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Deliverable D11.1

Specification of Phase 1 Test Programme

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Abstract:

This deliverable specifies the experiments that will be carried out in the TEN-34 Phase 1 Test Programme over the JAMES ATM network, which is physically separate from the TEN-34 production IP network. These tests of advanced services are carried out on an infrastructure separate from the operational services to avoid any negative impact on production traffic and to acquire operational expertise before any new service can be offered in a production environment.

The main emphasis in this phase lies in examining the underlying technology for its suitability to support advanced applications. A major part of the work is expected to be in the area of fine-tuning the systems to maximise the performance, and to understand the full implications of different traffic parameters. Most of the tests in Phase 1 of the test programme concentrate on the advanced provisioning of IP services, which will still be required for most applications of the NRNs.

Keywords:

ATM experiments, IP over ATM, TCP high-speed testing, SVC testing, ARP testing, NHRP testing, ATM Addressing, ATM network management, CDV testing, Native ATM performance testing, IP over VBR testing, RSVP testing

Table of Contents

Executive Summary

The TEN-34 Project aims at deploying a high-speed European backbone. Whilst in the first phase of the project only a native IP service will be provided, it is expected that more advanced services like video conferencing that are based on ATM technology can be introduced at a later stage. Such advanced services and their underlying technology need to be tested before they can be deployed on a production network.

It is essential that tests of advanced services are carried out on an infrastructure separate from the service network. This is mainly because conducting experiments on the service network could have a negative impact on the production traffic it carries, by degrading performance or even to the extent of causing parts or all of the network to become unavailable for service. Also, operational expertise is required before any new service can be offered in a production environment. Therefore the tests of the advanced ATM services will be carried out over the JAMES ATM network, which is physically separate from the TEN-34 production IP network, and intended for experimental usage.

The JAMES network does not yet offer all service classes needed by TEN-34, and there are initial difficulties with operational procedures and the fact that the service delivered by JAMES has not been precisely defined yet. These uncertainties have some impact on the experiment planning. It is expected that the operational problems can be solved in the near future. Concerns remain at this stage about the non-availability of more advanced ATM traffic classes such as VBR.

Participants to the tests are all the NRNs of the TEN-34 project. A test programme has been specified by the TEN-34 NRNs, consisting of ten experiments. These experiments will cover essential new technologies such as signalling, VBR services, and IP routing over ATM. In high-speed tests the performance of IP over ATM and native ATM performance will be examined.

In some areas of testing there is a common interest of JAMES and TEN-34 in the results of the tests. Therefore a set of joint experiments was identified. There will also be joint experiments with the PNOs involved in the JAMES project, which are a subset of the tests described here. Responsible persons from both JAMES and TEN-34 were identified for each joint experiment, who will co-ordinate the co-operation. A joint report of the results of the joint experiments will be submitted independently of the deliverables of JAMES and TEN-34.

In the period from the beginning of the TEN-34 project on 1 February 1996 until the end of June 1996, the experiments were specified and test plans developed. The first experiments started mid July. The majority of experiments are expected to be carried out in the autumn, with a number of them extending to the end of 1996. The remainderof the first phase until 30 April 1997 will be used for the re-evaluation of experiments under different settings and with additional refinements.

1. INTRODUCTION

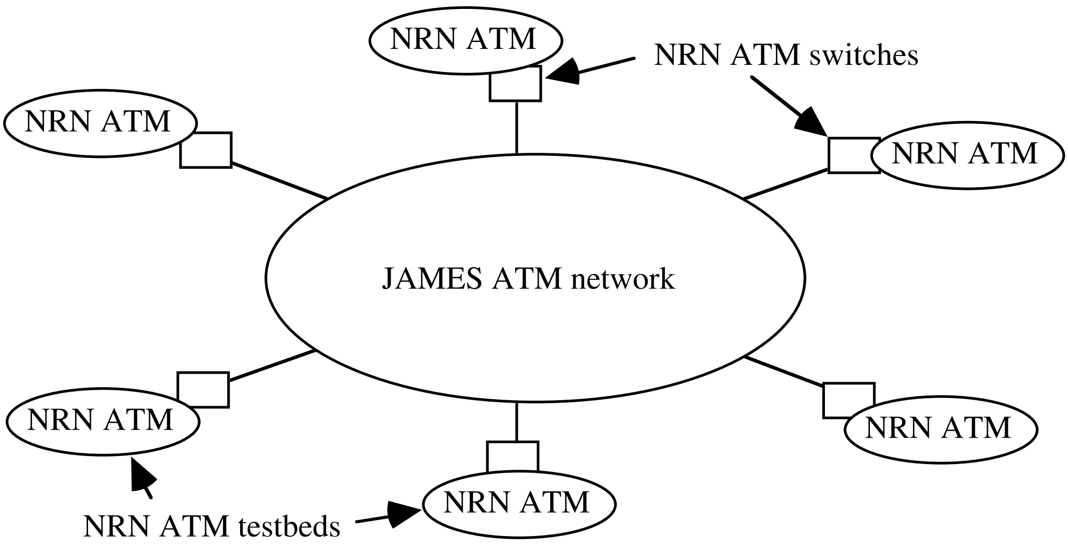
Initially the TEN-34 network will offer only a pan-European high-speed IP service. The research community requires more advanced features and services on the network. Examples are dedicated bandwidth for certain applications (e.g., Mbone), or the possibility for video-conferencing. These services, and the underlying technology to support them, must be tested before they can be offered as a standard service over a production network. This is the purpose of this Work Package. These tests are essential for two reasons:

1. It must be ensured that the new services have no negative impact on the standard IP services, which are running on the same network. The IP services are operated with service level agreements, and experiments on the same network might influence the IP service.

2. The new services must be operated in a production mode, which requires operational and technical experience before the services are offered to the customers.

The main emphasis of this phase lies in examining the underlying technology for its suitability to support advanced applications. A major part of the work is expected to be in the area of fine-tuning the systems to maximise the performance, and to understand the full implications of different traffic parameters.

The tests focus on the technological aspects of providing advanced services. First, general high-speed tests over ATM CBR services will be carried out to confirm similar measurements in other environments. These tests will be point-to-point tests. At a later stage similar tests will be carried out over native ATM connections. This means that applications would run directly over ATM, and not over the TCP/IP protocol stack. The next tests involve more parties and require therefore a meshed testbed. An overlay network over the JAMES network will therefore be implemented and virtual circuits set up according to the individual test specifications (see Section 5). This overlay network is currently being defined by TEN-34. It will interconnect the TEN-34 ATM testbeds with a set of virtual paths that meets the requirements of the specific experiments.



Most of the tests in Phase 1 of the test programme concentrate on the advanced provisioning of IP services, which will still be required for most applications of the NRNs. The switching of connections is a key technology here. The next step to improve the ATM service is to connect other ATM networks and then to enable IP routing over the ATM network. Two tests are planned in this area: ARP testing, which resolves the address of the next hop on the ATM level, and NHRP, which enables the resolution of multiple ATM hops for IP. The ATM addresses themselves can be in two formats: E.164 and NSAP. A converting function will be needed in order to provide general connectivity. This is also looked at in one experiment. Further areas of testing include network management, where issues such as network monitoring will be examined. This is particularly important for an operational service with service level agreements. As a related issue, security of the network management system as well as internal security of the network will be examined. Once VBR services become available over JAMES, tests will be carried out to test the suitability of VBR services to carry the highly aggregated traffic of an NRN. Bandwidth reservation through RSVP will be examined as a possible alternative to switching on the ATM level. Detailed descriptions of the experiments can be found in section 5.

All experiments will be carried out by a group of ATM experts of the NRNs in the TEN-34 project. A task force for Trans-European Networking (TF-TEN) was created in the framework of TERENA (see: http://www.terena.nl), where all experts of the NRNs participate to plan and organise the experiments. This task force is an open forum and the results of the experiments will be publicly available. 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

TEN-34 and JAMES are both projects funded by the European Commission. TEN-34 will develop and provide a service network for the European research community; JAMES aims at developing a Europe-wide ATM-based interconnection structure together with associated experimental services for trial purposes. For the tests outlined here TEN-34 is a user of the JAMES network in trailing new services based on ATM. This means that JAMES provides the testbed on which TEN-34 will carrying out the tests described in this deliverable. This will happen by connecting the national ATM testbeds to the JAMES network, and by establishing connections over JAMES. The advantage is that JAMES is a managed platform, thus TEN-34 does not need to be concerned with the ATM service. It has however also some potential problems in that TEN-34 is fully dependant on the JAMES network.

The main constraint with the ATM tests over the JAMES network is that JAMES only supports very basic ATM traffic classes. (Currently supported are CBR, leased line emulation, SMDS and LAN interconnect.) The only relevant service to TEN-34 in this context is CBR (LAN interconnect and SMDS services are not of interest to TEN-34.) Neither VBR nor any switching is available at the beginning of the project, and it is not clear when these services will become available. For TEN-34 this means that most advanced features of ATM cannot be tested, and there is only limited usefulness of CBR services. One way to bypass this limitation is to use JAMES only as a transmission service, and to introduce more advanced features in the ATM switches of the TEN-34 NRNs. For example, the tests for switching (SVC tests) will implement the switching capability on the NRN side, and only tunnel the signalling through the JAMES network. However this is only a sub-set of configurations to be tested and does not provide all information needed to implement SVC services on the TEN-34 production network, as the network itself must support switching as well to make full use of the new capability. The same issue applies to VBR services, which are not available yet on the JAMES infrastructure and can therefore not be tested.

The operational procedures for JAMES are not known to all participants yet. This makes the co-ordination of an international experiment difficult. Discussions with JAMES to set up working operational procedures are under way, but at these early stages of the service TEN-34 has had some difficulties in establishing contacts with JAMES.

Another obstacle is that at the time of writing no service level agreements from JAMES were available. To be able to carry out tests efficiently and to plan the experiments in advance, TEN-34 needs to know a set of basic service level parameters, such as the bandwidths available, the time to respond to a VP request and the time to set up a VP. Without this information it is very difficult to plan experiments efficiently. This problem was already discussed with JAMES, but up to the time of writing no SLAs have been made publicly available.

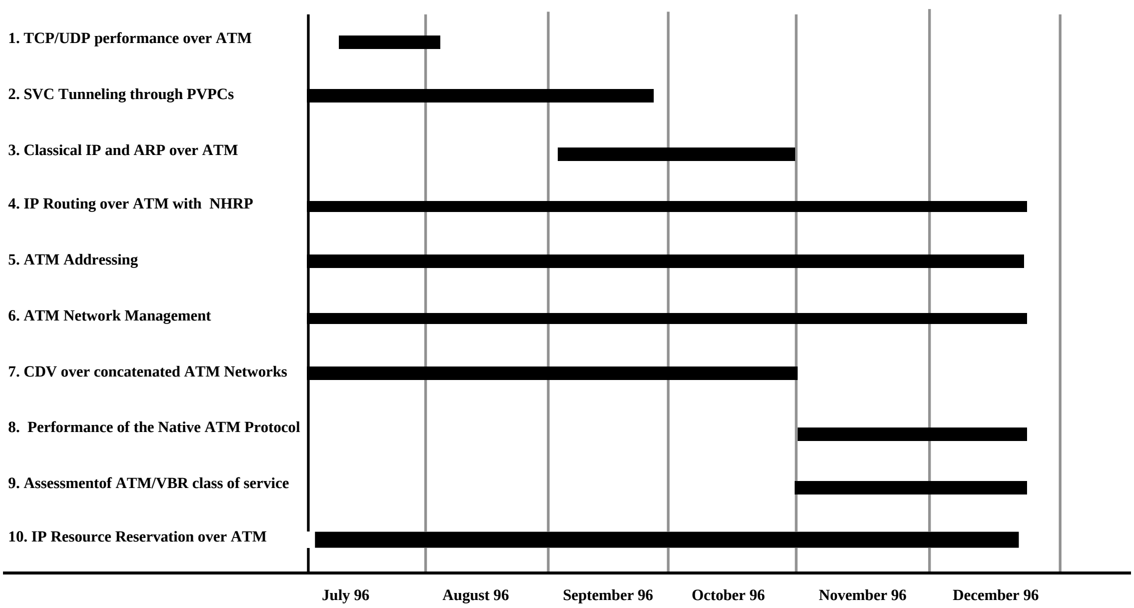
In conclusion, the JAMES network does not yet offer the advanced services needed by TEN-34; there are initial problems with operational procedures and the service delivered by JAMES has not been precisely defined. These uncertainties have some impact on the experiment descriptions in this document. It is expected that the operational problems can be solved in the near future. Concerns remain about the non-availability of advanced ATM traffic classes like ABR.

3. PLANNING OF THE EXPERIMENTS

Whilst the TEN-34 project started on 1 February 1996, bandwidth over the JAMES network did not become available until mid July. This period was used to specify the experiments planned to be carried out. The plan therefore calls for the practical phase of the experiments to start in mid July 1996. This first test programme ends on 30 April 1997. The planning envisages that the experiments will be concentrated in the first 11 months of the programme, provided there are no major problems. However, it is likely that some experiments will need to be re-evaluated with a different set-up, or that additional questions may arise during the tests which make additional testing necessary.

The preliminary ATM testing plan is depicted below.

Preliminary ATM Testing Schedule



The experiments requiring high bandwidth (Test No. 1) are first in the schedule, when the JAMES network does not yet carry all customers and has spare capacity. The later tests require only comparatively small capacities (app. 2 Mbit/s). For most of the tests an overlay network will be required, which is being set up at Test No. 2. The firsts tests over the overlay network are the SVC tunnelling tests (Test No. 2), the ARP tests (Test No. 3) and the NHRP tests (Test No. 4). Addressing problems (Test No. 5) are more of a theoretical nature initially; the practical tests depend to a large extend on the results of the tests mentioned above. Network management will be deployed on the overlay network, which allows the testing of the NM systems with the test traffic (Test No. 6). Further tests, of the cell delay variation over the network, together with the cell delay variation tolerance of the JAMES network (Test No. 7), tests of native ATM performance (without IP) (Test No. 8) and IP over VBR services (Test No. 9) will be carried out towards the end of the phase 1 test period. Another test concerns RSVP tests and the interaction with ATM (Test No. 10). All experiments are described in detail in section 5.

Most experiments mentioned here depend to a large extend on the availability of the ATM network and certain ATM services provided by JAMES. In the planning of the tests it was assumed that the required VPs will be available on request. Delays in this process can postpone the schedule of the experiments planned here. Also, some of the later tests involve features of JAMES that are not initially available, like VBR, which is planned to be available by September. Should there be delays in the availability of the JAMES services, this will have impact on the schedule of experiments planned here.

4. JOINT EXPERIMENTS WITH JAMES

In order to get an in depth understanding of the behaviour of the ATM network it is essential that a good co-operation between TEN-34 and the JAMES PNOs is established. As there is mutual interest in carrying out research in certain ATM areas it was thought to be advantageous to both sides to carry out these experiments jointly between JAMES and TEN-34.

On 26 June 1996 a meeting was held between JAMES and TEN-34 to plan the joint experiments. As the planning of the TEN-34 group working on the tests was at an advanced stage at this time, JAMES decided to initially join in all the experiments proposed by TEN-34, as described in this deliverable. In addition to these experiments additional work on security will be carried out between the parties. In the security area however more work needs to be done to precisely define the goals, and it is thus not included in the detailed test descriptions in this deliverable.

A more detailed work distribution between JAMES and TEN-34 will be set up with each individual experiment. To enable the involved parties on both sides to get together and plan the experiments, responsible persons on each side and for each experiment were identified. These persons will co-ordinate the efforts between JAMES and TEN-34 for each experiment, as far as there is mutual interest in the results. It is expected that not all parts of the planned experiments by one party will be of interest to the other. As a result a joint report about the joint experiments will be produced, in addition to the deliverables from JAMES and TEN-34. This joint report may contain parts of the deliverables of the separate projects, where there is an overlap in the work done.

5. DETAILED TEST DESCRIPTIONS

In the following sections each of the experiments is outlined in detail. All experiment descriptions define the goal of the experiment, phasing of the experiment, responsible person and other details. Some details like the participants for each experiments 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 has impact on the planning of the experiments.

The tests are:

5.1 TCP-UDP/IP Performance over ATM
5.2 SVC tunnelling through PVPCs
5.3 Classical IP and ARP over ATM
5.4 IP routing over ATM with NHRP
5.5 European ATM Addressing
5.6 ATM Network Management
5.7 CDV over concatenated ATM networks
5.8 Performance of the Native ATM Protocol
5.9 Asessment of ATM/VBR class of service
5.10 IP resource reservation over ATM

For each of the experiments a report will be produced that describes in detail the findings of the experiment. These reports will be included in the deliverables to the commission (D11.2 and D11.3). Experiments concluded by the end of October 1996, will be included in D11.2, the remainder in D11.3.

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 will include the following sections:

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

5.1 TCP-UDP/IP Performance over ATM

Experiment Leaders:
Mauro Campanella, INFN, Milano
Tiziana Ferrari, INFN/CNAF, Bologna

Participants:
INFN, KTH, NORDUnet, RedIRIS.

Goals:

1) Monitoring, whenever necessary, of the IP/ATM performance in the infrastructure of JAMES through the measurement of the following parameters (more can be added depending on the software used):
   - THROUGHPUT (data sent/time) for memory-to-memory data transfer. Tests can be done over a VP infrastructure with both full bandwidth available and bandwidth shared by many users.
   - IP packets ROUND TRIP TIME average and variance.
   - CPU utilisation (%) at both the sending and receiving host.
   - PACKET LOSS percentage.

2) Analysis of the network behaviour:
   - fairness of bandwidth distribution when a VP is shared by different applications;
   - relationship between the average throughput, SCR, PCR and the Maximum Burst Size (MBS) ;
   - impact of MBS on throughphput with different MTU sizes;
   - congestion in the switches in the user's and/or JAMES premises: is it possible?
   - other...

   when the infrastructure is stressed by different patterns of traffic:

   - many-to-one ==> test of the ATM switch output buffers management on the PTT side and of the input/output buffers management on the user side (receiver);
   - one-to-many ==> test of bandwidth distribution between each stream;
   - many-to-many ==> test of possible congestion at the input buffers of the PTT switches and in the output buffers on the sending NRN switch;
   - one-to-one half/full duplex with many TCP connections between the same couple of host ==> test of fairness in bandwidth distribution.

3) Analysis of the impact of the TCP window-based flow control algorithm on throughput over an ATM VP wide-area connection -"Long Fat Networks"- (tests repeated with different distances) -see Fig. 1-.

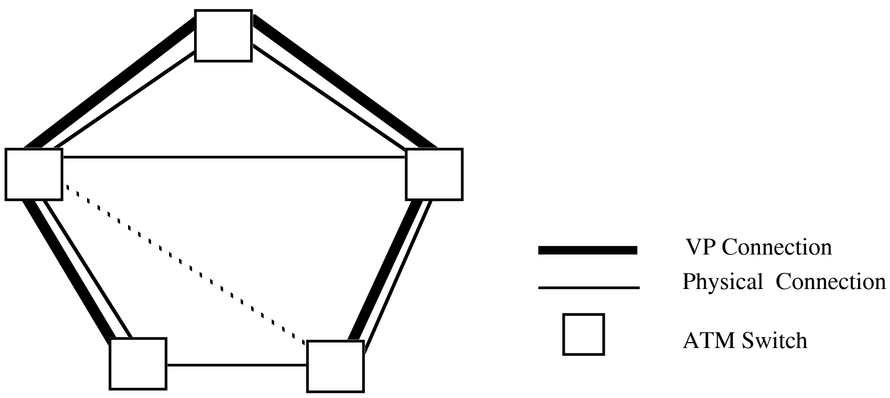


Fig 1: TCP flow control impact when different length VP connections are configured

4) Performance comparison of different implementations of the TCP-UDP/IP protocol stack in different operating systems (evaluation of optimised versions).

5) Impact of ATM cell loss on throughput when a non reliable datagram protocol (UDP) is used (interesting for that applications like MBONE which require UDP/IP).

Description:

The wide area ATM infrastructure operated by JAMES will give the opportunity to analyse the impact of the TCP/IP flow control mechanism on the performance of applications when high-speed links are used. The efficiency of the windowing flow control style will be measured by working on the setting of the socket options which directly determine the window size: the send socket buffer size and the receive socket buffer size. The impact of the application "message" size on the throughput will also be measured.

All the tests will be done by generating a real data stream between two or more end-points. Different and complex stream topologies will be configured in order to stress the switches and to analyse the TCP/IP flow control efficiency when congestion in an ATM network occurs.

The measurements collected so far will be compared to the results which have already been analysed both in different ATM network set-up and in a "classical" mesh of leased lines.

Two sets of tests are planned:

- 1: tests over a simple VP infrastructure with MAXIMUM available bandwidth;
- 2: tests over a mesh of many VPs with smaller capacity.

Pre-requisites:

None.

Dates and Phases:

The project will be divided in sessions. Each test session will be organised in two phases. In each session different partners will be involved and in each of them a different configuration of ATM VP's will be considered. The network topology tested in each session will depend on the network performance results of the previous test sessions.

Phases:

- phase 1 (2 days): Set-up of local infrastructure and set-up of a correct interconnection between participants over JAMES.
- phase 2 (3 days): Real traffic generation and performance measurement.

The same phases will be repeated in each session.

Session List:

Session 1:
 VP Italy - Sweden:
 Start Date: 15th July 1996
 End Date: 19th July 1996
Session 2:
 VP Norway - Spain:
 Start Date: 22nd July 1996
 End Date: 26th July 1996

Network Infrastructure:

An access to JAMES is required.

Local Infrastructure:

On the customer side, workstations for traffic generation and an access through an ATM switch or a router with one or more ATM interfaces are recommended.

Software / Hardware:

Software

Any kind of public domain software agreed by the partners. We suggest "Netperf" (by Hewlett Packard) with the following features:

- source distribution (programming language: C);
- UDP testing;
- round trip time testing of both UDP and TCP packets;
- native ATM testing;
- version 2.1 available by anonymous ftp at:
  ftp.infn.it//pub/Network/benchmark
  files:
  + netperf.ps.gz: program documentation (examples are not updated):
  + netperf2.1.tar.gz: source distribution, installation through the command "make install". Some changes to the makefile could be required;
- other documentation available at the Netperf homepage.

If other tools are available, it would be nice to run them to validate the measures collected by Netperf.

Hardware

- One or more workstations connected to a router (the router with an ATM interface to JAMES) or to an ATM switch.
- Recommended platforms (if netperf is used): HP-UX, IRIX, OSF/1, Solaris, SunOS.

Porting can be done to compile the sources on other platforms.

Related Work:

None.

5.2 SVC Tunnelling through PVPCs

Experiment Leader:
Christoph Graf, SWITCH, Zürich, Switzerland

Participants:
ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). (Preliminary list)

Goals:
- Gaining experience in interconnecting workstations with SVCs.
- Prove the suitability of SVC tunnelling over JAMES provided long distance PVPs.
- Providing an infrastructure for further tests based on SVCs and JAMES connections.

Description:
The most straightforward method to interconnect islands of SVC-based infrastructure to form one SVC cloud relies on switches that share the same addressing scheme, use compatible ATM signalling and directly exchange SVC information. If no or incompatible addressing or signalling is used on those intermediate systems, another approach must be used.

Switches, with support for SVCs and SVC tunnelling, can make use of directly connected, preconfigured PVPs to exchange SVC information among themselves. Support for signalling on the intermediate switches is not required in such a set-up.

This approach will be used to interconnect SVC-based networks over the JAMES infrastructure.

Each participating NRN will set up a SVC-based network in the first phase:
- Each participant will use valid NSAPs for all hosts' and switches' ATM addresses. The following block of NSAPs is reserved for JAMES tests and will be used for those hosts and switches where local valid NSAP addresses are not available: 39.756f.1111.1111.7001.0001.1000.xxxx.xxxx.xxxx.
- All relevant ATM interfaces will be assigned IP addresses out of 193.246.0.0/24 reserved for JAMES tests.
- Mapping between IP addresses and ATM addresses will be configured statically on each host.
- Connectivity on IP level between all hosts will be verified with standard TCP/IP tools (ping, telnet, ftp).
- The set-up and time-out of SVCs should be monitored on the workstations and switches. The set-up-time of SVCs will be measured.

Pairwise interconnects with JAMES provided PVPs configured to tunnel SVC information will follow in the second phase:
- Each participant will configure one PVP to another participant and will set it up for SVC tunnelling.
- Connectivity on IP level between one local and all hosts of the connected participant will be verified with standard TCP/IP tools (ping, telnet, ftp).
- The set-up and time-out of SVCs should be monitored on the workstations and switches. The set-up-time of SVCs crossing the PVP will be measured under different load conditions.
- In case of cell loss, the conditions leading to it and the impact will be documented.

Additional PVPs in the third phase will interconnect all SVC networks giving all involved hosts SVC access among each other:
- The additionally required PVPs will be added to the current configuration and set up for SVC tunnelling.
- Connectivity on IP level between one local and one host of each participating networks will be verified with standard TCP/IP tools (ping, telnet, ftp).
- The set-up and time-out of SVCs should be monitored on the workstations and switches. The set-up-time of SVCs crossing multiple PVPs will be measured under different load conditions.
- In case of cell loss, the conditions leading to it and the impact will be documented.

Pre-requisites:
None

Dates And Phases:

- Phase one: Set-up and test of local infrastructure
  + Date: 1/08/1996
  + Duration: 3 weeks
- Phase two: Pairwise interconnection of participants over JAMES
  + Date: End of phase one
  + Duration: 2 weeks
- Phase three: Full interconnection of all participants over JAMES
  + Date: End of phase two
  + Duration: 3 weeks

Network Infrastructure:

- None in phase one.
- The second and third phase require VPs (CBR or VBR) of at least 1Mbps to interconnect the participants pairwise. Details will be defined when the list of participants will be available.
- The third phase requires some additional VPs to provide full connectivity between those pairs of participants. Details will be defined when the list of participants will be defined.

Local Infrastructure:

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

- One ATM switch, capable of handling SVC tunnels, supporting UNI 3.0 signalling, supporting NSAP addressing, connected to the JAMES test network on ATM level
- At least one, preferably more, workstations equipped with a SVC capable ATM interface 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:

- ARP-tests
- NHRP-tests

5.3 Classical IP and ARP over ATM

Experiment Leader:
Ramin Najmabadi Kia, ULB/STC, Belgium

Participants:
ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). (Preliminary list)

Goals:
- Prove the applicability of RFC 1577 on an ATM WAN.
  - Study the scalability of the ATM ARP server mechanism.
  - Gain experience in the installation and operation of ATM ARP server in a geographically spread ATM WAN.
  - Study the operation and the interaction of multiple ARP servers belonging to different Logical IP Subnetworks (LIS).
- Provide the transport functionalities required by other tests.

Description:
Classical IP over ATM is described in RFC 1577. The goal of this specification is to allow compatible implementations for transmitting IP datagrams and ATM Address Resolution Protocol (ATMARP) requests and replies over ATM Adaptation Layer 5. The Classical IP over ATM as described in RFC 1577 is used to initially replace LANs, Local-area backbones between existing (non-ATM) LANs and dedicated circuits or frame relay PVCs between IP routers. Both ATM WANs and LANs are considered. Private ATM networks (local or wide area) will use the private ATM address structure specified in the ATM Forum UNI specification. This structure is modelled after the format of an OSI Network Service Access Point Address. A private ATM address uniquely identifies an ATM endpoint. Public networks will use either the address structure specified in ITU-TS recommendation E.164 or the private network ATM address structure. An E.164 address uniquely identifies an interface to a public network.

(Note: Addressing issues are being dealt with in a separate experiment, see section 5.5)

Only one LIS (Logical IP Subnetwork) will be set up in the first phase of the tests.

- The ATMARP server will be installed and configured in one location (to be determined).
- Several clients will be configured to be members of this LIS.
- Communication between LIS members will be monitored as well as the behaviour of the ATMARP server.

During the second phase at least two other LISs will be set up.

- Static Routing will be used between different LISs.
- Communication of IP hosts belonging to different LISs will be monitored as well as the respective behaviour of the ATMARP servers.

Depending on the results of the tests and on the reliability of the trialled set-up, it might be envisaged to interconnect production IP networks through the test environment to provide real user IP data for the experiment. For this test it must be sufficiently certain that the experimental environment works smoothly.

Test tools such as netperf will be used to make performance tests. Connectivity will be probed with traditional IP tools such as ping. Other measurements (ATMARP server load, address resolution delay, ...) may be performed based on the availability of required tools on the server.

At the end of each phase, a report describing the experiment, the set-up and the results of the tests will be provided.

Pre-requisites:
None

Dates And Phases:

As soon as the SVCTunnelling is implemented ARPtests may start:

	First Phase	Second Phase
Start Date	2/9/96	30/9/96
End Date	27/9/96	31/10/96
Duration	20 days	24 days

Network Infrastructure:

A set of ATM switches supporting UNI 3.0 signalling or later. SVC capable switches are preferred. This can be the result of the *SVC Tunnelling Through PVPs* experiment. In fact, if SVC is not available with JAMES infrastructure, this experiment will build on the network structure of the SVC tests.

Hardware/Software:

IP hosts with SVC capable ATM interfaces supporting RFC 1577. Location of these equipment will be determined later.

ATM node (router or host) implementing ATMARP server as described in RFC 1577. One such node may first installed at the ULB/STC premises. Other ATMARP servers may be installed elsewhere as well.

Related Experiments:

- SVC Tunnelling through PVPs
- TCP over ATM long distance performance
- TEN-34 ATM Network Management tests

5.4 IP routing over ATM with NHRP

Experiment Leader:
Olav Kvittem, UNINETT, Norway

Participants:
ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). (Preliminary list)

Goals:
- To set a NHRP service between at least 3 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 multi-organisation 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.

Tasks to perform are :

- Investigate clients and servers
- Test and validate SVC infrastructure
- Set up national NHRP servers
- Test and maintenance
- Report and recommendation

Pre-requisites:
- There is an NHRP-implementation on Cisco routers.
- The availability of NHRP clients on workstations need to be investigated.

Dates And Phases:
- Start preparation 1996-07-01
- Start implementation 1996-10-01; end of tests: 1996-12-20

Network Infrastructure:
- A SVC-based infrastructure with UNI 3.0 signalling and (static) ATM routing and addressing.
- A network capacity of 2 Mbps is sufficient.

Local Infrastructure:
ATM SVC-based network

Hardware/Software:
One more routers and workstation being NHRP client/server.

Related Work:

- SVC tests
- NBMA Next Hop Resolution Protocol (NHRP)- Still and Interment draft.
- Cisco's Implementation of NHRP
- NHRP tests
- RFC1577 (Classical IP over ATM)

5.5 European ATM Addressing

Experiment Leader:
Kevin Meynell, UKERNA, UK.

Participants:
UKERNA, University of Edinburgh, other NRNs (to be defined)

Goals:
To devise an ATM addressing scheme for European NRNs. It is also necessary to devise a method of address translation as most European PNOs have indicated they will be using E.164 addressing. This translation scheme needs to be trialled on the JAMES network.

Description:
The forthcoming introduction of ATM signalling has meant a universal addressing scheme needs to be devised. Such schemes have been discussed in a number of countries, but little work has been done to actually introduce a scheme compatible with others in the international community.

Many European NRNs have yet to implement an addressing scheme, but this has already been done by JANET (UK). Despite concerns that early adoption of a scheme could result in administrative problems in the future, it was necessary to have something to allow experiments with UNI (and eventually NNI) signalling and routing services.

The JANET scheme was devised with the intention that it would be as global as possible; only minimal changes would be necessary once feedback had been received from other researchers, the ITU and PNOs. This also means that it is relatively easy to adapt the scheme for international use.

One important aspect of an NSAP-based scheme, will be the requirement for address translation from E.164. Most European PNOs have indicated they will be using E.164, but this does not provide the fine address resolution required by the NRNs.

Some of the other ATM experiments of TEN-34 (see "related work" below) require a universal addressing scheme as soon as possible. It would be possible to conduct initial experiments using temporary addresses, but configuration would become increasing difficult as the scope of the experiments expanded. Furthermore, a lot of future re-configuration work can be avoided if a universal scheme is adopted early.

The practical part of the experiment will therefore focus on the Europe-wide deployment of addresses defined in this experiment. It is expected that address translation must be done between NSAP and E.164 addresses.

Pre-requisites:
None

Dates And Phases:
- Define addressing scheme: 29/07/96 to 28/08/96
- Comments from other NRNs: 29/08/96 to 13/09/96
- Incorporate revisions where necessary: 14/09/96 to 30/09/96
- Test over JAMES Network: 01/10/96 to 20/12/96

Network Infrastructure:
The intention is to implement a common addressing scheme suitable for the JAMES network. Initial SVC and ARP tests implementing this scheme will require use of the JAMES network.

Local Infrastructure:
No additional infrastructure required. (see SVC experiments)

Hardware/Software:
No additional infrastructure required. (see SVC experiments)

Related Work:

- SVC tests
- ARP tests
- JANET ATM Addressing Scheme

5.6 ATM Network Management

Experiment Leader:
Zlatica Cekro, University of Brussels, ULB/STC

Participants:
For the Phase 1 and 6: ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). JAMES PNOs where applicable. (Preliminary list)

For the other phases a minimum of 3-4 participants will be needed. (to be defined)

Goals:
- To gain experience of the management aspects on ATM management service offered by a public ATM network (here JAMES).
- To gain experience of system interoperability at the management plane in domains of configuration, performance, accounting, fault and security.

Description:
First, a questionnaire for the NRNs and JAMES PNOs for the Phase 1 will be used for producing an overview on management possibilities. Detailed test procedures based on already finalised standards will be specified for the phases 2-5. According to the ATM Forum: a specific management information flow (M1-M5) includes a conceptual view and a MIB (Management Information Base) for the five different management interfaces. Different models concerning MIB and protocols could be applied: ATM MIB (MIB-II), proprietary MIB like ATM Forum UNI ILMI MIB; protocols SNMP and CMIP with extensions SNMPv1, SNMPv2, ILMI (Interim Local Management Interface). We will concentrate the tests on two user management interfaces defined by the ATM Forum:

- M3 (ITU-T X interface in ITU-T M.3010) - Customer Network Management for ATM Public Network Service which is based primarily on the IETF SNMP standards with ATM MIB.
- ILMI - ATM link specific view of the configuration and fault parameters on ATM UNI based on SNMP and ATM ILMI UNI MIB.

According to the M3 specification "read only" management service (Class I of requirements) is mandatory if the service provider offers any management service. Class I of requirements includes:

- Retrieve General UNI Protocol Stack Information
- Retrieve General ATM Level Performance Information
- Retrieve ATM Level Virtual Path/Virtual Channel (VP/VC) Link Configuration and Status Information
- Retrieve Traffic Characterisation Information
- Retrieve Event Notifications from the Public Network Provider.

Operations, Administrations and Maintenance (OAM) flows enable the tests based on the ATM Layer mechanisms. Management Information Flows 4 and 5, described in ITU-T I.610, will be of special interest. These information flows (F4/F5) could be used to verify the existence of connectivity for a particular ATM connection. ILMI/UNI defines F4 and F5 OAM flows on Public UNI as End to End Loopback and UNI Loopback for respectively VPC and VCC services.

Class II of requirements is optional for the service providers. It includes addition, modification or deletion of virtual connections and subscription information in a public network.

Prerequisites:
User management systems with M3/ILMI interface on the user side. Support of the Management services defined in M3/ILMI on the TEN-34 (service provider side).

Dates and phases:
<u>Phase 1</u>
Investigate management possibilities at each point of attachment on the NRN side and on the PNO side (M3/ILMI interface).

Date: July 1, 1996,
Duration: 1-2 months.

Phase 2
Tests of access to the PNO management system from the NRN network management system like restrictions, security consideration (authentication).
Date: September 1, 1996,
Duration: 1 week.

Phase 3
Tests of general monitoring functions (Class I): monitoring information on the configuration, fault and performance management on a specific NRN's portion of the JAMES ATM network.
Date: September 15, 1996,
Duration: To be defined (Periodically during the other tests).

Phase 4
Tests of ATM Layer OAM End to End and Segment Loopbacks managed from the NRN management system for already established ATM connections (in-service measurements).
Date: November 1, 1996,
Duration: To be defined (Periodically during the other tests).

Phase 5
Tests of advanced management functions (Class II) on a specific NRN's portion of the JAMES ATM network if supported: addition, modification or deletion of virtual connections and subscription information.
Date: December 1, 1997,
Duration: 1 week.

Phase 6
A report of situation, experience and results of tests will be done. Inputs from other work packages with their experience on management issues will be taken into consideration. Some additional tests from Class I or Class II.
Date: December, 16 1997,
Duration: 2-3 days.

The duration of phases in different participant's premises could be different.

Network infrastructure:

No special infrastructure is requested except the support of MIB II, ILMI UNI MIB for the UNI at the user portion of the Public ATM network. The same infrastructure used by other tests could be used. Those are:

- ARP-tests,
- NHRP-test,
- SVC-tests.

VPs and VCs already established for those tests could be used.

Local infrastructure:

No special infrastructure is required except the Management system station with SNMPv2 for monitoring and data collecting.

Hardware/Software:

The releases of software that support the latest standards are required like MIB II and SNMPv2.

Related work:

Working documents like: IETF's "Tests for ATM Management" (based on F4/ F5 flows in the scope of SNMPv2 using Interface Test Table defined in RFC 1573), and ITU M.30XX series will be consulted.

5.7 CDV over concatenated ATM networks

Experiment Leader:
Victor Reijs, SURFnet bv

Participants:
SURFnet bv, University of Stuttgart and UNInett are participating. Cooperation with PNOs will be sought through JAMES (D. Hetzer, WP4.4).

Goals:
Determine the consequences of changing CDV (Cell Delay Variation) when ATM cells cross multiple loaded ATM switches within multiple management domains.

Description:
Every ATM switch in an ATM cloud will add an amount of cell delay variance to a cell. Certainly when loaded links are involved, cells will get more CDV due to buffering at the ingress side of a link. Furthermore, at every management boundary, the traffic contract at the ingress side, will have a CDVT.
The question is now: what traffic contract (CDVT especially) will be needed at every management boundary to handle the cell flow over multiple ATM clouds (without cell loss).

Pre-requisites:
None

Dates and Phases:
- Define test plan: July 1 until Oct. 1, 1996
- Make test configuration: Oct. 1 until Oct. 15, 1996
- Testing: Oct. 15 until Nov. 15, 1996

Network Infrastructure:

```
traffic generatorA - instituteA - NRNA - JAMES - NRNB - instituteB - traffic generatorB
                                                                     |
                                                                     +------ traffic loaderB
```

A VPC between at least two participating NRNs. This VPC should be a CBR connection with a low but measurable CDVT. This low CDVT is needed, in order that low CDV in the neighbouring network will have effect. The PCR of this connection is yet unknown, but it should be thus that a CDV has the most influence.

Local Infrastructure:
- at one NRNB a variably loaded ATM cloud, with multiple ATM switches (perhaps a multiple looped ATM VPC over the same low speed link could help?)
- ATM analysers to see what happens with the CDV
- traffic loaderB to generate more CDV in the NRNB ATM cloud
- traffic generatorsA, B which will be used to see the effect of load differences within the NRNB ATM network.
- the traffic contracts that should be studied are:
  - TCC between instituteB and NRNB
  - TCB between NRNB and JAMES
  - TCA between JAMES and NRNA

Hardware/Software:
- two ATM traffic analysers
- two works stations that function as traffic loader/consumer
- two workstations/analysers that function as traffic generators

Related work:

It will have to be studied if P-NNI will cover this subject. From a scan it seems that P NNI will cover this only on a broad and global side. The particle measures to take on the traffic contract seems to be outside P-NNI. So these principle will also be important for the CDVT traffic contract.

5.8 Performance of the Native ATM Protocol

Experiment Leaders:
Mauro Campanella, INFN, Milano
Tiziana Ferrari, INFN/CNAF, Bologna

Participants:
ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). (Preliminary list)

Goals:

1) Monitoring of the native ATM protocol performance in the infrastructure of JAMES through the measurement of the following parameters (more can be added depending on the software used):
   - THROUGHPUT (data sent/time) for memory-to-memory data transfer. Tests can be done over a VP infrastructure with both full bandwidth available and bandwidth shared by many users.
   - AALx frames ROUND TRIP TIME average and variance with different frame sizes.
   - CPU utilisation (%) at both the sending and receiving host.
   - CELL LOSS percentage

2) Analysis of the network behaviour:
   - fairness of bandwidth distribution when a VP is shared by different applications;
   - relationship between the average throughput, SCR, PCR and the Maximum Burst Size (MBS) ;
   - impact of MBS on throughput with different MTU sizes;
   - congestion in the switches in the user's and/or JAMES premises: is it possible?
   - other...

   when the infrastructure is stressed by different patterns of traffic:

   - many-to-one (1 host for each NRN) ==> test of the ATM switch output buffers management on the PTT side and of the input/output buffers management on the user side (receiver) -see Fig. 1-;
   - one-to-many (1 destination per NRN) ==> test of bandwidth distribution between each stream -see Fig. 1-;
   - many-to-many (1 or more hosts for each NRN) ==> test of possible congestion at the input buffers of the PTT switches and in the output buffers on the sending NRN switch -see Fig. 2-;
   - one-to-one half/full duplex with many TCP connections between the same couple of host ==> test of fairness in bandwidth distribution.

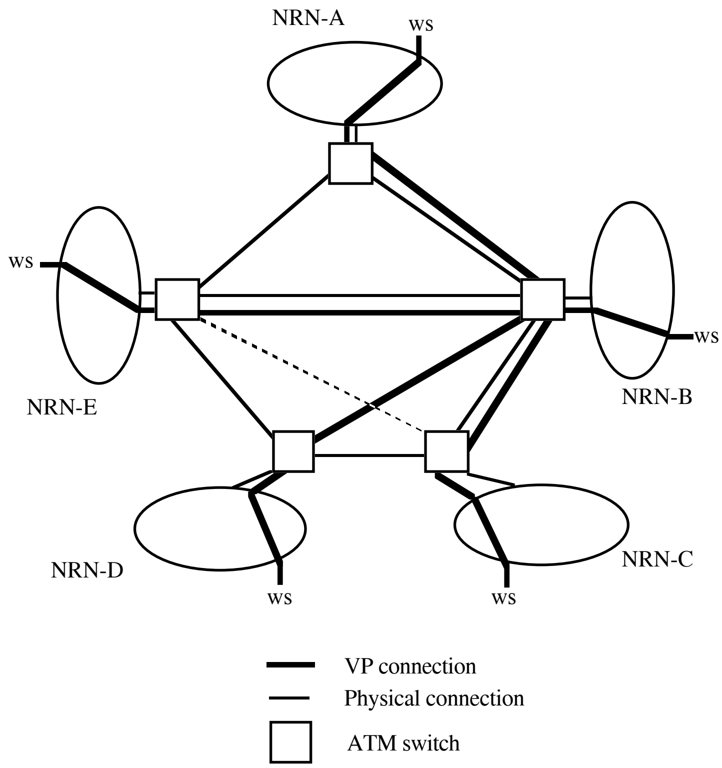


Fig1. 1-to-n and n-to-1 traffic patterns

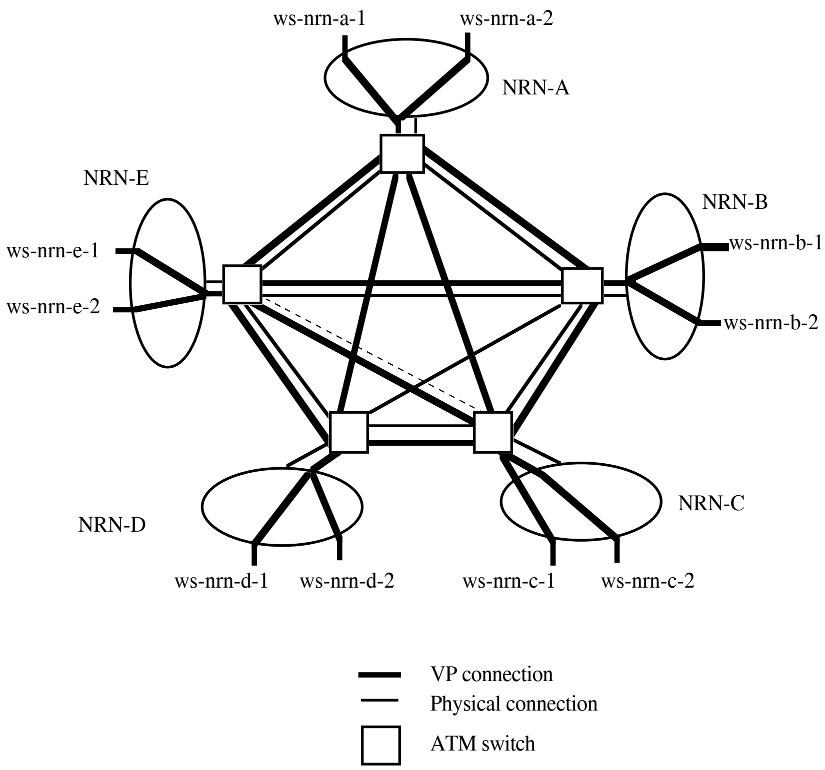


Fig.2 n-to-n traffic pattern over a complete VP mesh

3) Analysis of native ATM performance over VP connections different in length

4) Impact of ATM cell loss on throughput when the native ATM protocol is used. Since a recovery from cell loss is not implemented on the ATM level and so AAL5 packets are

discarded if cell loss occurs, only a comparison with a protocol that doesn't implement flow control, is possible. We could choose UDP/IP to estimate the UDP/IP overhead.

5) When standard Application Programming Interfaces (API's) will be available, a comparison of different implementations could be done to measure the ATM protocol stack efficiency.

Description:

Tests will be done to compare the performance of the TCP/IP and/or UDP/IP protocols running over ATM with the one achieved by applications when they address the ATM protocol directly.

A comparison between the TCP-UDP/IP protocols stack and the native ATM one gives the possibility to analyse impact of the TCP flow control mechanism on the application performance and to work out the UDP/IP overhead.

This could be done both through the use of public domain benchmarking software, which is available now, or by the development of software applications. The throughput and other ATM parameters could be used to understand the behaviour of the native ATM protocol.

In the first phase, benchmarking software will rely upon the usage of the non-standard application programming interfaces (API's) offered by the market; in order to collect this measures only end-nodes with the same vendor equipment will be involved.

In the second phase, if standard API's will be available, interoperability tests will be planned and a comparison of performances achieved on various platforms could possibly underline the efficiency of the API designs implemented in different operating systems.

All the tests will be done by generating a real data stream between two or more end-points. Different and complex stream topologies will be configured. The measurements collected so far will be compared to the results which have already been analysed both in different ATM network set-up and in a "classical" mesh of leased lines.

Pre-requisites:

Results should be compared with the measures collected in the experiment "TCP-UDP/IP performance over ATM".

Dates and Phases:

The project consists of 2 phases, each of them is divided into sessions.

PHASE 1: From 1.11.1996: ATM Application Interfaces (API's) already available on the market will be used, even if they won't be standard compliant. The type of API's used in the test will depend on the equipment available on the NRN premises.

PHASE 2: when the market will offer them, standard API's will be tested and performance measures will be compared to point out the more effective implementations. (dates to be defined).

In each session of phase 1 and 2, different partners will be involved and in each of them a different configuration of ATM VP's will be considered. The network topology tested in each session will depend on the network performance results of the previous test session.

Each session will be divided into 2 steps:

step 1 (2 days): set-up of local infrastructure and set-up of a correct interconnection between participants over JAMES.

step 2 (3 days): real traffic generation and performance measurement.

Network Infrastructure:

An access to 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. In the 1st phase ATM adapters offering ATM API should be adopted.

Software/Hardware:

Software:
Any kind of public domain software agreed by the partners. We suggest "Netperf" (by Hewlett Packard) with the following features:

- source distribution (programming language: C);
- native ATM testing over platforms with ATM API (even if non standard, e.g.. FORE, SUN, etc.);
- AAL3/4 and/or AAL5 frame round trip time measurement with different frame sizes chosen by the user;
- version 2.1 available by anonymous ftp at:
  ftp.infn.it//pub/Network/benchmark
  files:
  + netperf.ps.gz: program documentation (examples are not updated):
  + netperf2.1.tar.gz: source distribution, installation through the command "make install". Some changes to the makefile could be required.
- other documentation available at the Netperf homepage.

If other tools are available, it would be nice to run them to validate the measures collected by Netperf.

Hardware:

- 1 or more workstations mounting ATM adapter cards implementing ATM API. If Netperf is used for the benchmarking FORE ATM adapters must be used. Other kinds of API's could be used if available on the market, but software porting is required to use them. Workstations must be connected to a router (the router with an ATM interface to JAMES) or to an ATM switch.
- recommended platforms (if Netperf is used): HP-UX, IRIX, OSF/1, Solaris, SunOS.

Porting can be done to compile the sources on other platforms.

Related Work:
None.

5.9 Assessment of ATM/VBR class of service

Experiment Leader:
Olivier Martin, CERN, Switzerland

Participants:
Not defined yet.

Goals:
- To document ways to configure IP routers and local ATM switches in order to make optimum use of the ATM VBR service available in JAMES.
- To evaluate the cost and performance benefits of using ATM VBR class of service.

Description:
Public ATM/VBR services are expected to provide bandwidth at lower cost than ATM/CBR services, it is therefore very important to understand how to configure IP routers, native ATM hosts, and/or ATM switches in order to make best use of the underlying service and to assess its cost and performance benefits.

The project will try to assess the suitability of VBR for the following applications, at least:

1: transport of already aggregated (i.e. not so bursty) traffic.
2: packet video based applications (e.g. video on demand server, multi-party conferencing, etc.).
3: high speed file transfer

Various combinations of SCR (Sustained Cell Rate), PCR (Peak Cell Rate) and MBS (Maximum Burst Size) will be tried out, including CBR (Constant Bit Rate) like set-up.

Pre-requisites:
There should be an operational test IP-network over JAMES with at least 3 sites, each being equipped with Cisco/ATM routers, ATM workstations and ATM switches.

Dates and Phases:
- Planned start of experiment: 1/11/96
- Planned end of experiment: 20/12/96

Network Infrastructure:
There will be a need for a fully meshed connection of all participating sites through JAMES. Ideally three sites from the beginning. Details to be defined.

Exact characteristics of the Virtual Paths will be determined later, No permanent VP allocation will be required, periodic VPs of relatively small duration (i.e. a few hours) and preferably high capacity (e.g. 4 to 8 Mb/s bandwidth) will be used.

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

- One ATM switch, connected to the JAMES test network on ATM level
- A router with an ATM-interface.
- One or several ATM workstations.

Hardware/Software:
No special requirements besides ATM connectivity.

Related Work:
ABR/UBR tests

5.10 IP resource reservation over ATM

Experiment Leader:
Olav Kvittem, UNINETT, Norway

Participants:
ACOnet (AT), ULB (BE), CERN (CH), SWITCH (CH), DFN (DE), NORDUnet (SE and NO), SURFnet (NL), RedIRIS (ES), GARR (IT), UKERNA (UK). (Preliminary list)

Goals:
- To set up an experimental network using IP resource reservation (RSVP).
- To evaluate the benefits and scalability of using RSVP on a European academic scale.
- To use RSVP clients on workstations and RSVP capable routers.
- To study the mapping between RSVP and ATM

Description:
RSVP is maturing as an Internet draft. There are experimental implementations being developed. The project would try to evaluate how these implementations working in a pan European academic infrastructure.

- The first phase would be a study and preparation phase, in which implementations are sought and evaluated.
- The next phase would implement a small scale test network. On this test network one would set up and stress-test simple reservations.
- In the last phase a more complex network should be built so that group aggregation of reservation could be tested.

Pre-requisites:
- There should be an operational test IP-network over JAMES with at least 2 routers and 2 workstations that are RSVP capable.
- RSVP capable router

Dates And Phases:
- Start preparation 1996-07-01
- Start implementation 1996-10-01; end of tests: 1996-12-20

Network Infrastructure:
- There will be a need for one to a few connections through JAMES
- A network capacity of 2 Mbps is sufficient.
- VBR quality connection matching a VBR-like RSVP application

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

- One ATM switch, capable of handling SVC tunnels, supporting UNI 3.0 signalling, supporting NSAP addressing, connected to the JAMES test network on ATM level
- A router with an ATM-interface capable of running RSVP
- A workstation running RSVP-capable applications

Hardware/Software:
No special requirements besides ATM connectivity. RSVP-capable applications can have bindings to make and OS.

Related Work:
- SVC tests
- Issues for RSVP and Integrated Services over ATM - Internet draft
- Resource ReSerVation Protocol (RSVP) - Version 1 Functional Specification - Internet draft
- RFC 1458 - Requirements for Multicast Protocols
- RFC 1821 - Integration of Real-time Services in an IP-ATM Network Architecture
- RFC 1633 - Integrated Services in the Internet Architecture: an Overview

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Experiment 1

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INFN Internal Note n. 1069, July 1995
C.Battista, M.Campanella, T.Ferrari, A.Ghiselli, C.Vistoli.
Performance evaluation of TCP(UDP)/IP over ATM networks
S.Dharanikota, K.Maly, C.M.Overstreet, Computer Science Dep., Old Dominion University, Norfolk VA
A Performance Analysis of TCP/IP and UDP/IP Networking Software for the DECstation 5000
J.Kay, J.Pasquale; Computer Systems Laboratory, Dep. of Computer Science and Engineering, University of California, San Diego
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C.Villamizar, C.Song
High-performance TCP/IP and UDP/IP Networking in DEC OSF/1 for Alpha AXP
Digital Technical Journal, vol. 5, n. 1, win 1993
How a large ATM MTU causes deadlocks in TCP data transfers
K.Moldeklev, P.Gunninberg (Norwegian Telecom Research and Swedish Institute of Computer Science)

Experiment 2

Basic Documents:
Classical IP and ARP over ATM (RFC 1577)
Multiprotocol Encapsulation over ATM Adaptation Layer 5 (RFC 1483)
Default IP MTU for use over ATM AAL5 (RFC 1626)

Additional Information:
Integration of Real-time Services in an IP-ATM Network Architecture (RFC 1821)
ATM Signalling Support for IP over ATM (RFC 1755)
IPng Support for ATM Services (RFC 1680)
NBMA Address Resolution Protocol (NARP) (RFC 1735)
ASSIGNED NUMBERS (RFC 1700)
INTERNET NUMBERS (RFC 1166)

Experiment 6

ULB/STC Internal working documents:
QoS Analysis at User Level in an IP LAN/WAN Interworking Environment, Z. Cekro, R. Vandenbroucke, February 1996
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How a large ATM MTU causes deadlocks in TCP data transfers
K.Moldeklev, P.Gunninberg (Norwegian Telecom Research and Swedish Institute of Computer Science)

Glossary

AR	Access Router (Unisource term)
ARP	Address Resolution Protocol
AS	Autonomous System (Set of IP routers)
ASN	Autonomous System Number
ATM	Asynchronous Transfer Mode
BGP	Border Gateway Protocol (exterior IP routing protocol)
CBR	Continuous Bit Rate (ATM Forum: traffic class)
CLR	Cell Loss Ratio (QoS parameter)
CTD	Cell Transfer Delay (QoS parameter)
DBR	Deterministic Bit Rate (ITU-T: traffic class, e.g. CBR)
E.164	(ITU-T addressing standard)
E3	(Interface speed; 34 Mbit/s)
FDDI	Fibre Distributed Data Interface (100 Mbit/s)
FUDI	A TEN-34 subnetwork, initially based on FR, UK, DE, IT
HSSI	High Speed Serial Interface
ILMI	Interim Link Management Interface
IP	Internet Protocol
IR	Internet Reseller
IPLC	International Private Leased Circuit
LIS	Logical IP Subnetwork
MBS	Maximum Burst Size (ATM Forum: traffic parameter)
NHRP	Next Hop Resolution Protocol
NMC	Network Management Centre
NOC	Network Operation Centre
NRN	National Research Network
NSAP	Network Service Access Point (OSI term)
OAM	Operations, Administration and Maintenance
P-NNI	Private Network to Network Interface
PCR	Peak Cell Rate (ATM Forum: traffic parameter)
PNO	Public Network Operator
PoP	Point of Presence
PVC	Permanent Virtual Circuit
PVPC	Permanent Virtual Path Connection
QoS	Quality of Service
RSVP	Resource ReSerVation Protocol
SBR	Statistical Bit Rate (ITU-T: traffic class, e.g. VBR)
SCR	Sustainable Bit Rate (ATM Forum: traffic parameter)
SNMP	Simple Network Management Protocol
STM-1	(Interface speed; 155 Mbit/s)
SVC	Switched Virtual Circuit
T3	(Interface speed; 45 Mbit/s)
TCP	Transport Control Protocol
TR	Transit Router (Unisource term)
UDP	User Datagram Protocol
UNI	User Network Interface
VBR	Variable Bit Rate (ATM Forum: traffic class)
VC	Virtual Circuit
VCC	Virtual Circuit Connection
VP	Virtual Path
VPC	Virtual Path Connection