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# Deliverable D14.1

# Specification of Phase 2 Test Programme

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**Abstract:**

*This deliverable specifies the experiments that will be carried out in the TEN-34 Phase 2 Test Programme over the JAMES ATM network. In Phase 1 of the Test Programme (work package 11) the experiments focused mainly on the examination of various network technologies on their suitability to support advanced services. These experiments have shown that most advanced technologies such as SVCs are not yet stable enough to support operational services in a multi-vendor environment.*

*In Phase 2 of the Test Programme the emphasis will be on providing additional services, albeit with initially limited functionality. Methods of providing such services will be investigated and trialled over the JAMES network. The tests will also include new traffic classes and technologies such as ABR and ATM routing.*

*This deliverable specifies the experiments and activities planned for the Phase 2 Test Programme. A wide range of activities is specified for experimentation, but the intention is, based on initial experience, to focus on those technologies that might be applicable in the near future, and to provide details on how to use them in an operational environment.*

**Keywords:**

ATM experiments, IP over ATM, traffic management, ABR, signalling, ATM routing, resource reservation, ATM point-to-multipoint, ATM security, ATM address resolution, ATM addressing, ATM network management, native ATM performance, VBR, label based switching.

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## EXECUTIVE SUMMARY

The TEN-34 Project has created a high-speed European backbone, which has been in service for approximately three months at the time of writing this deliverable. Despite a significant part of the backbone being based on ATM technology, the backbone does not make use of any advanced features of the ATM technology yet. In fact the ATM virtual paths are used as mere replacements for leased lines. The reason for not using more advanced ATM services such as signalling lies in the difficulty of running those services reliably in a multi-vendor environment.

In Phase 1 of the Test Programme (work package 11) it was shown that the most advanced ATM features are not mature and stable enough to be run on a production network (see deliverable D11.3). These tests were carried out over the JAMES network, to ensure that the operational TEN-34 services were not disrupted.

In the second phase, the experiments will continue to examine new technologies on their suitability to be used for operational services. New technologies such as ABR, PNNI, ATM point-to-multipoint and label based switching will be tested. Some of the activities from the first phase will be continued in a similar form. Examples are the network management and the ATM security activities. In general, the focus will be more on the provision of new and advanced services in this phase. The scope of such services will most likely be limited, as the generic solutions are in most cases not working yet, or not stable enough for a production network. As in the first phase, all activities described here will be carried out by the national research networks which are partners in TEN-34, plus other European research institutes.

The activities in the second phase will also be carried out over the JAMES network. A low-speed overlay network has been set up for the experiments, and additional VPs might be requested where either higher speeds or additional links are required. The lack of services on the JAMES network still remains a critical issue. Whilst for example SVCs have been tested extensively by TEN-34, the JAMES network did not support signalling. Shortcomings of this kind have to be circumvented by TEN-34, which makes the experimentation more difficult. SVC and ABR have recently been announced for fall 1997, which does not leave much time for experiments, as the JAMES project ends in March 1998. Since the TEN-34 project ends in July 1998 the experiments have to either finish by March 1998, or be continued in NRNs where applicable.

One of the experiences gained in the first phase is that ATM is too complex to be treated in compartmentalised experiments. There is a significant danger that important details and experiences are not recorded in this way. For example one of the experiences gained during the first phase and on the production network is that ATM circuits should never be denoted in bit/s, but only in cells/s, as bit/s is/are not unique in ATM terms. There have been a number of misunderstandings on this. To highlight such experiences it was decided that in phase 2 there will be a general section in the reports covering important findings like this.

# 1. Introduction

The majority of the TEN-34 network has been operational for about three months. A substantial part of it is based on ATM virtual paths (VPs). However, those VPs are only used as straightforward substitutes for leased lines. Each VP carries only one virtual circuit (VC), so there is no full mesh between the routers on which those VCs are terminated. The topology of the VCs follows the topology of the VPs. Also in terms of traffic classes, only CBR and VBR services are used, and where VBR is used, it is used without overbooking. There are also no advanced technologies in use such as RSVP, and the service offered to national research networks (NRNs) is only an IP service.

It was one of the goals of the test programme to make more advanced services and technologies available on the TEN-34 network. During the first test phase a number of experiments on new technologies and services were carried out. The overall conclusion was that none of them are advanced enough to be used in a multi-vendor production environment such as TEN-34.

In the second phase there will be more experiments on new services such as ABR and PNNI. However, there will also be a stress towards more services on the production network. It is not expected that new traffic classes or signalling will be advanced enough to be used on TEN-34 during the lifetime of the project, but it is envisaged that some improvements of the service could be implemented based on the experiments described here. It is very likely that none of those will be run in the way they are supposed to be, like for example SVCs to the desktop. But limited improvements such as manual bandwidth reservation through the network are deemed to be possible within the next year.

The basic principle of the test set-up and the usage of the JAMES network has not changed from phase 1. Please refer to D11.1 for further details of this.

All experiments will be carried out by a group of ATM experts of the NRNs in the TEN-34 project, and some research centres and universities. The Task Force for Trans-European Networking (TF-TEN), which was created in the framework of TERENA (see: http://www.terena.nl) for the first phase of the experiments will again plan and organise the experiments. This task force is an open forum and the results of the experiments will be publicly available. As in the first phase, the co-operation of the PNOs running the JAMES network is being sought to get the best possible understanding of the transmission network, as it might impact on the test results. Also, modifications to the PNO test set-up might be required to evaluate measurements under different conditions.

# 2. Usage of the JAMES Network

As in the first phase most of the experiments of the second phase will also be carried out over the JAMES network. Whilst this network supplies the TEN-34 partners with a basic transmission infrastructure for experiments, the JAMES network does not make use of any advanced ATM features. Only CBR and in some places VBR are offered, which means that this experimental network is not more aggressive in terms of using advanced technologies than the current TEN-34 production network. SVCs have been available on JAMES for a few months on a very limited scale which is far from what is required for appropriate testing. Both SVCs and available bit rate (ABR) were announced for fall 1997[1]. Given that the JAMES network ends in March 1998, this does not leave much time to experiment on these services.

The experiments which require services which JAMES does not provide, will as far as possible be carried out through tunnelling. This means that for example the signalling information which is normally carried on a specific VC will be switched into a JAMES VP, so that JAMES does not see the signalling. Effectively the advanced services will then be running on NRN equipment, and JAMES will be used only as a transmission infrastructure. This way of working did allow us to test SVCs in phase 1, despite JAMES not supporting it. However, this approach is not optimal, as some effort needs to go into bypassing the shortcomings of JAMES. It would also be beneficial to be able to validate some of the results in a fully switched network.

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1 See: "Open Links", a France Telecom Newsletter for international Carriers, N.1, May 1997

The operational procedures on JAMES have been slightly improved, but are still far from ideal. Whereas in the beginning of the JAMES service a new JAMES user description (JUD) had to be submitted for each change in the network, now a JUD specifies a set of connection points, and changes in the VC set-up can be handled more easily. It is still not specified how long it takes to set up a VP, and set-up times of several weeks have been observed. It is very difficult to plan ahead under such circumstances, but as TEN-34 has a static overlay network of low-speed VPs over JAMES these problems don't occur too often - only if there are changes or if a higher speed VP is required. There is still only one contact person in JAMES per PNO, which means that requests just get delayed in case the relevant person is not in the office. All these problems have been highlighted by TEN-34 from the beginning of the project, but in most cases without success.

In conclusion, the JAMES network still does not offer the advanced services needed by TEN-34. The problems with service level agreements and operational procedures have not yet been addressed by JAMES adequately.

## 3. Planning of the Activities

For phase 2 of the test programme, the TF-TEN group defined 13 activities which are detailed below. Some of them are a follow-up from the last phase, for example network management and addressing. Besides trialling new technologies, these experiments provide an ongoing service to the other testers. For example there is a network monitoring tool that can be used by all participants to check the status of the network.

A significant number of activities is planned for new technologies such as ABR and PNNI. Most of these technologies require special software in switches and routers, not all of which is available today. It is not known in all cases whether the software required will be available within the time frame of the project, it is therefore possible that some activities may get delayed or cannot be done at all. The definition of the activities was carried out in a generic way such that the areas of interest are defined. Single activities can cover a wide range of potential experiments, not all of which can be carried out due to limited resources. Despite the attempt made here to specify the activities as precisely as possible, it cannot be ruled out that parts of these experiments cannot be carried out, due to a lack of time or missing implementations. As all this research is on very recent technological developments, it is impossible to make more detailed specifications at this stage.

Each activity is lead by a researcher of the TF-TEN group. It is expected that only a small sub-set of researchers is involved in each of the activities, so that most of the activities will be run in parallel by small groups. The timing of the experiments depends mainly on external influences such as availability of software. Basic infrastructure requirements such as SVCs and ATM-ARP can be made to work at least in a limited way, so that activities in this phase don't depend much on the outcome of other activities.

## 4. Joint Experiments with JAMES

As outlined in the specification of the first phase, it is important to have the co-operation of JAMES for some of the experiments to be able to have the full view on the network. For some activities it might for example be important to have cell time stamps within the JAMES network, This was already done once in the CDVT experiment of phase 1.

In addition to the co-operation, it is planned to carry out some experiments together with JAMES, and first discussions on this took place over e-mail. There is some principal interest from both sides in the experiments defined here, so it is expected that a joint experimentation programme can be defined. At the time of writing this report, these discussions were not at a stage where a joint experimentation programme could be defined.

# 5. Detailed Test Descriptions

In the following sections each of the planned activities are outlined in detail. All activity descriptions define the goal of the activity, phasing of the activity, responsible person and other details. Some details like the participants for each activity were not know at the time of writing, because not all questions regarding available equipment and manpower could be answered yet. Also it is uncertain what services JAMES will make available, which in turn, has impact on the planning of these experiments.

The tests are:

5.1 ATM Routing
5.2 Label-based Switching
5.3 ATM Resource Reservation
5.4 IP Resource Reservation
5.5 ATM Point to Multipoint
5.6 ATM Signalling
5.7 ATM Policy control and accounting
5.8 ATM traffic management
5.9 ATM address resolution
5.10 ATM Addressing
5.11 Performance of the Native ATM Protocol and native ATM applications.
5.12 ATM Network Management
5.13 Security in ATM Networks

For each of the activities a report will be produced that describes in detail the findings of the experiment. These reports will be included in the next deliverable of this work package, the "Results of the Phase 2 Test Programme" (D14.2).

The final deliverable, the "Summary Results of the Test Programme" (D14.3), will then summarise the findings of both phases and present the results in a concise and easily usable form, without repeating too much technical detail. The goal of this deliverable is to act as a reference and a summary of the work conducted by TF-TEN in the framework of the TEN-34 project.

As in D11, the reports will clearly state the usability of the tested ATM feature in a production environment. Suggestions for migration to the service network will be outlined as well. It will be indicated whether further studies on a subject are required. Each experiment report includes the following sections:

- Name of the experiment
- Experiment leader
- Participants in the experiment
- Dates and phases
- Network infrastructure
- Results and findings
- Relevance of service and migration suggestions
- Test-related problems and general comments
- Further studies
- References

## 5.1 ATM Routing

***Experiment Leader:***

Günther Schmittner, JKU, Linz, Austria

***Participants:***

Not yet defined.

***Goals:***

- Study operation of ATM switches running PNNI in the WAN
- Prove interoperability between different PNNI implementations
- Verify interaction between PNNI-based and static ATM routing
- Gain experience in running a stable ATM routing infrastructure
- Prove the applicability of PNNI for a European ATM infrastructure
- Study the applicability of I-PNNI
- Compare functionality of PNNI with NNI

***Description:***

PNNI is an ATM Forum specification for connecting either ATM nodes (switches) or ATM networks. Thus, PNNI stands for either Public Node-to-Node Interface or Private Network-to-Network Interface depending on the particular context in which PNNI is being used. Thus, PNNI can be used either as an interface between different ATM networks or as an interface between ATM switches within a single ATM network.

The objectives in the design of PNNI can be summarised as follows:

- A functional interface between ATM switches to allow full-function networks of arbitrary size and complexity to be constructed.
- Scalability
- Multi-Vendor
- Proprietary Subnetworks
- Open Implementation
- Dynamism
- Efficiency
- Usefulness

In order to accomplish these functions PNNI consists of the following components:

- Topology and Routing
- Path Selection and Signalling
- Traffic Management
- Network Management

PNNI uses a hierarchical concept for its routing based on multiple (up to 104) topology levels. These levels are related to ATM addresses and make use of prefix-based routing. ATM switches running PNNI interact on each level independently among each other. The concept of Logical Group Nodes (LGN) simplify the exchange of routing information on the various layers.

When data connections are being set using PNNI signalling, the ATM switches find and allocate a path through the network which satisfies the requested QoS characteristics. PNNI uses a source routing vector for this path which is carried in the form of a designated transit list (DTL). Mechanisms for alternate path selection are implemented using a crankback protocol. Path selection and allocation is done using two different forms of Call Admission Control (CAC).

Interim Inter-Switch Signalling Protocol (IISP) (aka PNNI Phase 0) implements an early ATM routing function using static routing tables in the ATM switches. IISP is aimed to interoperate with PNNI-based routing.

The experiment will study the operation of PNNI on various ATM switches in different NRNs over JAMES. To support the necessary signalling a tunnelled network of private ATM switches is used over the JAMES infrastructure using VP bearer service. Of particular interest are the interoperability between different PNNI implementations, the interaction between PNNI-based and static ATM routing and the applicability of PNNI for an European ATM infrastructure.

As the efficient operation of PNNI is related to the allocation of ATM addresses, a careful planning of address allocation is needed. Interaction between the different ATM address types will also be investigated.

I-PNNI (Integrated PNNI) aims at integration of layer-3 (network protocol layer) topology information with the underlying ATM topology. Thus layer-3 routing will make use of the information gained from layer-2 routing. Yet to date, there exists no ratified specification of I-PNNI. Therefore a practical implementation in the context of this experiment seems rather unlikely.

NNI is the interface used between ATM switches in public ATM networks. It is in some sense complimentary to PNNI in private ATM networks. A comparison of the functionality of both interfaces is an interesting task. However, similar to I-PNNI, there is no final specification available today.

***Pre-requisites:***

There are several implementations of PNNI on the market which should comply to ATM Forum PNNI 1.0 Specification completely or in part (e.g. single peer group support only).

***Dates and Phases:***

- Start preparation 1997-07-01
- Start implementation of small PNNI islands 1997-09-01
- Deploy a multiple peer-group PNNI network 1997-12-01

***Network Infrastructure:***

- A SVC-based infrastructure with PNNI signalling.
- UNI 3.x capable switches and static ATM routing using IISP (PNNI Phase 0) can be incorporated.
- A network capacity of 2 Mbps is sufficient.

***Local Infrastructure:***

A PNNI capable ATM switch.
In addition IISP capable switches with static routing can be used.

***Hardware/Software:***

Any ATM switch running an ATM Forum compliant version of PNNI 1.0.

***Related Work:***

- ATM Signalling
- ATM Resource Reservation
- ATM Addressing

## 5.2 Label-based Switching

***Experiment Leader:***

Jean-Marc Uzé, RENATER, Paris, France

***Participants:***

Not yet defined.

***Goals:***

- Study of the Multiprotocol Label Switching IETF activities
- Survey of existing solutions and protocols to integrate layer 2 and layer 3 (IFMP, TDP, ARIS, ...)
- Experimentation of Cisco Tag Switching:
  - Gain experience of this new technology
  - Evaluate the gain of performances
  - Prove its applicability/scalability on an European ATM network
  - Study its flexibility in delivering routing services, e.g. QoS, load balancing
- Other solutions could be also tested

***Description:***

The label-based switching is a technique based on an integration of layer 2 switching and layer 3 routing. This technique has been designed for high speed networks to use, in a more efficient way, the performances of ATM switching with the scalability and flexibility of IP routing. The idea is to set up ATM VCs for traffic that doesn't need to be routed at each hop. Some mechanisms are based on flow detection (e.g. IP switching), others on the routing topology (e.g. Tag Switching).This technique is also opened to other protocols but we will study only the applicability for an IP service on ATM infrastructure.

Tag Switching is a technique that assigns a label or "tag" to packets toward its final destination. In a conventional router network, the packets are processed by all routers which determine the next hop toward the final destination. In a Tag Switching network, the ingress router assign a label to each destination network. The packets in this network are then switched through this network by these tags toward the egress router. A Tag Switching network consists of a core of tag switches with tag edge routers on the periphery. The tag edge routers and tag switches use standard routing protocols (BGP, OSPF...) to build routing tables. A tag (a couple VPi/VCi in ATM networks) is then assigned for each route in the tag network. The tag information is distributed via a Tag Distribution Protocol (TDP) to all tag switches and tag edge routers. This protocol will set-up all VCs in the ATM backbone to forward the different possible IP flows.

The goal of the experiment is to test the Tag Switching in a local area network and in a wide area network. Tests would be done on the JAMES network with TF-TEN participants. The objective is to build a Tag Switching network as big as possible with LS1010 switches in the core and 75xx routers in the periphery. The Tag Switching experiment will be done in several phases, many in a local environment to gain experience and facilitate the implementation on JAMES.

***Pre-requisites:***

A beta-version of Cisco Tag Switching software will be available this summer and could be used in our tests. A commercial version is planed for the end of this year.

***Dates and Phases:***

- Start preparation (survey, study): 1997-07-01
- Start implementation in a local environment: 1997-09-01
  - simple topology in a SVC network (e.g. router---switch---router---router)
  - simulation of the JAMES network with SVC tunnelling (same topology)
- Start implementation in the JAMES network: 1997-12-01
  - bilateral tests

- the full network depending on the participants

***Network Infrastructure:***

- The JAMES overlay network VPs
- A network capacity of 2 Mbps is sufficient.
- The VPs have to be reserved for the experiment during the test period (configuration constraint for Tag Switching tunnelling)

***Local Infrastructure:***

An access switch to JAMES (It can be the switch involved in the experiment).

***Hardware/Software:***

- A Tag Switching capable ATM switch (LS1010)
- A Tag Switching capable router (C75xx)
- The Cisco Tag Switching software (beta or commercial version)
- The countries not having a router can also participate to the experiment

## 5.3 ATM Resource Reservation

***Experiment Leader:***

Günther Schmittner, JKU, Linz, Austria

***Participants:***

Not yet defined.

***Goals:***

- Study operation of ATM switches running PNNI in the WAN
- Prove interoperability between different PNNI implementations
- Verify correct resource management in PNNI-based networks
- Prove the applicability of PNNI for resource management in a European
- ATM infrastructure
- Compare functionality of PNNI with NNI

***Description:***

PNNI manages and allocates network resources for SVCs in an ATM network. It keeps track of the current status of all switches and links in order to manage resources in an accurate and efficient way.

When an end station requests a connection with specific QoS parameters, PNNI is able to find a possible path (if any) satisfying the request and will allocate the necessary resources in the network. It can be mathematically proven that it is not possible to find the optimal path, except by an exhaustive enumeration algorithm, which is not feasible. Some implementations allow a specification of criteria as a base for the selection of possible paths.

The experiment will study resource management of PNNI in a network of European NRNs. As this network will be based on tunnels over the JAMES infrastructure using VP bearer service and mostly CBR service, it will be of particular interest how different service classes are managed by PNNI.

NNI is the interface used between ATM switches in public ATM networks. It is in some sense complimentary to PNNI in private ATM networks. A comparison of the functionality of both interfaces is an interesting task. However, there is no final specification available today.

***Pre-requisites:***

There are several implementations of PNNI on the market which should comply to ATM Forum PNNI 1.0 Specification completely or in part (e.g. single peer group support only).

***Dates and Phases:***

- Start preparation 1997-07-01
- Start implementation of small PNNI islands 1997-09-01
- Deploy a multiple peer-group PNNI network 1997-12-01

***Network Infrastructure:***

- A SVC-based infrastructure with PNNI signalling.
- At least UNI 3.x capable switches.
- A network capacity of 2 Mbps is sufficient.

***Local Infrastructure:***

A PNNI capable ATM switch.

***Hardware/Software:***

Any ATM switch running an ATM Forum compliant version of PNNI 1.0.

***Related Work:***

ATM Signalling
ATM Routing
ATM Addressing

## 5.4 IP Resource Reservation

***Experiment Leader:***

Simon Leinen, SWITCH, Switzerland

***Participants:***

Not yet defined

***Goals:***

- Study operation of RSVP in an IP network [rsvp]
- Test mapping of IETF ``integrated service'' classes to ATM QOS [issll]
- Investigate alternative ways of providing differentiated qualities of service (classes of service) using IP routers [queuing]

***Description:***

For the second phase of TF-TEN experiments, we will look at possible ways to provide different qualities of service to TCP/IP users.

**RSVP:** RSVP is being standardised by the IETF as a signalling protocol for resource reservation. However, there are important open issues such as

- Quality-of-service-aware routing
- Policy control
- Mapping to specific lower layers such as ATM

The experiment will study these problems in the context of provisioning QOS on a large backbone network.

**ISSLL:** The mapping of the service parameters defined by the IETF Integrated Services standards onto ATM is of particular interest. Such mappings are defined by the IETF "ISSLL" (Integrated Services over Specific Link Layers) working group.

**Queuing:** In addition, alternative ways to provide different service classes shall be investigated, such as weighted fair queuing with statically configured traffic classification.

***Dates and Phases:***

1997/06/01-1998/03/31
: Follow developments in IETF working groups rsvp, intserv, issll, qosr.

1997/06/01-1997/08/31
: Prepare a list of application and routing software that supports RSVP [rsvp] and the ATM service mapping [issll]

1997/06/01-1998/08/31
: Follow the progress of the ATM Signalling experiment and try to ensure that the network infrastructure requirements can be met. [issll]

1997/08/01-1997/08/31
: Experiment with simple set-ups using RSVP to request QOS for an application over a (partially) RSVP-capable router path [rsvp]

1997/09/01-1998/01/31
: Set up Weighted Fair Queuing on some IP routers between participants.
: Investigate whether a useful quality of service can be obtained for specific real-time flows, in the presence of best-effort traffic. [queuing]

1997/09/01-1998/03/31
: Provided that the ATM infrastructure supports signalling of SVCs with specified traffic parameters by then, modify the set-up from the second experiment so that ATM's QOS facilities are used to support QOS guarantees for IP flows. [issll]

***Network Infrastructure:***

- IP connectivity between all participants [rsvp, issll, queuing]
- RSVP-capable routers, at least on those links that present ``bottlenecks'' [rsvp, issll]
- Access to the JAMES infrastructure for each participant [issll]
- An ATM infrastructure that allows setting up SVCs with specified traffic parameters. A few CBR or VBR SVCs of 100-200 cells per seconds must be obtainable from the ATM network. [issll]
- Routers with configurable queuing parameters, at least on ``bottleneck'' links [queuing]

***Local Infrastructure:***

Software:
- On end-systems:
    - RSVP signalling software such as ISI rsvpd
    - RSVP-aware applications such as the ISI Mbone tools
- On routers:
    - RSVP implementation [rsvp, issll]
    - RSVP-ATM SVC mapping [issll]
    - Configurable queuing and traffic classification [queuing]

Hardware:
- A workstation that supports the software and networking requirements
- A router that supports the software and networking requirements.

***Related Work:***

- ATM Signalling experiment [issll]
- ATM Policy Control and Accounting experiment [rsvp, issll]
- ATM Point to Multipoint experiment [issll]

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## 5.5 ATM Point to Multipoint

***Experiment Leader:***

Robert Stoy, DFN/RUS University of Stuttgart, Germany

***Goals:***

- Evaluation of the capabilities of the ATM-WAN and ATM-LANs with regard to establishing a ATM-Multicast network.
- Evaluate the interworking of IP-Multicast on top of a ATM-Multicast network.
- Configuring and testing a ATM-Multicast network infrastructure step by step - from static to dynamic - and mapping IP-Multicast on it.
  Configuring and testing will be done on these steps:
    - Test and Usage of Point to Multipoint PVCs together with PIM
    - Test of Tunnelled Point to Multipoint SVCs
    - Test of PIM Dense Mode over P2MP SVCs (SVCs will be tunnelled if SVC over JAMES are not available)
    - Test of PIM Sparse Mode over P2MP SVCs (SVCs will be tunnelled if SVC over JAMES are not available)
    - Optional Experiments with MARS-Implementations in local ATM networks (MARS for HFC-Networks will be developed at RUS till end of '97, Possibly we could use a standard version for our purposes)
- Using the MBONE-Tools to test the experimental ATM-Multicast infrastructure on application level.
- The experimental multicast infrastructure is open for tests of - if available - native ATM-Multicast applications.

***Description:***

Multicast is the routing mechanism within a network that realises a saving and economising usage of network bandwidth if group communication is used. On ATM based IP networks this mechanism is currently applied on the IP-level by usage of IP-Multicast on routers that are connected through point to point VCs on ATM level. ATM-Multicast technology is needed to bring the multicast routing intelligence down to the ATM level, and hence to provide ATM-QoS directly to the end stations, where in future native ATM-Multicast - or currently available IP-Multicast applications are used.

***Pre-requisites:***

- Each participating side has a CISCO Router, that is connected to a point to multipoint andSVC capable ATM Switch.
- The CISCO Router is connected to a test ATM-LAN on which at least one, preferably two workstations are connected.
- On the workstations the mbone tools are running.

***Dates And Phases:***

- Start: July 1st. 1997
- WP 1, Start July 1st. '97, 2 months
  Evaluation of ATM- and IP Multicast Capabilities of Equipment used at TF-TEN Partners
  Evaluation and following the work in relevant specification and standardisation groups, mainly ATM Forums MPOA and IETF's ION working groups.
- WP 2, Start Sept 1st. '97, 1 month
  Working out a IP Multicast on top of ATM Point to Multipoint test configuration between at least three partners of TF-TEN.
- WP 3, Start Oct. 1st. '97, 3 months
  Start with a static and manually configured ATM Point to Multipoint in the LANs of the test partners and on the WAN.
  Testing IP-Multicast on top of this static configured ATM Point to Multipoint configuration.
- WP 4, Start Jan. 1st. '98, 3 months

Depending on the results of the upper phases, try to configure a dynamic set-up of Point to Multipoint SVCs or tunnelled P2MP-SVCs in the WAN between the local networks and in the local networks of the test partners. Testing IP-Multicast on top of this configuration. Using as application the MBONE Tools. If results were successful, extend the dynamic multicast configuration to more TF-TEN members.

- WP 5, Start Jan. 1st. '98, 3 months
  Set up in parallel to WP 4 - separated from the production MBONE - a high speed Multicast Backbone on top the configured IP over ATM Multicast Backbone.
- WP 6, Start July 1st. '97 9 months
  During all phases the work of the specification and standardisation groups IETF ION and ATM FORUM MPOA are followed.
- End: March 31th. '98

***Related Work:***

- Work of IETF ION and ATM FORUM MPOA groups
- ATM Signalling
- ATM Routing
- ATM Resource Reservation
- IP Resource Reservation

## 5.6 ATM Signalling

***Experiment Leader:***

Christoph Graf, DANTE, Cambridge, UK

***Goals:***

- Implement a SVC network based on UNI4.x signalling
- Study co-existence of QoS and best effort traffic on the same network
- Investigate reliability/performance issues related to signalling
- Verify interworking of different UNI signalling versions in the same network
- Native signalling in the WAN
- Providing an infrastructure for further tests requiring a SVC network.

***Description:***

UNI signalling adds to an ATM network, the capability to set-up and tear down virtual channel connections in an automated fashion. This is a pre-requisite when using ATM to switch bandwidth between applications.

This experiment is a follow-up to the SVC tunnelling experiment conducted in phase 1 with a different focus:

- Newer versions of UNI signalling became or will become available and should be tried out. Besides new functionality with extended QoS parameters, interworking with older UNI signalling versions becomes an issue.
- JAMES might soon offer native signalling support. Experimenting in phase 1 was limited to signalling tunnelling due to missing signalling support on JAMES. If during this experiment signalling support will be added to JAMES, it will be tried out.
- Other traffic classes than UBR should be tried out. Possible interference between different traffic classes on the same network might occur and needs to be analysed.

***Pre-requisites:***

None

***Dates And Phases:***

- 06/97-07/97: Preparatory work
    - Study signalling capabilities of available equipment
    - Collect information about planned future releases supporting newer versions of UNI signalling
- 08/97-09/97: Network implementation
    - Implement SVC network based on UNI4.x. Where not available, use UNI3.x.
    - Use signalling tunnelling, if JAMES cannot offer native signalling
- 10/97-12/97: Perform experiments on network
    - Study interworking issues between different UNI versions
    - Study issues related to carrying different traffic classes on the same network
    - Measure performance and reliability
    - Investigate performance and reliability problems

***Network Infrastructure:***

Based on the "Overlay Network". Some additional PVP connections might be required to carry different traffic classes.

***Local Infrastructure:***

During the tests, each participant must have full control over the following equipment, interconnected on ATM level:

- At least one ATM switch:
    - supporting UNI signalling
    - supporting NSAP addressing
    - connected to the JAMES test network on ATM level
- At least one, preferably more, workstations or routers:
    - equipped with SVC capable ATM interfaces available to the IP stack using AAL5.

***Hardware/Software:***

No special requirements besides ATM connectivity. Only standard TCP/IP tools (ping, telnet, ftp) are required.

***Related Work:***

- ATM Routing
- ATM Addressing

## 5.7 ATM Policy control and accounting

***Experiment leader:***

Victor Reijs, SURFnet bv, the Netherlands

***Participants:***

SURFnet bv, University of Twente and SWITCH

***Goals:***

Determine how SVC's in ATM can be controlled on a policy level (so this does not directly concern the already standardised resource reservation in P-NNI or P-UNI). This will certainly not only be a technical study (there are no implementations yet known), but also an inventorisation of the ideas how to control SVC's within the NRN environment.

***Description:***

When SVC's are provided to the end users, the NRN/connected-institutes need a method to control a certain user if allowed to set up a specific SVC with its traffic parameters. This control mechanism should guard the network from unauthorised/unintended use of the network (so a user will not be allowed to set-up an SVC in the morning of 70 kcell/s for a whole day and only use it effectively for a few minutes).

Several items will be covered in this activity:

- inventorise the need for controlling the set up of SVC's
- NRN's will be asked for their policy concerning the SVC provision and the method how they would like to do it.
- watch closely the developments in the IETF-RSVP Policy Control environment (Internet Policy Control).
- inventorise possible methods for doing policy control (standards, ideas, proprietary solutions, etc.)
- determine if the MIB (AToM MIB, MIB-II) will provide enough information for accounting
- review/test possible implementations of policy control

***Pre-requisites:***

None

***Dates and phases:***

- start activity: June 1, 1997
- inventorise NRN needs: June 1, 1997 until Oct. 1, 1997
- closely watch IETF-RSVP work: June 1, 1997 until March 1, 1998
- inventorise possible methods: June 1, 1997 until March 1, 1998
- review/test possible implementation: Sept. 1997 until Jan. 1998
- check MIB's: Sept. 1997 until Jan. 1998
- final report: Febr, 1998
- end activity: March 1998

***Network infrastructure:***

Most of the activity is paper work and talking with manufacturers of equipment. As soon as equipment becomes available with implementations, these will be tested in a NRN environment.

***Hardware/software:***

ATM switches that support policy control (not yet known)

***Related work:***

The IETF-RSVP 's work on Policy control is very important for this activity.

- RSVP Extensions for Policy Control
- Open Outsourcing Policy Service (OOPS) for RSVP

ATM signalling and ATM resource reservation.

## 5.8 ATM traffic management

***Experiment leader:***

Victor Reijs, SURFnet bv, the Netherlands

***Participants:***

SURFnet bv, University of Utrecht and other partners, to be determined.

***Goals:***

The main goal of this activity is get an idea how existing (UBR, CBR, VBR, EPD, IPD, PPD, etc.) and new (ABR) functionalities will work in the LAN/WAN ATM networks. Both LAN and WAN networks are important for two specific network environments:
1) end-to-end ABR over concatenated LAN and WAN networks, which have equal service categories
2) localised ABR/UBR; the WAN has a different ATM service categories (like CBR or VBR) than the LAN (ABR or UBR).

***Description:***

The following activities will be done, to reach the above mentioned goal:

- understand and test ABR
  The flow control mechanisms described in 'ATM Forum traffic management specification version 4.0' need to be understood. Not only in a small/local area network environment, but also in a large scale/WAN environment. Studies should be directed to the effects of end-to-end delay and instability of control loops in practical networks.
  The flow control mechanisms are: EFCI, ER and VS/VD
- understand and test packet discard functionalities
  A lot of terms are found in product descriptions. Preferred packet discard functions should be described and understood.
  Terms to investigate: EPD, PPD, IPD, etc.
- concatenation of networks with different service categories
  In case the networks do not have the same service categories (like in WAN->CBR/VBR and in LAN->UBR/ABR), one has to investigate what will happen and how problems can be solved. These scenarios should be tested.
  Tunnelling and traffic shaping are related to this.

***Pre-requisites:***

None

***Dates and phases:***

- start activity: June 1, 1997
- understand ABR: June 1, 1997 until Sept. 1, 1997
- understand packet discard: June 1, 1997 until Sept. 1, 1997
- test ABR in LAN: July 1, 1997 until Oct. 1997
- test concatenated ABR/CBR networks: July 1, 1997 until Dec. 1997
- test ABR in WAN: Jan. 1998 until Febr. 1998 (If JAMES provides this)
- final report: Febr 1, 1998
- end activity: March 1, 1998

***Network infrastructure:***

Most of the work will be done in the NRN environment. In case tunnelling is possible and subject to study, this can be done over the JAMES network. It is preferred that JAMES will also have the 'advanced' ATM functions like EPD/IPD/ABR/UBR implemented, so that real PAN European tests can be done.

***Hardware/software:***

- ATM switches that support packet discard functionality (EPD, PPD or IPD)
- ATM switches that support ABR flow control mechanisms (EFCI transparency, ER and/or VS/VD)
- NIC that support ABR flow control mechanisms (EFCI or ER)

***Related work:***

- SVC management activity of TF-TEN
- ATM routing resource reservation of TF-TEN

***References:***

- ATM Forum traffic management specification version 4.0, ATM Forum, April 1996
- ATM Switch Traffic Management Essentials (see: http://www.igt.com/wht-atmtraffic.htm)
- Implementing Early Packet Discard (EPD) in ATM (see http://www.rennes.enst-bretagne.fr/~maknavic/epd.html)

## 5.9 ATM address resolution

***Experiment Leader:***

Olav Kvittem, UNINETT, Norway

***Participants:***

not defined yet.

***Goals:***

- To evaluate the usefulness and scope of MPOA in relation to NHRP
- To make a summary and comparison of ATM address lookup techniques
- To set a NHRP service between most of the countries, each having at least one NHRP server.
- To use NHRP clients on both workstations and routers.

***Description:***

An IP-system at the edge of an ATM-network needs to find for a destination IP-address the ATM-address for the optimal next hop over the ATM-network so that it can set up a call there. A partial solution to this problem is the ATM ARP in RFC1577 (Classical IP over ATM) which solves the problem for one IP subnet. This does not scale to large multiorganisation networks. The Next Hop Routing Protocol (NHRP) proposes a solution for shortcutting subnetbased routing so that one can minimise the number of hops through the same ATM cloud.

Another solution is Multiprotocol over ATM (MPOA). from ATM-Forum. It is using NHRP-like mechanisms and covers multiple protocols, of which only IP is of interest. This specification is expected due to LAN Emulation (LANE) which covers the local area and is out of scope for this project.

Tasks to be performed are :

- Investigate the different lookup mechanisms
- Set up NHRP service based
- Test and maintenance
- Report and recommendation

***Pre-requisites:***

There is an NHRP-implementation on Cisco routers.

***Dates And Phases:***

- Start preparation1997-07-01
- Start implementation1998-07-01

***Network Infrastructure:***

- A SVC-based infrastructure with UNI 3.0 signalling and ATM routing and addressing.
- A network capacity of 2 Mbps is sufficient.

***Local Infrastructure:***

ATM SVC-based network

***Hardware/Software:***

One more router and workstation being NHRP client/server.

***Related Work:***

- NBMA Next Hop Resolution Protocol (NHRP) - Still and Internet draft.
- Cisco's Implementation of NHRP
- RFC1577 (Classical IP over ATM)
- TF-TEN NHRP tests - phase 1
- ATM-Forum specs

### 5.10 ATM Addressing

***Experiment Leader:***

Kevin Meynell, TERENA

***Participants:***

Not yet defined.

***Goals:***

This project aims to produce recommendations for ATM addressing schemes; the investigation of the problems faced by multi-homed ATM networks and organisations using different service providers; and the investigation of address translation techniques and possibly test some implementations.

***Description:***

This project aims to continue the activities related to ATM addressing that were conducted in Phase I. ATM signalling is gradually being introduced (e.g. UNI and PNNI) and this requires addressing schemes to be produced. A few NRNs have already implemented addressing schemes, but there do not appear to be any European-wide recommendations currently available.

It was originally envisaged that a universal addressing scheme would need to be defined, but this proved impractical, and unnecessary to some extent. Most NRNs have indicated they would prefer to use NSAP addressing and these formats are already well-defined. It is really only necessary for each NRN to obtain an NSAP prefix from their ISO National Member Authority (e.g. BSI in the UK, or DIN in Germany). The NRN may then allocate the undefined octets in a manner that suits its topology/organisational structure. Nevertheless, it shall be one of the aims of this project to investigate different NSAP-addressing schemes, and attempt to make some recommendations for NRNs that have yet to devise their own schemes. The project will also investigate the problems relating to multi-homed ATM networks and to organisations using different service providers.

Most of the European PNOs however, have indicated they will be using E.164 addressing, the ITU standard relating to international ISDN numbering. Consequently, this means there must be a method for NSAP addresses to traverse the PNO-provided networks.

The ATM Forum specifications suggest how NSAP and E.164 addresses should interoperate, but there are not currently any standards relating to this. It has therefore been necessary for vendors to implement their own solutions. An aspect of this project will be to follow the standardisation process and how it relates to the European NRNs. It is also hoped that the testing of some address translation implementations (e.g. Cisco LightStream) will be possible within the project timescales.

***Pre-requisites:***

The testing activities will require address translation implementations for the ATM switches (e.g. Cisco LS-1010).

***Dates and phases:***

- Start Project: July 1997
- Investigate addressing schemes: Ongoing
- Test address translation implementations: Ongoing
- Produce recommendations: February 1997

***Network Infrastructure:***

The testing activities will require an ATM network. Ideally, this would be a network natively supporting signalling, but tests could be tunnelled across an overlay network.

***Local Infrastructure:***

No additional infrastructure required.

***Hardware/Software:***

The testing activities will require ATM switches that support address translation.

***Related work:***

- ATM Routing and Resource Reservation
- ATM Signalling
- ATM Address Resolution
- ATM Forum Standards (e.g. UNI, NNI)
- ITU-T Standards

### 5.11 Performance of the Native ATM Protocol and native ATM applications.

***Experiment Leader:***

Stefania Alborghetti, INFN Milan, Italy.

***Participants:***

Not yet defined

***Goals:***

1) Survey of existing native ATM implementations:

- list and description of :
    - ATM application programming interfaces (API's ), i.e. API's specifically tailored to support native ATM services;
    - protocol stacks directly developed from ATM API's;
    - applications based on native ATM protocol stacks or API's.

  In the following these elements are referred as a "native ATM implementation".

- Comparison of existing native ATM API's standards and different vendor's or public domain API's developments;

2) Analysis of the Tcp-onip native ATM implementation, by Hossam Afifi. Testing of:

- the whole protocol stack;
- some applications based on such protocol stack.

3) Study of the performance of the proprietary Fore ATM implementation using the benchmark netperf utility by Rick Jones. Measurements of the throughput (data sent/time) on both a local and a wide area network will be taken. Tests can be done over a VP infrastructure with:

- full bandwidth available to a single connection;
- bandwidth shared by different concurrent connections;
- different ATM classes (CBR, VBR);
- congestion of the network.

The aim is to monitor the NIC behaviour in terms of different network parameters. An analysis of the most suitable ATM network classes for a better efficiency of native ATM protocol stacks could follow from these measurements.

4) Comparison of:

- TCP/IP based applications,
- native ATM applications

in terms of both efficiency and network behaviour.

***Description:***

The interest is focused on applications directly accessing the ATM infrastructure and exploiting its advanced features using determinate ATM API's.

Due to a lack of intercommunication between the ATM lower layers and the TCP/IP protocol stack, almost all the present IP based applications cannot benefit from the ATM specific services even if they run on ATM networks. Such services are visible though to native ATM applications, i. e. applications directly developed from native ATM API's.

During this work some native ATM standards and developments will be examined and compared carefully. In particular the ability of a native ATM implementation to deliver a per virtual-channel QoS to user applications will be investigated. Depending on the characteristics of the various implementations and on the hardware platforms available for testing, a few native ATM applications will be implemented and tested. Some applications will eventually be developed and modified in order to adapt them to our needs. Applications in which the QoS plays a fundamental role will be developed and tested in a deeper detail.

As regards performance, measurements of native ATM data transfer will be carried out through the benchmark netperf utility and the proprietary API of Fore systems. Tests will be done in different network conditions in terms of load, concurrence, fairness of bandwidth share and congestion. Tests will also be done on different ATM classes (CBR and, if available, VBR or ABR).

***Pre-requisites:***

Native ATM protocol stacks and applications should be made available for implementing and testing on the available hardware platforms. The availability over James of further classes of ATM services (in addition to CBR) would be certainly useful.

***Dates and Phases:***

The duration of the project is one year. The work will be divided in three different parts.

During the first part all known existing native ATM implementations will be carefully investigated. In addition, the experimental set-up will be implemented and tested. Performance measurements, using the netperf benchmark utility, on local area network will be taken.

During the second part the most suitable native ATM applications will be implemented and eventually developed at least on a local area network. As independent and parallel work, the performance of native ATM data transfer on the wide area network will be tested, using the netperf benchmark utility alike in the local area network.

In the last part of our work, the implementation of the applications will be completed and possibly ported to the wide area network. In addition, the performance and features of IP based and ATM native applications will be compared. Exploiting the native ATM data transfer tests, an investigation of the most suitable ATM services to a better performance of native applications will be covered.

Each part of the work is expected to last almost four months.

***Network Infrastructure:***

An access to the JAMES infrastructure is required.

***Local Infrastructure:***

On the customer side, a native ATM access must be available. For this reason an ATM switch should be connected to the JAMES infrastructure.

One or more workstations with ATM adapters providing ATM API's for a direct access to the ATM/AAL layers must be connected to the switch.

***Software/Hardware:***

Software:

Any kind of public domain software agreed by the partners. Among the currently known possibilities are:

- TCP-ONIP, developed by Hossam Afifi, which implements a protocol stack based on the direct communication between TCP and the ATM layer using a dummy IP layer;
- Netperf, developed by Rick Jones at Hewlett Packard, version 2.1 for the performance tests.

If other tools become available, they will possibly be examined and tested. A signalling debugging tool would also be useful.

Hardware:

Any kind of platform made available by the partners:

- At least 1 switch connected to James, possibly implementing a good debugging of signalling events (like the LightStream1010 from Cisco's Systems);
- Two or more workstations mounting ATM adapter cards implementing ATM API. If Netperf is used for bench marking, FORE ATM adapters must be used. Other kinds of API's could be used if available on the market, but software porting could be required to use them. Recommended Platforms are:
    - HP-UX,
    - IRIX,
    - OSF/1
    - Solaris or SunOS.

***Related work:***

ATM signalling and routing and both IP and ATM resource reservation.

## 5.12 ATM Network Management

***Experiment leader:***

Zlatica Cekro, University of Brussels (ULB/STC), Belgium

***Participants:***

All NRN. Special work will be done at ULB/STC and SURFnet.

***Goals:***

- To gain experience of the user aspects on ATM management service offered by the Public ATM network.
- To gain experience of system interoperability at the management plane in domains of configuration, performance, accounting, fault and security.

***Description:***

Four groups of tests can be specified. The first three are the continuation of the Phase I and the fourth, Xuser interface tests, is a new one.

1) Operations, Administrations and Maintenance flows

- Operations, Administrations and Maintenance (OAM) flows enable the tests based at the ATM Layer mechanisms. Management Information Flows 4 and 5, described in ITU-T I.610, will be of special interest.
- Loopback End-to-End tests over one vendor and over multi-vendor equipment will be performed.
- The possibility of using OAM flows for performance monitoring on the ATM level will be investigated.

2) Web Based Management

Interfaces between PNO and user will include tests and evaluation of the following Web based management domains:

- Access possibilities and security aspects,
- Monitoring functions,
- Configuration functions.

The Web based management tools with SNMP use IP and UDP communication for management flows. It could be realised over Internet or over ATM network. Both variants will be tested.

As in the domain of HTTP/SNMP interworking there is no standard. Experience on different solutions on the user interface side and on the network side will be evaluated.

3) SNMP based management interface tests

SunNet management platform based on SNMP will be used for access, read MIBs and statistics collection at NRN ATM edge devices. The tests will be based on the ATM Forum specifications and IETF ATM related documents.

Both SNMP using Internet and/or ATM Overlay network will be tested.

4) Xuser based management interface tests

This test group has a common interest with JAMES in performing functional tests and interoperability tests over international borders. The standards in this domain are CMIP based and are not yet fully completed in the domain of Xuser interface.

The starting point will be Xcoop Specification ETSI NA5-2212 and JAMES WP4.2.

The following Ensembles (named according to concept of NM Forum) for the Xuser interface were specified: Subscription, Virtual Path (VP) service, Fault Management, Performance Management and Accounting Management.

Here, the Accounting Management is related to the customer's needs for accounting management functionality that enables the customer to access for instance invoicing information.

The Xuser Interface is located between a Customer Premises Network (CPN) which is originating the VP Service request and a certain PNO. The Xuser management services provide capabilities for managing the public resources which are by contract allocated to customers by the public operator. Thus, via the Xuser interface, an abstract view of the public resources is provided (as far as the VP service provider will allow).

There are three possible areas in the scope of test scenarios:

1) User Service Access Validation Area - Interface between the customer resources and the PNO service provider, Xuser interface;
2) Operator Network Validation Area - Interface between the PNOs, Xcoop interface;
3) End-to-end (user-to-user) Service Validation area - integration of Xuser interface and Xcoop interface.

The tests under 1 and 3 would be of special interest for the TEN-34.

***Prerequisites:***

- Access to the NRN edge devices and to the user portion of equipment at the PNO side.
- Management platform with the SNMP based user interface.
- Definitions of common scenarios with JAMES for tests of Xuser/Xcoop interfaces and management platform with CMIP based interface.

***Dates and phases:***

Test groups for OAM, Web based Management and SNMP based interfaces: July 1997 and will be performed continuously to the end of the project.

Test group for CMIP based interfaces will depend of the planning on the JAMES side (WP 4.2). It will be good if it starts in September-October 1997.

***Network infrastructure:***

No special infrastructure is requested for the test groups under 1, 2 and 3. For the tests under 4 the network infrastructure requirements will be specified together with JAMES.

***Local infrastructure:***

User management systems with the following user interface characteristics are needed:

- For the OAM tests: MIB extensions for OAM activation/deactivation
- For the Web based Management tests: Web server and software tools.
- For the SNMP based interfaces test: Management Platform based on SNMP
- For the CMIP based interface tests: Management Platform based on CMIP.

***Hardware/software:***

The releases of software that support the latest standards are required on the ATM edge devices as well as on the user management platforms.

***Related work:***

- Analysis of latest specifications of ITU-T, ATM Forum, IETF and NM Forum in this domain.
- Study of ETSI NA5-2212 and JAMES WP4.2, TCv4, EURESCOM P408, EURESCOM P708.
- As these specifications are taking in account other documents like ITU-T X.160, EURESCOM P612, EURESCOM P616, EURESCOM P710, they will be studied as well.

### 5.13 Security in ATM Networks

***Experiment leaders:***

Paulo Neves and José Vilela, RCCN, Portugal

***Goals:***

It is intended to present at the end of this work package two surveys regarding ATM Security issues: one on the existence and evolution of security specifications for ATM, and the other on the state of application of these standards on current ATM equipment.

***Description:***

As was established by the first phase of the experiments, the issue of security on ATM networks is still under research and early standardisation stages. The definition of concrete, viable, and useful experiments involving current equipment is therefore very difficult and their results would, at this moment, lack generality.
In this framework, we propose to produce a review of the ongoing standardisation process, analysing the currently available documents and drafts, and a survey on the equipment support for these standards.

***Dates and Phases:***

- Survey on Security Specs, starting 1997-07-01
- Survey on implementation status of security related standards, starting 1997-09-01

***Pre-requisites:***

As most of the work will be documental there are no pre-requisites or network infrastructure needed.

***Related Work:***

- ATM Policy Control and Accounting
- ATM Network Management
- ATM Signalling

***Further Work:***

The security issues concerning configuration/administration interfaces of current ATM equipment, as well as other security issues raised in the course of the other experiments, should also be analysed, and if possible, a set of general recommendations on how to improve security should be produced.

## GLOSSARY

| | |
|---|---|
| ABR | Available Bit Rate |
| ARP | Address Resolution Protocol |
| ATM | Asynchronous Transfer Mode |
| CBR | Continuous BitRate (ATM Forum: traffic class) |
| DBR | Deterministic BitRate (ITU-T: traffic class, eq CBR) |
| E.164 | (ITU-T addressing standard) |
| EFCI | Explicit Flow Control Indication |
| EPD | Early Packet Discard |
| ER | Explicit Rate |
| ILMI | Interim Link Management Interface |
| IP | Internet Protocol |
| IPD | Intelligent Packet Discard |
| LIS | Logical IP Subnetwork |
| MBS | Maximum Burst Size (ATM Forum: traffic parameter) |
| MPOA | Multiprotocol over ATM |
| NHRP | Next Hop Resolution Protocol |
| NIC | Network Interface Card |
| NRN | National Research Network |
| NSAP | Network Service Access Point (OSI term) |
| OAM | Operations And Maintenance |
| PCR | Peak Cell Rate (ATM Forum: traffic parameter) |
| P-NNI | Private Network to Network Interface |
| PNO | Public Network Operator |
| PPD | Partial Packet Discard |
| PVC | Permanent Virtual Circuit |
| PVPC | Permanent Virtual Path Connection |
| RSVP | Resource ReSerVation Protocol |
| SBR | Statistical BitRate (ITU-T: traffic class, eq VBR) |
| SCR | Sustainable BitRate (ATM Forum: traffic parameter) |
| SNMP | Simple Network Management Protocol |
| SVC | Switched Virtual Circuit |
| TCP | Transport Control Protocol |
| UDP | User Datagram Protocol |
| UNI | User Network Interface |
| VBR | Variable BitRate (ATM Forum: traffic class) |
| VC | Virtual Circuit |
| VP | Virtual Path |
| VPC | Virtual Path Connection |
| VS/VD | Virtual Source/Virtual Destination |
| UBR | Unspecified Bit Rate |