANE and NHRP, but adds some level of complexity. MPOA is a heavy specification based on LANE and NHRP. The benefits of using MPOA should be compared to the benefit of using LANE and NHRP in parallel, without MPOA.

The shortcut calculation will be delegated to a few IP routers, thus reducing the complexity of the routing topology. The number of IP routers that are needed will decrease and simpler MPOA devices could replace most of them.

MPOA should be used when a large number of legacy Ethernet and Token Ring LANs are connected to an ATM backbone, in order to establish shortcuts for IP traffic between MPOA ingress devices and MPOA egress devices connected to these legacy LANs.

Other scenarios could be used. For example, scenario B.5 (NHRP) could be used if the traffic is essentially IP based, with the use of LANE to support non-IP traffic. In this case, scenario B.1 (IP over LANE) is even not needed since all the inter-LIS IP traffic is handled by an edge NHRP router. Scenario B.1 could also be used stand-alone if the legacy LANs are directly interconnected by LANE bridges configured in a few ELANs.

6.7 Scenario B.7: use of RSVP over ATM

IP hosts/routers are interconnected by ATM SVCs/PVCs and RSVP is used to specify the QOS at the IP layer, which is then mapped to ATM QOS. This scenario must be complemented with others to support address resolution, multicasting and shortcutting.

Several documents have been released by the IETF [RFC2379, 2380, 2381, 2382]. Still work has to be done in order to tune the mapping of QOS parameters at the IP level onto ATM Classes of Service.

The first opportunity is to achieve homogeneous guarantee of QOS over IP islands and over ATM clouds. In fact it is the RSVP protocol itself that sets up and tears down connections. This provides a homogeneous interface to applications requesting QOS, independently of the underlying network. Secondly, QOS is implemented at the data link layer over ATM SVCs and routers are relieved from a part of the computational burden; the switches being directly responsible for scheduling the connections.

The RSVP over ATM solution is interesting, whenever RSVP management critically impairs router performance, since the RSVP/ATM solution is implemented directly on the switches.

The benefits of this scenario are the advantages of QOS, the easy management of QOS reliant connections, and the achievement of end-to-end QOS through ATM and IP clouds.

This scenario can be used for applications that need QOS at the IP layer and a high flexibility in the creation of subnets with QOS. Each end system can belong to more than one subnet, where the QOS policy is different. This is allowed by setting more than one logical interface on the ATM boards.

This scenario can be seen as complementary to MARS (B4). In fact multicast and QOS over broadband are the next generation network services that enable advanced applications for enterprises.

Criticism has been raised concerning RSVP scalability and a reasonable scenario could be to have RSVP in the intranet and Differentiated Services in the backbone, with adequate mapping features.

In order to associate IP and ATM resource reservations, packet classification must be performed at the edge devices. The use of the IPv6 flow label field, in combination with the IPv6 source address can offer an efficient packet classification process. The flow identifiers are contained within RSVP messages and are used to associate incoming IPv6 packets with installed RSVP flows.

6.8 Scenario B.8: use of Differentiated Services over ATM

Differentiated Services are used to define different priority levels to IP flows, which may then be mapped to bandwidth reservation at the ATM level. Again, this scenario must be complemented with others to support address resolution, multicasting and shortcutting.

This technology is standardized by the IETF Differentiated Services (DiffServ) Working Group [RFC2475]. While there is a consensus, mainly within the community of ISPs, that DiffServ is a mainstream to provide QOS, it is still far from wide deployment.

DiffServ scales well to the size of the Internet (there is no need to keep a per-flow state in transient routers) and is relatively easy to achieve in nearly every router able to classify packets. On the other hand, it is not yet clear, whether common agreement can be achieved in a short time on the precise number of queues, and the priority levels within each queue supported by DiffServ. There is no little progress in mapping DiffServ to ATM.

The main opportunity is the simplicity of the DiffServ in both provisioning and contracting. A Service Layer Agreement (SLA) could be easily documented and well understood by the end user. Though, there might be no end-to-end QOS guarantees in this SLA. A potential threat comes from the need (and willingness of ISPs) to monitor every packet of a DiffServ flow in each particular domain. Although accounting for DiffServ seems to be less complicated than for IntServ, it is not elaborated yet. Also it is not clear how ISPs will treat DiffServ for multicast flows.

DiffServ is clearly cheaper in the backbone than IntServ. However, in the case of IntServ a customer has the freedom to enable/disable RSVP signalling from the local application level. In the case of DiffServ, an ISP would probably charge the customer per marked flow, which obviously creates additional problems for a customer network administrator; a firewall (or Network Address Translator) must be configured at the gateway to an ISP to filter outgoing/incoming flows with respect to the customer policy.

Typically, this scenario should be used in a large corporate network where several interconnected infrastructures are linked with PVC/SVC connections and are under the same administrative control.

The latest version of the IPv6 specification includes a traffic class field of 8 bits, which within the Differentiated Services working group is being termed the "DS field". Six bits of the DS field are used as a codepoint to select the per-hop behavior a packet experiences at each node. Future work will exploit the efficient processing of the IPv6 header and the associated DS field structure to provide better delay characteristics.

6.9 Scenario B.9: use of MPLS

Multi Protocol Label Switching (MPLS) is a recent technology based on the label swapping paradigm. When using MPLS over ATM, the ATM switch fabric directly performs IP datagram forwarding. The entire ATM control plane is replaced with a lightweight MPLS control plane and IP routing protocols. As soon as a switched path (Label Switched Path in the MPLS terminology) is established, the IP flow will no longer be routed but switched, thus utilizing fast ATM cell transport. Note that MPLS is not restricted to ATM as the link layer.

MPLS is being defined by the IETF [MPLS] and most probably, the final standard will be based on a mix of two proprietary solutions: ARIS (IBM) and Tag Switching (Cisco).

Opportunities and threats are not yet well identified, as this technology is still being defined.

MPLS could be useful to reduce the complexity of forwarding IP traffic over ATM, to perform efficient traffic engineering, and to enable the easy definition of new routing semantics for IP traffic, such as Virtual Private Networks (VPNs). A scalability benefit is achieved by reducing the size of the routing table of routers in some circumstances, as MPLS allows aggregating routes to different destinations in the same path. It allows to go one step further than CIDR by aggregating routes to incompatible (non CIDR-aggregable) destinations. No clear benefit has yet been established regarding forwarding performance. The cost of MPLS is the replacement of the traditional hop-by-hop forwarding paradigm by the label switching paradigm, aiming at a new IP model.

6.10 Scenario C.1: use of classical IP with MARS

CLIP and MARS are used in parallel in the same LIS. Classical IP emulates a unicast service, while MARS emulates a multicast and a broadcast service. Two address resolution servers are deployed in parallel, one for CLIP and one for MARS. All services are provided as best effort services, but ATM connections may be opened with a given QOS.

The main opportunity is to take advantage of ATM broadband and QOS capabilities for IP forwarding, in a multi-protocol environment, while maintaining the usual way of configuring IP networks. A threat could come from MPLS and/or IP over SONET/SDH, if the ATM technology doesn't succeed to emerge.

This scenario enables the use of the same broadband technology for LAN-WAN interconnection, and to dynamically and easily configure virtual IP subnets. The transition to this scenario may be achieved incrementally by gradually replacing the legacy network by an ATM network.

The ability to manage virtual IP subnets is a clear benefit. In a WAN environment, the cost of communication between clients and servers must be taken into account (as with LANE). This cost may be reduced by using several synchronized servers at different locations (but not with CLIP version 1).

This scenario may be used to provide a full emulation of IP services over ATM, including unicasting, multicasting and broadcasting. In addition, it allows to support a wide range of QOS capabilities for intra-LIS communications. The traditional IP forwarding and routing is maintained.

Other scenarios using RSVP, DiffServ or NHRP may be used to support QOS capabilities for inter-LIS communications. E.g., by using NHRP, a direct ATM SVC (shortcut) may be established between two devices in different LISs with any QOS. Scenario B.4 could even be used alone to support unicasting (not standardized but practical). Scenario B.9 (MPLS) could be used if the complete deployment of ATM is not needed, e.g. if the traffic is mainly IP based.

No further version of MARS is foreseen and two versions of classical IP have been defined. The compatibility between Classical IP versions 1 and 2 is covered by scenario B.3.

The combination of Classical IP and MARS is necessary to support IPv6. Refer to scenarios B.3 and B.4 above.

6.11 Scenario C.2: use of MARS with NHRP

MARS and NHRP are used in parallel in the same LIS. On one hand, NHRP emulates an intra-LIS unicast service such as CLIP and is used to find shortcuts for inter-LIS traffic. On the other hand, MARS complements NHRP by emulating intra-LIS multicasting and broadcasting. All services are provided as best effort services, but ATM connections may be opened with a given QOS.

Both MARS and NHRP are IETF standards and have numerous extensions: MIB, IPv6, mobile, etc., however these extensions are not symmetrical, due to a different nature of these two protocols. Another extension of NHRP is a DiffServ approach over NHRP shortcuts. On the contrary, MARS does not support any notion of QOS.

The opportunities for MARS are in obtaining IP multicast service over ATM. Additionally, combination with NHRP provides a flexible mapping of IP flows to underlying ATM infrastructure. Scalability is a possible threat with MARS. Opportunities that are coming from NHRP are mainly with the better usage of the underlying ATM connectivity.

A company with a rich and long history of ATM deployment and with skilled network management will progress most rapidly and take advantages of NHRP, while its combination with MARS requires thorough and precise engineering.

The cost depends on the number of MARS and NHRP servers to be installed and maintained. In the case when scalability/reliability would require server replication, it gives rise to the need for an additional protocol (SCSP) to synchronize caches of servers.

The scenario should be used with rich ATM connectivity and when a best-effort IP multicast service, which might be constrained to a single LIS, is not a limitation.
In the future, it is foreseen that MARS could be upgraded to support QOS and it is likely to be backward compatible. On the other hand, it is difficult to predict which (if any) IP shortcut technology will succeed in the marketplace, since a number of alternative proposals exist.

6.12 Scenario C.3: use of trunking with RSVP

IP hosts/routers are interconnected via ATM SVCs/PVCs. RSVP allows to specify a resource reservation between two routers. The corresponding flows are then mapped onto different ATM VCs according to the resource reservations. There is no address resolution mechanism between IP and ATM, because the mapping is done statically. RSVP is used as reservation protocol and RSVP QOS can be mapped onto ATM QOS. Mapping can be done per-flow or based on RSVP aggregation.

The role of ATM is minor. Static address resolution simplifies the mapping and, if there is no QOS mapping, this is limited to datagram encapsulation.

It is one of the easiest solutions to realize when one wishes to guarantee QOS to IP applications between networks that are interconnected via ATM (e.g. for a public operator). For strict QOS guarantees a trunk for each RSVP flow or CAC at the edge routers is needed.

This solution could probably work in the future. However, for the moment it is not yet clear whether RSVP is the solution for QOS in IP networks.

6.13 Scenario C.4: use of trunking with Differentiated Services

IP hosts/routers are interconnected via ATM SVCs/PVCs. Differentiated Services are used to define different priority levels to IP flows by hosts/routers. These flows are then mapped onto different ATM VCs according to the priority assigned to them.

The state of the art in this scenario is strictly dependent on the DiffServ scenario (B.8), since ATM trunking is really consolidated.

For ISP customers, this scenario provides an easy way of specifying a Service Layer Agreement (SLA), where an exact mapping of priorities into ATM QOS can be defined along the whole DiffServ path. For large corporate/campus ATM backbone, this solution enables network managers to apply policies for prioritising traffic. Although accounting for DiffServ seems to be less complicated than for IntServ, it is not elaborated yet. Also it is not clear how ISPs will treat DiffServ for multicast flows.

This scenario is best suited for corporate network managers, who are able to define prioritisation policies and map them onto ATM classes of service.

DiffServ is cheaper in the backbone than IntServ and has lower maintenance costs. On the other hand RSVP theoretically allows each networking application to be allocated a QOS with little or no modification, whilst this is not the case with priorities.

Typically, this scenario should be used in a large corporate network where several interconnected infrastructures and linked with PVC/SVC connections and are under the same administrative control, such as ISP backbones.

7 Transition graph

The Figure 1 gives an idea of possible scenarios evolution. An arrow from ‘a’ to ‘b’ indicates, that scenario ‘a’ may be replaced by scenario ‘b’ for the reason indicated on the arrow.

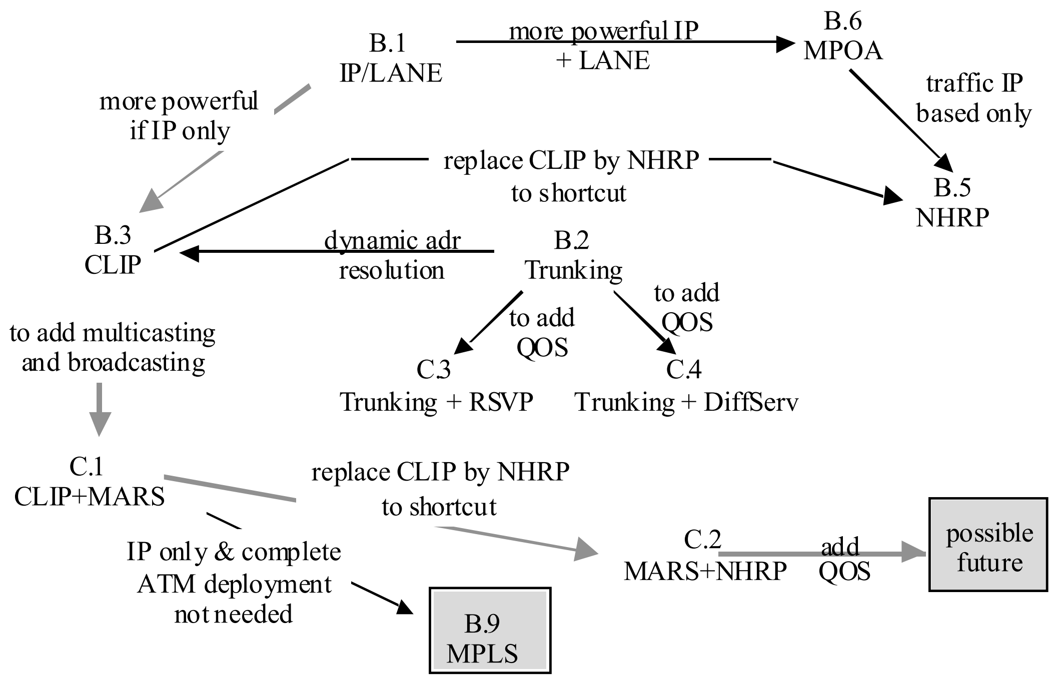

Figure 1: Transition graph of scenario evolution choices.

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9 References

[RFC1483] Multi-protocol encapsulation over ATM Adaptation Layer 5, IETF, July 1993.

[RFC1577] Classical IP and ARP over ATM, IETF, January 1994.

[RFC1755] ATM Signaling support for IP over ATM, IETF, February 1995.

[RFC1932] IP over ATM: A Framework Document, IETF, April 1996.

[RFC2022] Support for Multicast over UNI 3.0/3.1 based ATM Networks, IETF, November 1996.

[RFC2149] Multicast Server Architectures for MARS-based ATM multicasting, IETF, May 1997.

[RFC2225] Classical IP and ARP over ATM, IETF, April 1998.

[RFC2226] IP Broadcast over ATM Networks, IETF, October 1997.

[RFC2331] ATM Signaling Support for IP over ATM - UNI Signaling 4.0 Update, IETF, April 1998.

[RFC2332] NBMA Next Hop Resolution Protocol (NHRP), IETF, April 1998.

[RFC2333] NHRP Protocol Applicability Statement, IETF, April 1998.

[RFC2334] Server Cache Synchronization Protocol (SCSP), IETF, April 1998.

[RFC2335] A Distributed NHRP Service Using SCSP, IETF, April 1998.

[RFC2336] Classical IP to NHRP Transition, IETF, July 1998.

[RFC2337] Intra-LIS IP multicast among routers over ATM using Sparse Mode, IETF, April 1998.

[RFC2379] RSVP over ATM Implementation Guidelines, IETF, August 1998.

[RFC2380] RSVP over ATM Implementation Requirements, IETF, August 1998.

[RFC2381] Interoperation of Controlled-Load and Guaranteed-Service with ATM, IETF, August 1998.

[RFC2382] A Framework for Integrated Services and RSVP over ATM, IETF, August 1998.

[RFC2475] An Architecture for Differentiated Service, IETF, December 1998.

[LANE1] LAN Emulation over ATM Version 1.0, The ATM Forum Technical Committee, af-lane-0021.000, January 1995.

[LANE2] LAN Emulation Over ATM Version 2 - LUNI Specification, The ATM Forum Technical Committee, af-lane-0084.000, 1997.

[MPLS] Multi-protocol Label Switching Architecture, draft-ietf-mpls-arch-05.txt, IETF, April 1999.

[MPOA] Multi-Protocol Over ATM, Version 1.0, The ATM Forum Technical Committee, af-mpoa-0087.000, July 1997.

[UNI3.0] ATM User-Network Interface (UNI) Specification, Version 3.0, The ATM Forum Technical Committee, af-uni-0010.001, September 1993.

[UNI3.1] User-Network Interface (UNI) Specification, Version 3.1, The ATM Forum Technical Committee, af-uni-0010.002, September 1994.

[UNI4.0] ATM User-Network Interface (UNI) Signaling Specification, Version 4.0, The ATM Forum Technical Committee, af-sig-0061.000, July 1996.