

# NETWORKING SUPPORT FOR COLLABORATIVE VIRTUAL REALITY PROJECTS IN NATIONAL, EUROPEAN AND INTERNATIONAL CONTEXT

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## Abstract

*The report describes experiences from networking support for two three years virtual reality projects. Networking requirements depending on the virtual reality environment and the planned distributed scenarios are specified and verified in the real network. Networking problems especially due to the collaborative, distributed character of interaction via the Internet are presented.*

## 1 Introduction

The report describes experiences from networking support for two three years virtual reality projects. The project 'Digital Product Development with Virtually Cooperating Teams using Optical Networks (ProViT)' is a national project and explores digital product development tools in combination with novel information- and communication technologies. The prototypical developed cooperation techniques require both efficient live audio and video streaming and real-time encoding for voluminous und sensible data exchange.

The project 'Digital Artistic and Ecological Heritage Exchange - Transcontinental Guidance and Exploration in Globally Shared Cultural Heritage (DHX)' aims to establish a networked virtual reality infrastructure and content development environment for museums and cyber theatres, for mutual exchange of digital cultural and natural heritage. European and Asian partners are participating for transcontinental shared immersive experience in a global scale using high-bandwidth trans Euro-Asian networks.

Both projects use the 'AVANGO™ – Virtual Environment Framework' a software framework designed to allow the rapid development of virtual environment applications for immersive and non-immersive display setups like CAVE™, i-CONE™ and Responsive Workbench.

## 2 Interaction and communication

The main focus of the projects was the interaction and communication of remote persons in a virtual scenery. The planned distributed application scenarios were analyzed to recognize typical interaction and communication schemes. A number of interaction models were defined that describe the interaction type and data and also the audio/video streams for remote communication. The interaction type is a combination of manipulation type (master-slave, equal-rights) and the representation of the acting person (avatar, video avatar, remotely guided character, remote user representation).

A typical scenario for a ProViT application is the planning of a machine tool by producer, sub-supplier, engineer and client. They meet as real persons in a virtual environment. The interaction includes for example the exchange of machine parts in the tool machine or the simulation of machine functionality. The interaction model specifies the transmission paths of model and tracking data, the communication model specifies the necessary audio/video streams for the representation of the persons.

A typical scenario for a DHX application is the meeting of two persons in the virtual implementation of a real museum or building, e.g. the baptistery of Pisa. One of the visitors can be a guide that explains the history and the interior of the building to the other visitor. The persons are implemented as avatars and moved by navigation tools. The interaction model specifies the transmission paths of model and tracking data, the communication

model specifies the audio streams necessary for explanations and questions. A video of the real persons can be faded in. Figure 1 shows one example from the interaction and communication models.

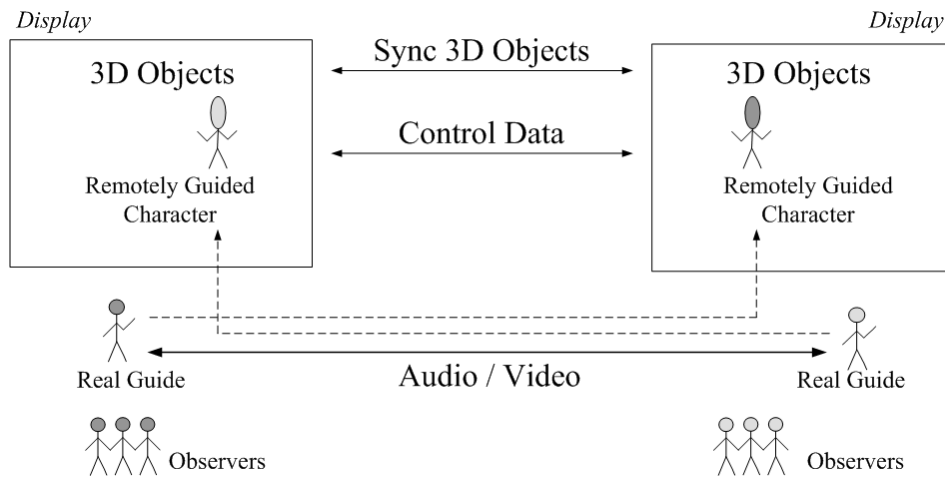


Figure 1 Interaction and communication model

Figure 2 presents two snapshots from first distributed tests of the above scenario. They are taken at the same time and show the two different views of the user within the baptistry of Pisa. Each user can see the remote user moving within his section of the scene. A real video of the remote user can be displayed in a separate window or streamed into a separate picture in the scenery.

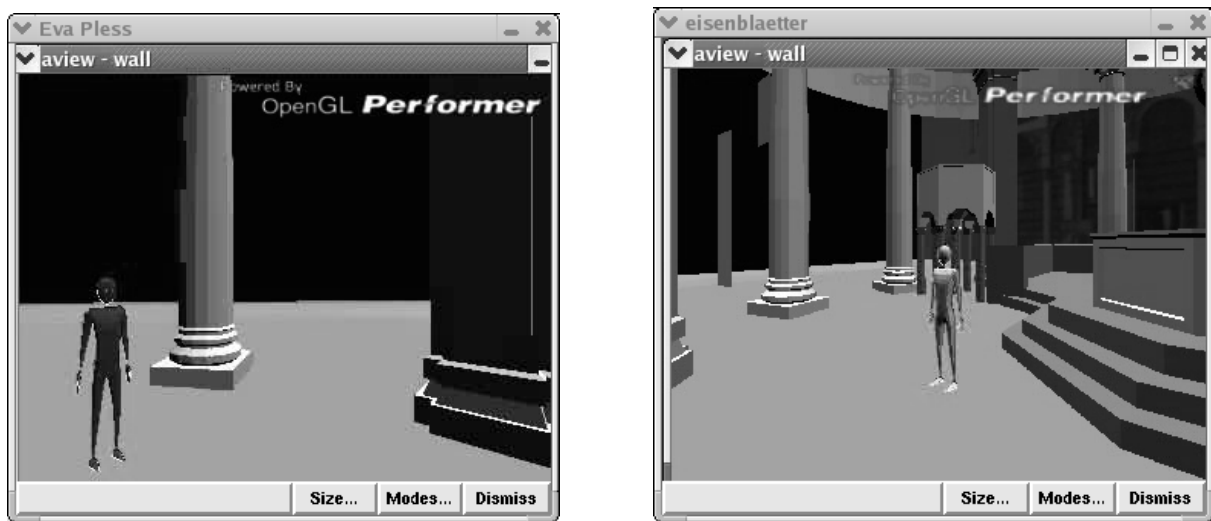


Figure 2 Snapshots from first distributed DHX tests

As an immersive tele-presence system was not yet available in the beginning of the projects, the integration of audio/video had to be simulated by live audio/video streaming or conferencing tools. A number of real-time streaming tools have been studied and tested with the project partners. Special attention was directed to encoding, transmission bandwidth, transmission quality and reliability.

The Access Grid™ system, an ensemble of resources including multimedia large-format displays, presentation and interactive environments, and interfaces to Grid middleware and to visualization environments, approved to be a powerful tool for collaboration and communication. An Access Grid server was set up for the cooperation of the project partners. The Access Grid audio/video tools 'rat' and 'vic' were widely integrated into the DHX scenarios to support individual audio/video communication.

### 3 Networking issues

The networking requirements depend on the virtual reality environment and the planned scenarios. The analysis of the distributed applications with regard to networking and the interaction and communication models provide

the base for the deduction of networking requirements. The distributed AVANGO applications communicate via the IP unicast and multicast protocol, 'rat' and 'vic' via IP unicast or multicast. The bandwidth needed for unicast and multicast transmission was estimated from the number of real-time audio/video streams and the amount of modelling and tracking data that has to be exchanged for the planned scenarios. For the interaction data for two partners and the transmission of a highly compressed video a data rate about 2 Mbps is sufficient. Tolerable values for transmission delay (< 300 ms), jitter (< 10 ms) and data loss (< 1 %) were fixed from experience.

Both projects use normal Internet connectivity for networking. This means that IP Version 4 is used as basic transmission protocol and UDP as transport protocol. The requirement of multicast services was problematic in the ProViT project. The project partners are FhG institutes scattered over Germany. Each institute is free to select a service provider. Therefore the ProViT network is covered by different providers and some of them do not offer multicast facilities. This problem was solved by the configuration of proxy machines as routers, installing pimd as PIM (Protocol Independent Multicast) multicast routing daemon and tunnelling multicast traffic over IP unicast. Figure 3 shows the tunnelling network configured in a way that all five ProViT partners are able to communicate at the same time. All multicast traffic and the project specific unicast traffic between the internal Avango nets at the partner sites is exchanged via the tunnels.

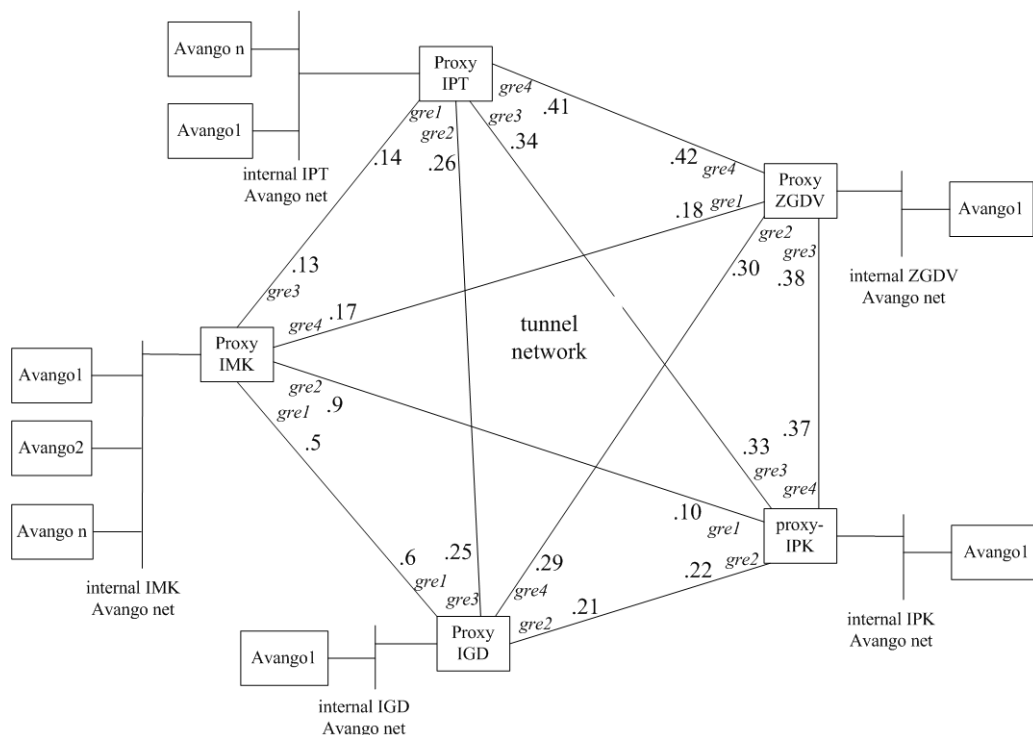


Figure 3 Multicast tunnelling

The European National Research Networks (NREN) and the GÉANT net, used by the research institutes that are the DHX partners (compare Figure 4), support multicast traffic. Multicast traffic is also routed to the Korean network. Therefore the European and International multicast connectivity was no problem.

GÉANT and RENATER support already IP Version 6. It is also tested in the national European networks. As IPv6 is supported via the TEIN link to Korea and the Korean DHX partner is involved in IPv6 installation and test, the DHX project executed first IPv6 unicast tests between Germany and Korea. Multicast tests will follow, after some multicast routing problems have been solved. First contacts have been established with the providers of the DHX network to use advanced QoS features, that are implemented in the GEANT IPv6 network and some NRENs. The DHX project will investigate in QoS trials with Less than Best Effort and IP Premium services in the course of this year.

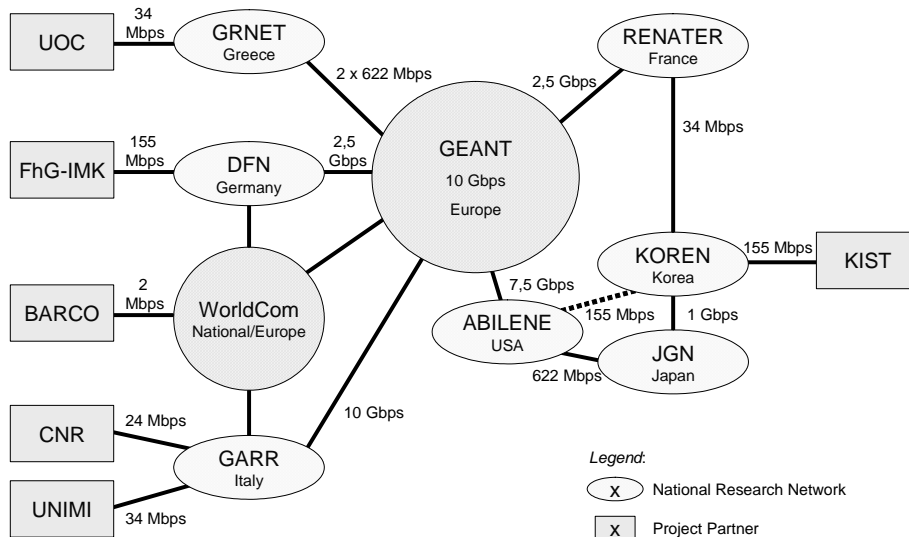


Figure 4 DHX network topology

## 4 Networking experience

In the following paragraphs the experiences gained in the course of the projects will be presented. Useful tools for monitoring, checking of network state and performance testing will be described. Special attention is laid upon the problems encountered and upon possible solutions.

### 4.1 Networking tools

One of the important tasks of networking support is to monitor the state of the network. At the moment the end-user has only poor means to do this, because the network consists of administratively separated domains. GÉANT and the NRENs became aware of this problem and started the Performance Enhancement Reponse Team (PERT) to support the end-users in network diagnosis and an advanced performance monitoring infrastructure. Momentarily they offer looking-glasses that allow to observe the state of routers and to trace routes. Some NOCs offer network usage maps or traffic graphics for router interfaces. These possibilities are helpful for the interpretation of results from performance measurements.

Very helpful tools for multicast statistics and diagnosis are the multicast beacon servers installed at national and European NOCs. They allow to check whether the transmission of multicast traffic to and from other beacon clients works well and provided statistics as loss, delay and jitter.

A number of tools help to investigate the network connectivity between collaborating partners and to monitor the state of the network. These are trace tools (e.g., ping, traceroute, mtrace), performance measurement tools and traffic simulation tools (e.g., iperf, NetIQ Qcheck and Chariot). The latter one was employed to simulate the traffic of the planned applications and to tests whether the available network fulfils the requirements.

Furthermore tools that monitor interface traffic and capture application packets (iptraf, nsl, ethereal) are very helpful. The interface monitoring tools were intensively used to observe data exchange between remote applications. Sometimes the amount of data exchanged highly exceeded or fell below the values specified by the developers and the bandwidth requirements had to be corrected. Some awkward programming, e.g. unnecessary exchange of model data, was corrected, after the data flow was monitored and documented. Capturing of data packets helped to resolve address problems in client/server applications and in tunnelling and multicast problems.

### 4.2 Performance investigations

At project start the proceeding was the same for both projects. The network topology and the link bandwidth were determined by interviews and information provided by the Internet. Each project partner made available a computer at its location and installed the necessary testing software (e.g. NetIQ endpoints). A series of different performance test was executed at different times of day. The latter was especially interesting for intercontinental tests to see, whether completely different working hours influence the network load in another way than equal working hours. We started with IP unicast tests and continued with multicast tests, after the necessary network facilities had been installed and configured. The tests included response time, throughput and real-time

streaming emulation tests, which provide results for data loss and jitter. The results were represented in tables **Figure 5** and discussed at meetings with the partners. Figure 5, for example, shows the results from two NetIQ Chariot measurements executed between all DHX partners at the same time. The values give an impression of the scope of delay between the different sites. If values deviate very much from the results expected, traffic statistics at NOC routers, if available, were consulted to locate bottlenecks. As the situation in the backbone and partner networks change continually, by installation of firewall system for example, the performance tests have to be repeated from time to time, to get an impression of the actual network situation and performance.

E1 \ E2	2004	proxy-imk	proxy-cnr	proxy-unimi	proxy-uoc	proxy-kist
proxy-imk	2901-15:21		19	47	269	307
	0202-11:32		19	37	238	305
proxy-cnr	2901-15:21	19		36	304	320
	0202-11:32	19		26	256	319
proxy-unimi	2901-15:21	47	36		361	353
	0202-11:32	37	26		265	338
proxy-uoc	2901-15:21	289	294	331		558
	0202-11:32	233	242	282		565
proxy-kist	2901-15:21	307	320	353	607	
	0202-11:32	305	318	338	528	

Figure 5 Results from DHX response time tests (ms)

To get a live impression of network performance, audio/video streaming and video conferencing was tested with some partners. Although the planned applications need live streaming, some streaming tools (VideoLAN, VBrick Server/Player, Microsoft Media Encoder / Player, RealOne Player, QuickTime Player) with buffering at the receivers side were employed to test whether the network connections between the project partners provide a constant quality of service. The buffering allows to smooth the effect of delays. The effects of highly changing network quality can be observed very well at the receivers video and audio output.

Streaming with buffering was mainly tested with the Korean partner via the TEIN link, because performance tests to Korea showed the most critical results. Sample files in MPEG1 and MPEG2 format with a bandwidth from 0,4 to 4,0 Mbps were streamed. In accordance with the former performance test results streaming from Korea to Germany showed only minor defects, whereas the reverse direction provided severe problems due to the high load of the TEIN link.

Conference tools allow to send real-time audio/video data between locations at selected data rates. Especially real-time audio transmission reacts very sensitive to jitter and data loss. These tools were also used to test the quality of the network connections between partners and to help to decide whether dedicated connections with guaranteed quality of service will be needed for the project applications.

After first tests with the audio/video tools 'vic' and 'rat' showed satisfying results, they were used for the communication between project partners in both projects. In an early phase of the DHX project audio communication made problems. Especially a conversation with the Korean partner was only possible after the upgrade of the TEIN link from 10 to 34 Mbps.

Newer real-time audio/video tests between Germany and Korea via the IPv6 connection of the TEIN link, where the traffic is very low, showed very good audio/video quality. This enabled the Korean DHX partner to participate at the DHX review meeting in April 2004 by means of an audio/video conferencing system.

### 4.3 Security and firewall issues

As the attacks from the Internet at private networks extremely increased, private security provisions increased, too. Private networks are protected by access lists and firewall systems. These arrangements massively effect collaboration, because the distributed applications normally reside in different private networks and connection establishment is not allowed from one network to the other. Even multicast traffic, which is naturally determined for a wide number of receivers, is restricted in private networks. For this reason a lot of address and access arrangements have to be discussed and configured by all project partners. Address changes at one side force all partners to change the security configuration.

Some models to configure simple but secure distributed cooperation networks were discussed and tested in the ProViT project. Figure 6 shows one example. The gateway can be configured with two interfaces, one in an internal and one in an external subnet. Normally the gateway is linked to the internal subnet and protected by the firewall as usual. This link is closed for distributed testing and the alternate link to the external gateway is opened instead. A further security measure could be to detach all machines in the avango network from the internal subnet.

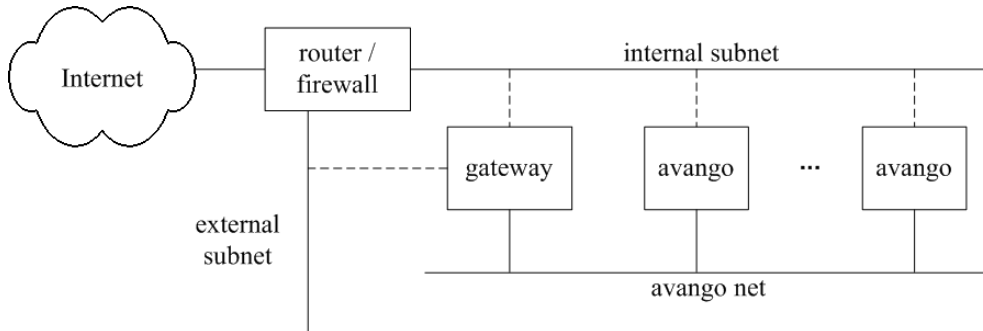


Figure 6 Alternative positioning of gateway

Virtual private networking (VPN) may solve security problems. But this service is problematical if more than one service provider is involved, as the transition from one service provider to another is not guaranteed. Some service providers even do not support VPN. Furthermore the high administrative effort to install VPN connections for multilateral, temporary collaboration is not justifiable.

#### 4.4 Problems

Experience from networking support for the projects showed a number of problems that will be discussed in the following. These are mainly available bandwidth, routing, multicast know-how, cooperation, responsibility and network change problems. Examples from the projects will illustrate the different issues.

The traffic of the collaborative applications of the projects needed at least a bandwidth of 2 Mbps. Even if high bandwidth is available in the Internet backbone (compare Figure 4), the access bandwidth of the private networks is restricted, mostly for financial reasons. Research centres or small companies cannot afford high access costs. The available small access bandwidth has to be shared by all traffic and the connections are overloaded at work time. Figure 7 shows a traffic statistic from February 2004 of a link in Greece to the University of Crete (UOC), a DHX partner, which clearly shows that the link is totally overloaded. The average throughput measured between FhG-IMK and UOC amounted to 370 Kbps, which is less than required for the planned distributed application. Response time, throughput and streaming tests, that are repeated from time to time to all project partners, show very differing values. Normally the values changed to the worse in the course of the time.

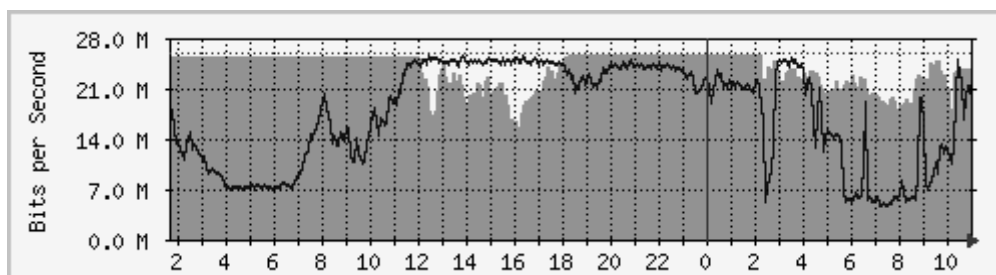


Figure 7 University of Crete (UOC) <ATM 25.3 Mbps>

If performance or routing problems come up and can not be explained by information received from the above mentioned networking tools, a number of network administrators from private or public NOCs have to be contacted, to find a bottleneck or the cause of a reachability problem. Those contacts are difficult to achieve and the process to find the cause of problems is very time consuming (among other things because of different working hours). For example, during the preparation of some streaming demonstration from Germany to Korea, traces showed an asymmetric routing between Europe and Korea. Traffic to Korea was routed via the ABILENE network and traffic from Korea via the TEIN link. The one-month upgrade from 10 to 34 Mbps of the TEIN link

to resolve bandwidth problems at the demonstration day would not have had the intended effect. It needed more than one week intensive communication with different NOCs until the problem was localized and removed.

IP multicast is a reasonable solution, if more than two partners collaborate in real-time. But multicast know-how is restricted to a small group of people. For example, a sudden decrease of multicast throughput was caused by multicast rate control which was rather difficult to locate. More than one network operations center (NOC) had to be contacted and asked for measurements to find out, where the restriction was configured. The next time, when the NOC of another partner configured multicast rate control, the gained experience helped to find the cause of performance decrease much quicker.

Another multicast problem is the employment of multicast routing daemons on private gateway machines. The installation and configuration of different operation systems for multicast and also the configuration of the multicast routing daemon requires good knowledge of the multicast routing protocols as e.g. IGMP (Internet Group Management Protocol) and PIM. Multicast beacons that provide useful statistics and diagnostic information about a given multicast group help to control the multicast configuration and to localize multicast reachability problems.

Some advanced multicast features that are planned or tested in the GÉANT network, e.g. source specific multicast, per-group-monitoring, restricted multicast group access, would help to reduce the complexity of the multicast architecture and to monitor and restrict the access to multicast groups. Especially the latter is necessary to encourage distributed cooperation, because it guarantees privacy. The Access Grid system supports already some privacy and encrypted data traffic, but not all DHX multicast traffic is controlled by the Access Grid system.

Different responsibilities within an institution create another problem. The development and the testing of applications is executed by other persons than the network administration. Networking support can be in some cases very time-consuming and special installations, configurations and problem solving for projects has to be done beside other work. The networking personal does not feel responsible for projects and refuses to invest much effort in special networking problems. This fact requires often long discussions about necessities and produces sometimes conflicts and long delays. In addition network operators are rather restrictive because their responsibility is focused on the security of the network and the observance of security policies.

The developers themselves are not very much interested in networking problems. Their interest naturally focuses at the application. They happily change machines and addresses without thinking about the consequences in regard to distributed networking. Whenever performance tests are planned, it has to be announced some days before. First step of a test should always be a reachability test for the machines included in the test case. Normally some are not reachable because of new addresses or firewall configurations or they are just switched off. In a next step it has to be tested, whether all necessary procedures (e.g. iperf server, NetIQ endpoints, streaming server) have been started. Then the test series can be started in hope that no unforeseen event will interrupt it.

A more serious problem is that the state of the whole networks dynamically changes. If for example performance tests are repeated after some weeks, they can show totally different results. The cause is very difficult to explore. One always has to take in account that tests or demonstrations do not work, because somewhere network changes or malfunctions take place. At a DHX review demonstration for example the multicast connection came up just half an hour before the fixed demonstration time. Neither the Italian nor the German partner had any chance to solve the problem, because the problem turned up within the Italian net. Because of a very exact planning and test at the day before, the demonstration was a success (compare Figure 8).





Figure 8 Snapshots from DHX review demonstration

Another example for network change concerns the routing between Germany and Korea. In the beginning of the DHX project, all IP traffic was routed via the TEIN link. This changed and at the moment the IP unicast traffic is routed via the TEIN link, whereas the multicast traffic is routed via the ABILENE network. But one cannot be sure about the routing, because sometimes it changes from one day to the other. Changed routing can considerably influence the performance of the distributed applications and the communication.

## 5 Conclusion

Though the Internet offers the facilities and services needed for collaborative projects in National, European and International context the collaboration and communication processes have to be permanently supported by experienced networking specialists. The work of these specialists would be enhanced, if better facilities for the end-user were provided to monitor the state and the performance of the network. The developers will be able to improve the quality of applications, if they get simple tools to monitor and influence the networking behaviour of applications. Extended and simple possibilities to configure secure networks between partners and to use quality-of-service connections would help to improve the base for collaboration and communication.

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