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Optical National Research Network and its New Applications

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1 Introduction

This report describes the progress in solving the *Optical National Research Network and its New Applications* research plan as well as the results achieved in 2004. This was the first year of a seven-year research plan whose completion is planned for 2010.

Our work on the research plan started in 2004 and because of this, we had to deal with the “teething” problems: e. g., the research plan financing structure required an amendment of the Association budget for 2004 which was approved by the General Assembly as late as July, 2004. As a result, the research plan had been financed from a provisional budget until July 2004.

We must point out that we regard the assurance of the research plan activities financing for a seven-year period as a great success. This period is reasonably long for starting and successfuly completing the extensive research activities. Considering the enormous range of research work and large number of researchers participating in this work, we divided the research plan solution into twelve thematic activities:

- CESNET2 backbone network development
- Optical networks
- Programmable hardware
- Network and traffic monitoring
- Performace monitoring and optimisation
- AAI and mobility
- IP telephony
- METACentre
- Virtual collaborative environments
- Support of distance education
- CESNET CSIRT
- Medical applications

The activities comprise areas from the lowest transmission layers through middleware, authentisation, authorisation, security up to research and development of the application services. Each activity has its head and a deputy head who coordinate a particular team and are responsible for professional level and effective utilisation of allocated funds. The results achieved in framework of the activities are internally evaluated within the CESNET Association twice a year and the results of the evaluation are used to improve the research efficiency in the successive periods. We exert heavy efforts to improve the collaboration and interaction of activities and to get user feedback. Our goal it to provide the users with the results of the research activities as soon as possible.

We promote international collaboration and participation especially in projects of the 6th EU Framework Programme. Last year we participated successfully in several important projects – GN2 (Multi-Gigabit European Academic Network), EGEE (Enabling Grids for E-SciencE), SCAMPI (A Scalable Monitoring Platform for the Internet), LOBSTER (Large Scale Monitoring for Broadband Internet Infrastructure), and 6NET.

We have achieved internationally recognized results in some areas such as the Customer Empowered Fibre Networks, use of Field-Programmable Gate Array technology to implement hardware accelerators for routing and monitoring IP services, multimedia applications and use of the GRID technology. These accomplishments in the European as well as in the worldwide frameworks confirm that the research plan is oriented correctly and that the issues we solve correspond with recent developments in relevant fields.

Regardless of the complications mentioned above, we managed to reach our goals defined in the accepted research plan for 2004. The following chapters contain detailed information on the progress of individual activities and and results achieved. Because of the wide extent of these projects, different authors wrote their separate chapters; this document may be regarded as a collection of papers with a common theme.

Part I

Research Activities

2 CESNET2 Backbone Network Development

Within the development of the CESNET2 backbone network in 2004, we focused on building the Prague-Brno DWDM line, representing a foundation for developing the optical transfer layer and upgrading the transfer capacities of the IP network to 10GE. The optical transfer layer will also allow for providing services on the optical paths level (Lambda services) for research activities and connected participants within the national and international scopes.

By initiating the development of the new generation NREN, CESNET2, we have completed the design of the new backbone network architecture. In the IP network development area, we have accelerated the processes, aiming to simplify the general topology and phase out and replace the GSR12016 network core routers which could no longer support the development of other services and features, such as the IPv6 unicast/multicast and jumbo frame support because of their moral obsoleteness. Concerning the logical architecture and network properties, we have completed the migration to Sup720-3BXL processors in access routers that was indispensable for providing support for the dual-stack IPv4/IPv6 including a connection to the GÉANT network.

Crucial changes were made during the IPv4 multicast implementation (AnyCast RP solution) when we also changed the method for connecting large university MANs and campus networks. Migration to external connections utilizing eBGP, eMBGP and MSDP protocols (these networks have also their own RP) and private AS now excludes any mutual influence with the backbone network. The administration of these connections has been simplified, increasing the reliability and availability of all IP network services, especially the IPv4 multicast.

An inseparable part of the IP network services development is the provision of the Quality of Services (QoS) that includes – in addition to the necessary technical implementation – also the need to deal with many issues concerning the definition of an acceptable general framework of rules for applying the QoS policy to particular user categories.

The development of the CESNET2 NREN also covers the development and operation of the essential supportive infrastructure needed to maintain a continuous and reliable operation of the network and ensure support for projects and participants of NREN on the national and international levels (coordination and cooperation with the GÉANT network and other European NRENs).

The development and changes of the backbone network can be summarized into several points:

- Implementation of high-performance SUP720-3BXL processors in OSR7609 access routers in GigaPoPs, including the Internet peering routers. The SUP720 processors with their internal switching matrices boost the router performance up to 720 Gbps, supporting HW IPv6 routing and making installation of 40 Gbps interfaces possible in the future. The new IOS version in these routers offers extended features in the MPLS VPN technology area, QoS, and IPv6 multicast support (scheduled for 2005), which are necessary for further IP network properties development.

- Establishing a direct peering with the Polish academic network, PIONIER, via a Gigabit Ethernet, which allows independent peering of this network with the SANET network utilizing the EoMPLS technology.

- Simplifying the basic network topology and elaborating a design of a new generation IP/optical network architecture.

- Migrating the IPv6 unicast routing from the workaround solution based on dedicated 6PE C7500 routers to OSR7609 and completing the dual-stack IPv4/IPv6 topology in the MPLS network environment.

- Building the basic Prague–Brno DWDM line which is vital for the further development of the optical transfer layer as well as for migrating the backbone network to 10GE.

- Upgrading the main GigaPoPs in Prague and Brno to 10GE including replacement of inconvenient network core routers with new ones, supporting 10GE and other new features (e.g., IPv6 multicast).

- General increase in stability and availability of the network using the Cisco NSA services.

- Developing the necessary supportive infrastructure.

2.1 Backbone Network Physical Topology

The basic physical network topology (see Figure 2.1) employs leased pairs of optical fibres. Some of the smaller PoPs (e.g., Děčín, Cheb) are connected via a single fibre only, utilizing the available technology of MRV fast Ethernet converters. The remaining PoPs are connected to the backbone network with 10 Mbps and 34 Mbps radio circuits or leased circuits.

The basic logical topology of the backbone network comprises ten GigaPoPs interconnected through data circuits with transfer capacities of at least 10 Gbps

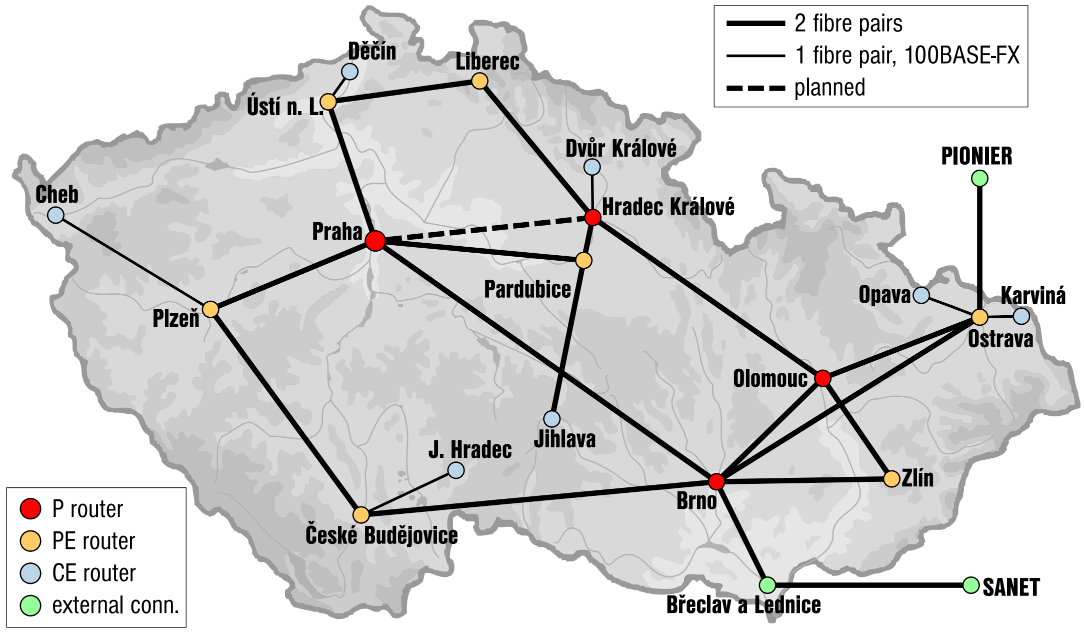

Figure 2.1: Physical optical topology of the CESNET2 backbone network

(see Figure 2.3). The backbone circuits utilize 10GE PHY LAN, 1GE (Gigabit Ethernet) and POS STM-16/OC-48 to provide transfer rates of 2.5 Gbps. GigaPoPs are connected to the backbone network always with two data circuits to provide for an access backup.

Optical circuits are fitted with various technologies. Gigabit circuits spanning over shorter distances (up to approx. 120-140 km) need no regeneration or amplification, enabling us to deploy replaceable optical transceivers (Pluggable Optics) in interfaces of routers and CWDM-1550 switches (superseding formerly used GBIC-ZX) and DWDM GBICs with 100 Ghz channel spacing in compliance with ITU-T (e.g., České Budějovice-Brno, 308 km with the EDFA amplification via Keopsys amplifiers).

In the field of new generation replaceable optical transceivers, we have started using also SFP (Small Form Factor Pluggable) GBICs that offer smaller dimensions and lower power consumption and will support extended optical parameter monitoring (DOM, Digital Optical Monitoring) within a greater range of operating temperatures (–5 to +85°C). However, these transceivers can be installed only in the appropriate new type of interfaces (they are not interchangeable with standard GBICs). For 10GE interfaces, we intend to perform the testing of DWDM Xenpaks for 10GE transfers via a DWDM system. A new generation of 10GE GBICs are the so-called XFP (Xenpak Form Factor Pluggable), however, these will be supported only by newer types of 10GE router interfaces.

Optical circuits with higher attenuations (more than 32 dB) are fitted with Keopsys optical EDFA amplifiers (preamplifiers and boosters). Some lines feature also L2 switches functioning as signal repeaters. Use of switches along an optical line is a cheaper fitting alternative, though its great disadvantage is its need to be placed on the line (installing the switch at a required location is not always possible) and protocol dependency (L2 Ethernet).

Using EDFA amplifiers located only at the ends of lines (NIL, Nothing in Line method) is therefore a preferred alternative. These amplifiers boost only the optical signal and are protocol-independent (Gigabit Ethernet, POS, etc.). In cooperation with the *Optical networks* activity, we test our own EDFA PC-based amplifiers (PC Light) as an alternative to commercially available EDFA amplifiers in the operating part of CESNET2. These amplifiers are installed in the 1GE circuit Prague–Hradec Králové where we also employ DWDM GBICs for the connected routers.

Migrating the backbone network to leased optical fibres is the basic prerequisite for building an optical transport network. A technology suitable for this is DWDM, allowing multiple optical channels to be operating within a single leased fibre and providing the means for integration with the existing IP network and migration to a backbone network combining IP services and optical services in future stages (using an appropriate control plane, such as GMPLS), including installation of optical switches for dynamically switching the optical transfer lines.

The first DWDM line was put into service by the end of 2004. The public tender winner was a solution provided by Cisco Systems based on a modular DWDM system, ONS 15454 (for the system description see *www.cisco.com*). When the line sections were measured, the DWDM deployment project had to be modified since the measured chromatic dispersion values did not match the original assumptions (e.g., negative values were measured in one section). The DWDM system comprises two end DWDM terminals (ET, End Terminal) with tuning-enabled 10GE transponders and three active elements needed to amplify and compensate for the dispersion along the optical line (see Figure 2.3).

The DWDM system installation allowed for increasing the capacity of the connection between the Prague and Brno nodes to 10GE. For the upcoming period, we plan expanding the DWDM transport system with additional sections, aiming to complete the main backbone optical ring (Prague–Brno–Olomouc–Hradec Králové–Prague) using the promising ROADM technology. The optical transport layer development includes also a proposal for establishing a connection with the GÉANT2 network on this level. The operation of the GÉANT2 network should be launched in the third quarter of 2005. However, it has not been made clear yet which solution will be chosen for the optical backbone of this network (DWDM system, SONET/SDH transport, or optical switches).

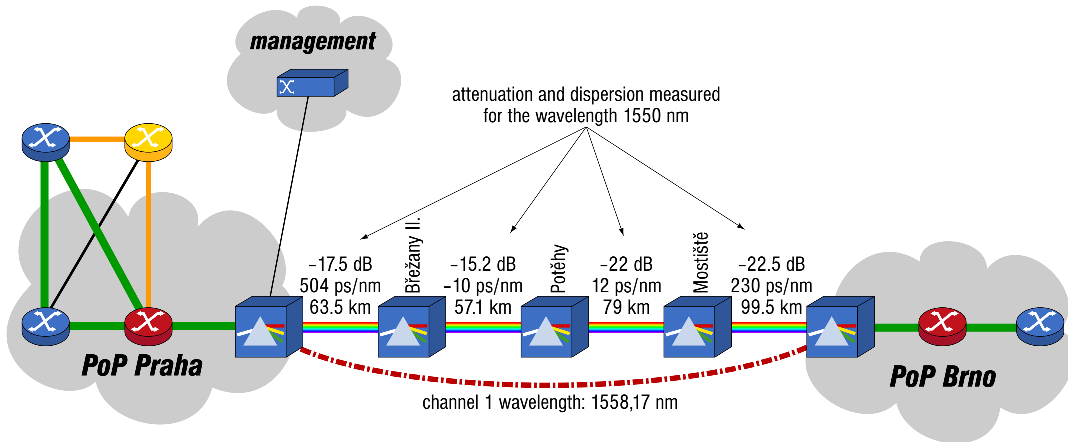

Figure 2.2: Equipment used on the Prague-Brno DWDM line

2.2 Backbone Network Logical Topology

The basic transfer protocol employed within the backbone network is IP/MPLS. OSPFv2 is used locally as the IGP protocol of the MPLS network. The actual network logical topology is divided into two functional levels to which the topology of each GigaPoP is adapted:

Core Backbone Level: The network core comprises the GS22016 and OSR7609 routers (marked red in Fig. 3) where all backbone data circuits are terminated. The new backbone network topology design, in compliance with the planned development of the DWDM network, preserves core routers only in the basic network circuit GigaPoPs (Prague-Brno-Olomouc-Hradec Králové-Prague). Besides, these routers need replacing with newer versions, since the GSR12016 no longer allows further network development (10GE, IPv6 multicast, jumbo frame support) and due to their inconvenient properties, their upgrade would not be financially feasible. We have therefore installed OSR7609 routers in the network core in the Prague and Brno GigaPoPs with sufficient technical/economical parameters (especially concerning the price per single 10GE port). The upcoming period will see the replacement of the remaining GSR12016 routers (in Prague, Olomouc and Hradec Králové GigaPoPs). We will also focus on selecting suitable routers with features that are better suited for the network core router requirements (with respect to the 10GE support, buffer memory capacities on ports, performance and stability).

Network Access Level: We utilize the Cisco OSR7609 (with high-performance SUP720-3BXL processors) as access routers and Cisco 7206-VXR with NPE-G1 as MPLS PE in smaller nodes (Ústí n. Labem, Zlín). These routers

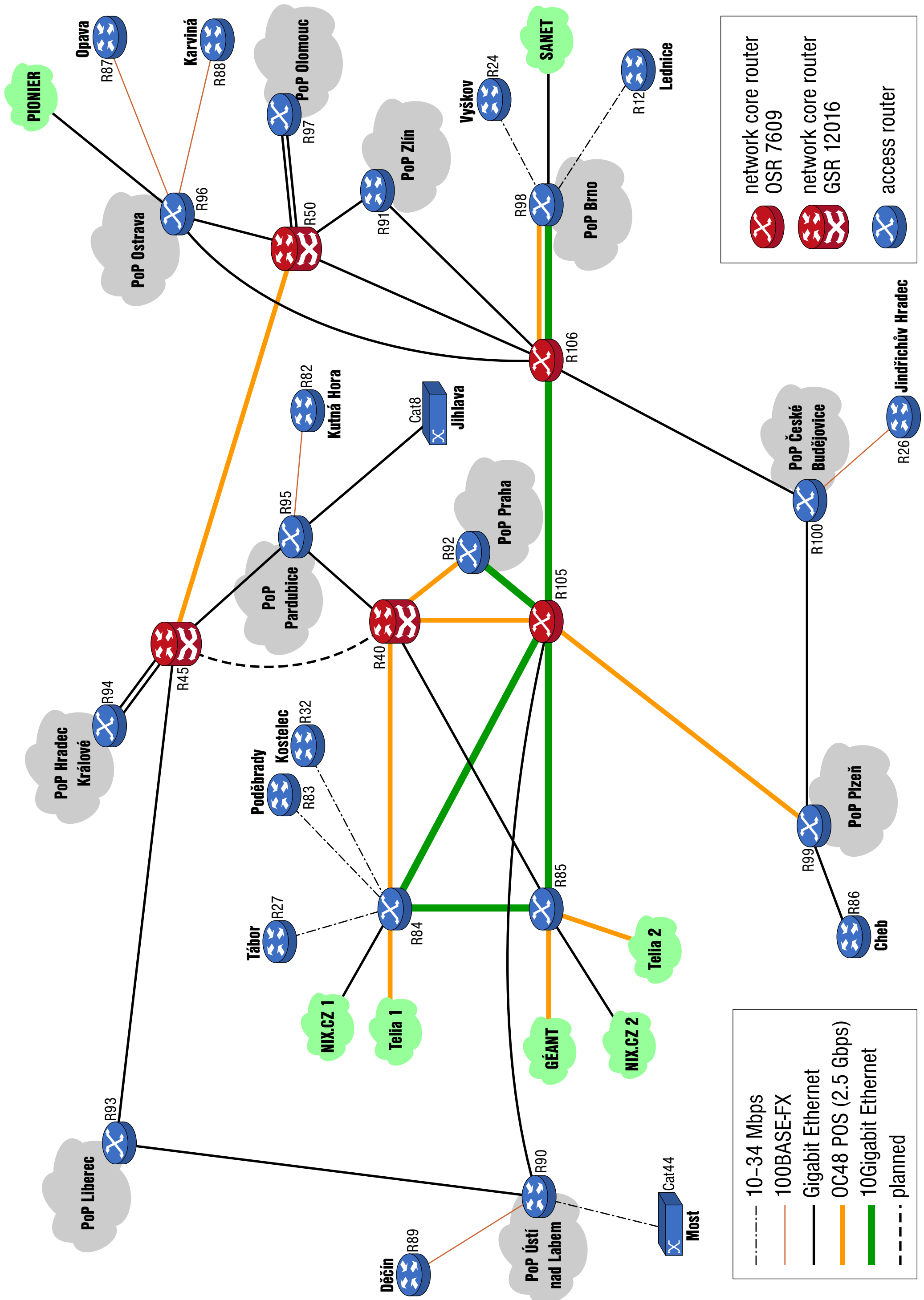

Figure 2.3: Logical topology of the CESNET2 backbone network

provide connected participants with all functions and services of the backbone network (MPLS, MPLS VPN, QoS, IPv4/IPv6 routing, IPv4 multicast, NetFlow statistics export, access filters). Academic metropolitan (Pasnet, BAPS, etc.) and university networks are connected via the gigabit Ethernet, while other participants and detached workplaces use lower capacities (10/100 Ethernet). The interconnection of access routers with core routers is ensured with 10GE LAN PHY, OC-48 POS, or 1GE.

Smaller network nodes (PoP) are connected to these access routers by 100 Mbps optical circuits (single-fibre connection), 34/10 Mbps radio circuits (conversion to 100BASE-T at circuit ends is used in case of 34 Mbps), and leased fixed circuits with smaller capacities. These nodes are fitted with smaller routers with limited functions (MPLS CE) from the C2621/C2651-XM/C2691 family that support only VRF Lite functionality. These routers are now being replaced with new L3 switches, Catalyst 3750, with parameters and features fully in compliance with the requirements of gigabit networks (10/100/1000 ports, 32 Gbps throughput, SFP GBIC support, IP routing, giant frame support). The IPv6 protocol has not yet been implemented in stable IOS versions. However, it is supported in experimental versions in the testing and verification of which we actively participate within the manufacturer's beta test program.

Logical topology of every node is divided into several parts: the service segment, the participants' connection, and the connection of testing segments. The service segment includes OOB access, VoIP gateway, UPS, and other service equipment and servers. Connection of participants is ensured through dedicated 802.1Q VLANs in the access router. VLANs are usually terminated in the participants' access routers; in some cases, VLANs are also used to create EoMPLS L2VPN within the backbone network (mapping of a given participant's VLAN to EoMPLS is employed here).

The MPLS technology enables us to create L3VPN and point-to-point L2VPN (in accordance with draft-martini-l2circuit-trans-mpls-05) within the entire backbone network. EoMPLS (Ethernet over MPLS) is used for L2 connections of detached sites. This connection method has an indisputable advantage if seen from the backbone network perspective, since the participant's traffic does not affect the L3 MPLS backbone (an example is the peering of the SANET and PIONIER networks ensured via the CESNET2 backbone).

The next network development stage assumes testing of features provided by the VPLS technology (Virtual Private LAN Services) in accordance with the PWE3 concept (Pseudo Wire Edge to Edge Emulation), when the MPLS network performs the function of a distributed L2 switch. The VPLS technology will be supported on deployed router types in 2005.

2.3 IPv4 Unicast Routing

As an internal routing protocol within the backbone network, we use the internal BGPv4 (iBGP) among access PE routers (see Figure 2.4). External R84, R85, and R98 routers contain RR1, RR2, and R3 route-reflectors needed to provide routing redundancy. Other PE routers are fitted with route-reflector clients. Use of route-reflectors lowers the necessary number of peers in the backbone network. Static aggregated blocks are used in GigaPoP access routers and no redistribution from internal routing protocols is carried out. Large metropolitan and university networks (PASNET, ČVUT, etc.) use their private autonomous systems and are connected to the backbone via the eBGP protocol. Preferred connections for smaller 3rd party networks are based on static routes.

2.4 IPv4 Multicast Routing

To exchange multicast (group-oriented transmission) routing information, we use the internal MBGP protocol. Again, iMGBP uses three route-reflectors in the R84, R85 and R98 routers. Unlike in the case of the unicast routing, route-reflector clients are configured in all P and PE routers, since proper RPF (Reverse Path Forwarding) functions must be ensured also in network core routers. RPF, as a part of the forwarding process, provides protection from loops or duplicated multicast packets. This inspection is provided in the backbone network environment by iMGBP (assuming that all multicast data sources are announced using this protocol).

The entire backbone network uses the PIMv2-SM protocol. We have considerably simplified the general multicast topology to leave only one central RP (IP 195.113.144.2) in use in the R85 and R98 routers where redundant AnyCast RP topology is implemented. Large metropolitan and university networks now operate their own RP (within an independent multicast domain) and active multicast data sources are announced with the MSDP protocol. Other connected participants can make use of the central RP where the dynamic protocol (Cisco Auto-RP or BSR) announcing has been cancelled. These participants must configure the RP address statically in their access routers.

The existing logical multicast topology is incongruent (unicast is transferred via MPLS whereas the multicast transfer lacks the MPLS labels). Filtering of announced active sources and groups is also carried out in all nodes on the MSDP level in compliance with the recommendations of Cisco and the GÉANT2 network (restricting operation of the Novell NDS, ImageCast, and other services utilizing the multicast, which are not intended for announcing to the backbone network and MBone).

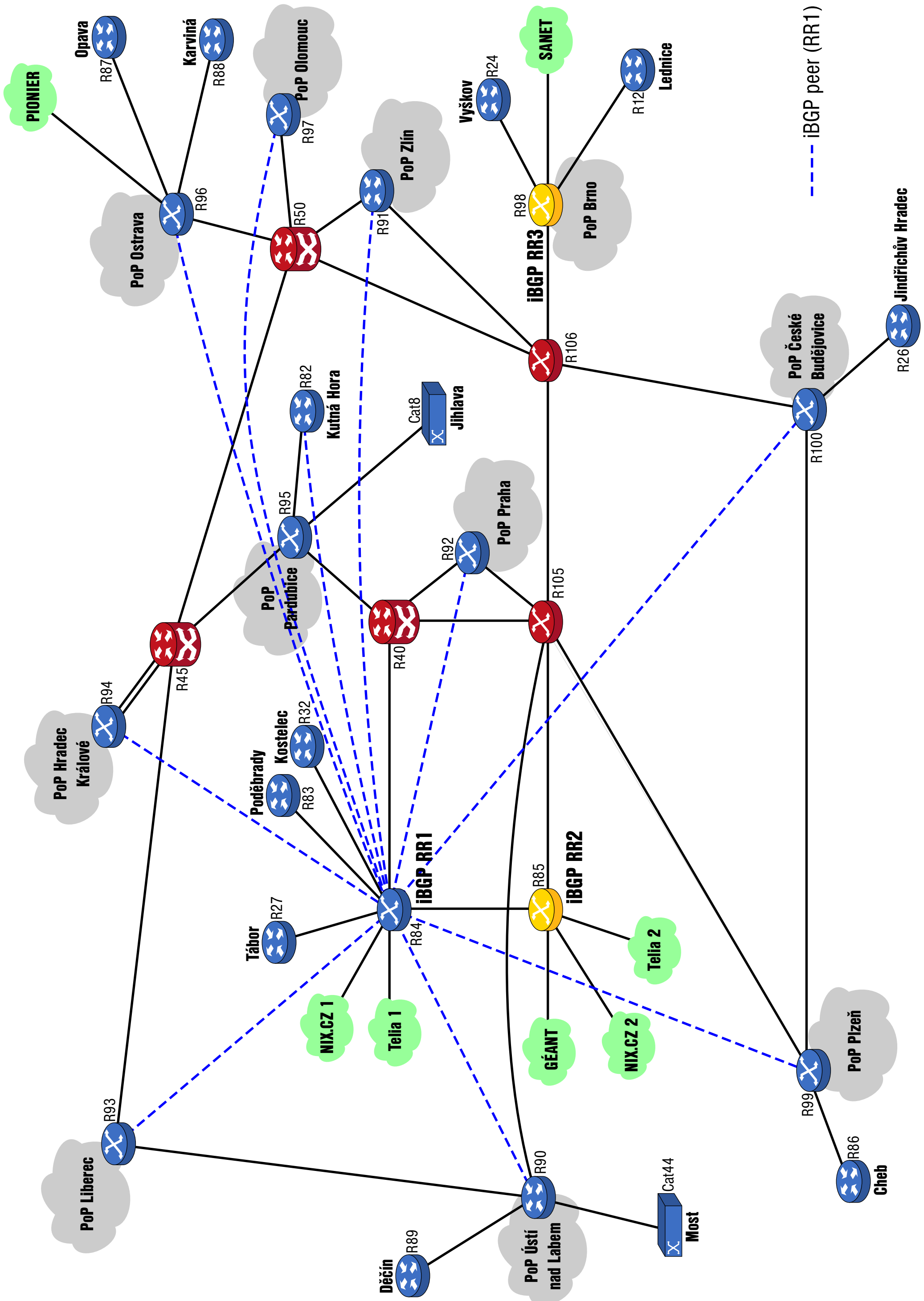

Figure 2.4: Internal unicast routing (example of the RR1 route-reflector in R84)

The current solution of the multicast distribution in the backbone network supports also SSM/IGMPv3 (Source Specific Multicast) that uses a reserved IP range of 232.0.0.0 0.255.255.255 and does not require RP to operate.

In addition to the traditional allocation of multicast addresses using dynamic protocols such as SDR (SAP), these addresses can be allocated statically in accordance with RFC 2770 based on the AS number. The given mechanism implies that our AS2852 has a corresponding range of public multicast addresses of 233.11.36.0/24 from which addresses are allocated.

2.5 IPv6 Unicast/Multicast Implementation

Deploying new SUP720-3BXL processors that support hardware IPv6 transfers in OSR7609 access routers allowed for converting the temporary IPv6 solution with dedicated 6PE C7500 routers to access routers. The backbone network now supports the dual-stack IPv4/IPv6 unicast routing via MPLS (PE/6PE). The participants using IPv6 are typically connected by a dedicated 802.1Q VLAN since most participants do not support dual-stack in their networks.

The IPv6 multicast is not currently supported. Results of our laboratory testing are used to prepare a workaround solution for which we will utilize the original solution with 6PE C7500 routers. We will use IPv6 multicast tunnels among these routers for the multicast distribution. Our alternative solution will be implemented in the beginning of the second quarter of 2005. IOS versions supporting the IPv6 multicast for OSR7609 access routers will be available by the end of 2005.

2.6 QoS Implementation

Implementing the QoS (Quality of Services) within the NREN environment has the following objectives:

- Define a simple and consistent QoS policy operating framework for the CESNET2 network to be applied to connected organizations and their users.
- Provide necessary support for the transit operation of CESNET2 networks with guaranteed QoS so that a general quality of services for end users of various DiffServ domains is achieved.

- Ensure full compatibility with the Premium IP QoS service as defined in the GÉANT network.

- Ensure high compatibility with other QoS services provided by the GÉANT network.

- Design a unified configuration model that could be used for all types of HW operated in the CESNET2 network.

The “point-to-cloud” type of the DiffServ model, using the E-LSP technique over the MPLS infrastructure, was chosen as a basis for the technical architecture needed to implement the QoS. If the capacity of the backbone network is not fully utilized, some QoS classes can make use of the remaining capacity as an addition to the minimum guaranteed bandwidth. We have defined the following service classes for various types of applications, depending on the bandwidth, latency and packet loss requirements:

- Premium IP (PIP)
- Network Control (NC)
- Gold IP+ (GIP+)
- Silver IP+ (SIP+)
- Best Effort (BE)
- Less than Best Effort (LBE)

Proposals for IP packets labeling using DSCP, mapping to the Exp field of the MPLS heading, and the bandwidth reservation for each class within the Exp-LSP MPLS/DiffServ CESNET2 domain are listed in the Table 2.1.

Service class	*PHB*	*DSCP*	*Exp MPLS*	*Bandwidth*
Premium IP	EF	EF, CS5	5	25 %
Net. Control	AF	CS7, CS6	7, 6	5 %
Gold IP+	AF	AF4x, CS4	4	30 %
Silver IP+	AF	AF3x, CS3, AF2x, CS2	3, 2	14 %
Best Effort	Default	0 (ostatní)	0	25 %
LBE	AF	AF1x, CS1	1	1 %

Table 2.1: Proposal of PHB, DSCP/Exp mapping, and bandwidth reservation for individual QoS classes

During our testing operation, we implemented QoS first in Plzeň and then in Liberec and Ostrava. The testing operation has taken place without problems and the QoS implementation in other nodes is scheduled for the beginning of 2005.

2.7 External Connections (Peering)

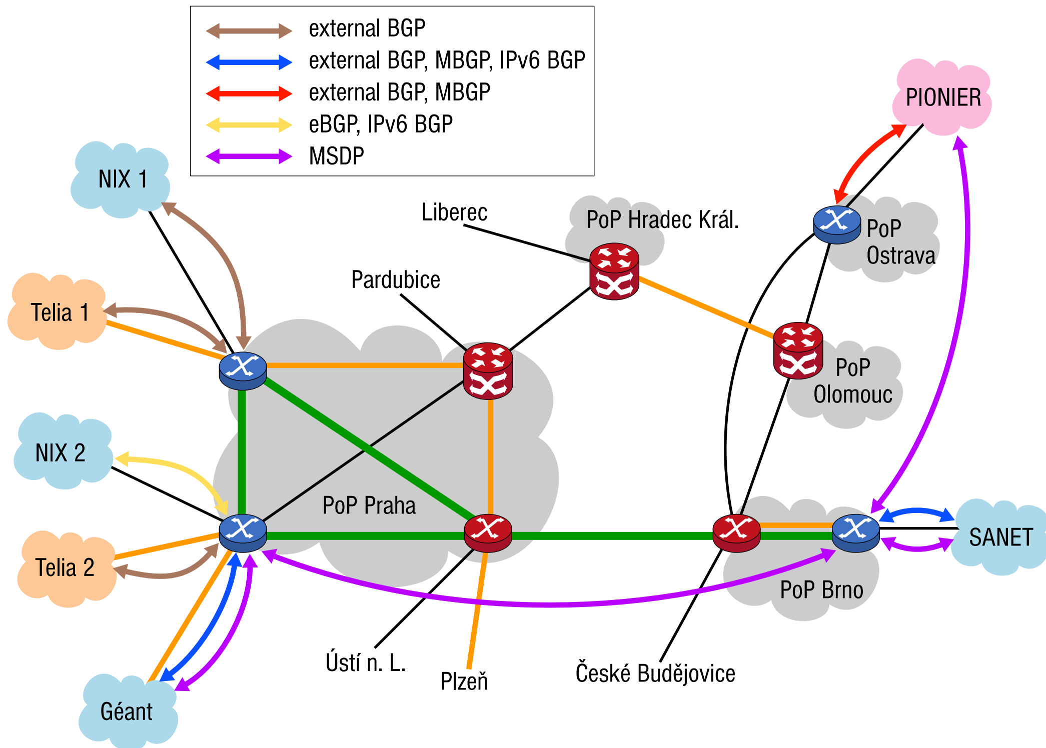

Figure 2.5: External peering of the CESNET2 network

The CESNET2 uses the following external connections and peering.

Foreign connectivity (commodity traffic): We are provided with the global foreign connectivity by the Telia International Carrier. The connection capacity is 2.5 Gbps (POS STM-16/OC-48 in R84) restricted to 800 Mbps. A backup connection is set up with another 2.5 Gbps circuit leading to the second router of the Telia node (R85 Internet peering router).

Connection to the GÉANT network: Featuring the capacity of 2.5 Gbps, the connection to the GÉANT network uses a local POS STM-16/OC-48 connection to a node located in the premises of the CESNET Association. The GÉANT node in Prague is connected to Germany (Frankfurt am Main) with a 10 Gbps circuit and to Poland (Poznan) and Slovakia (Bratislava) using two POS STM-16/OC-48 circuits. The GÉANT network provides IPv4 unicast/multicast and IPv6 unicast connections to European, American and Asian scientific & research NRENs and centres.

National Peering in NIX.CZ: Access to the NIX.CZ is provided via two GE circuits terminated in R84 and R85 Internet peering routers (load balancing and backup). Circuits are implemented using leased optical fibres and fitted with appropriate GBICs (GBIC-LX/LH and CWDM-GBIC on the second, longer line). The R85 router provides also a native IPv6 peering. As the total traffic to NIX is now exceeding 1 Gbps, we are planning to upgrade the connection to 10GE.

Peering with the SANET and PIONIER Networks: The interconnection with the Slovak academic network, SANET, uses optical fibres leading from Brno to Bratislava. The line is fitted with CWDM-GBIC-1550, using the Catalyst 3524 switch functioning as a repeater. The connection to the Polish academic network called PIONIER is also based on optical fibres, this time connecting Ostrava and Bielsko-Biala and fitted with CWDM-GBIC-1550. This line is shorter, measuring approx. 120 km, and hence no amplification is needed here.

To connect both networks, we employ the 802.1Q encapsulation. One VLAN is always used for the CESNET peering whereas the second VLAN is mapped to the MPLS L2 tunnel (EoMPLS) that allows direct L2 peering of these networks. The CESNET2 network in this case provides only the L2 transport service for these NRENs.

In addition to the mutual peering of our networks, we provide – within this connection – peering for SANET in NIX.CZ and vice versa, and the SANET network provides CESNET2 with peering in SIX. This saves foreign connectivity resources for both networks. Mutual announcing of networks to peering centers is based on BGP communities (tags).

2.8 Backbone Network Development Plans for the Upcoming Period

We are planning to expand the transport optical DWDM network to other nodes and to complete the basic DWDM ring if possible (see Figure 2.6) in 2005. In addition, we will test properties of the new ROADM technology as a means for creating optical channels within the DWDM system.

In connection with the optical layer development, we will continue also building the IP layer and migrating to 10GE. This migration will involve the deployment of higher-performance routers in the network core and the addition of the 10GE interface to access routers. The deployment of new routers is crucial for the future development of network properties, in particular:

- Support for jumbo frames, i.e., transfer of 9 KB data frames within the entire network and connection to the GÉANT network
- IPv6 multicast implementation
- Upgrade of GigaPoPs to 10GE

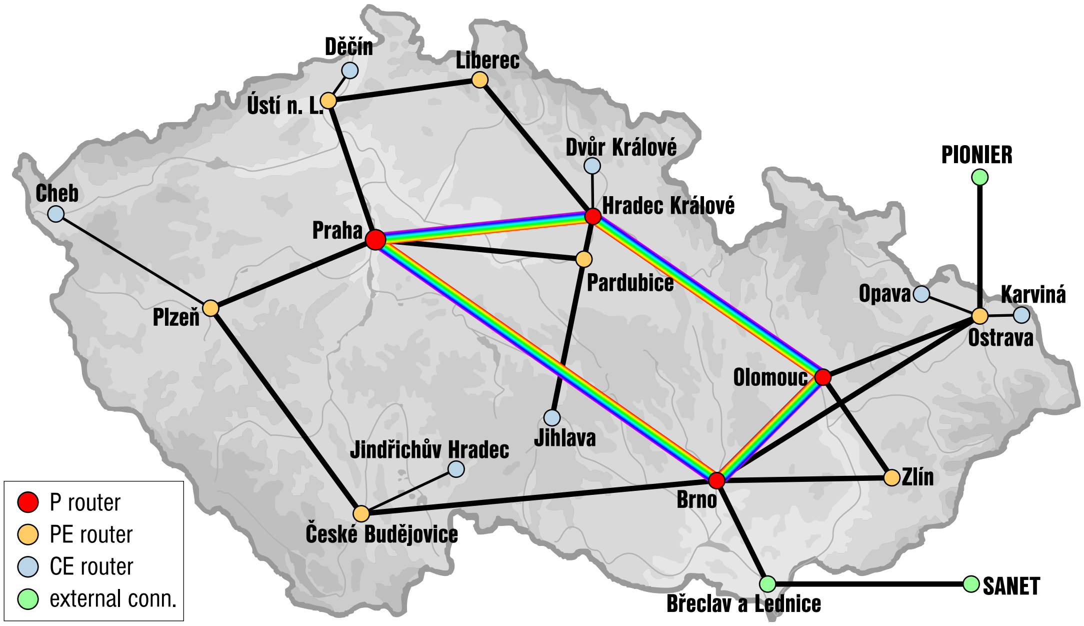

Figure 2.6: Planned DWDM development in 2005

We also assume reaching full QoS implementation and QoS compatibility with the GÉANT network, which is needed to provide QoS services in the international scope.

As far as new protocols and features are concerned, we will concentrate on testing and deploying the IPv6 multicast. Initially, a workaround solution will be implemented, with migration to backbone routers to be performed later. We will also continue developing the MPLS technology in the VPLS area (Virtual Private LAN Services) and MPLS QoS.

During the year, we will perform necessary upgrades of connection capacities for the foreign connectivity and the connection to NIX.CZ (to 2×10GE). An important task will be to establish a connection to the newly created pan-European research network GÉANT2 which should be put into service in the second half of 2005, with a capacity of at least 1×10GE, and to ensure the compatibility of this connection (in the area of IPv4/IPv6 unicast/multicast and QoS implementation) as well as the connection on the optical level in future stages.

3 Optical Networks

3.1 Objective of the activity

In 2004, the *Optical Networks* activity was focused mainly on the CEF (Customer Empowered Fibre) network research and development and on cooperation on the global experimental lambda infrastructure GLIF (Global Lambda Integrated Facility) research and development. Within this activity, we were dealing with:

- acquiring suitable optical fibres,
- methods of data transmission via CEF networks,
- transmission facilities for CEF networks,
- feasibility of free space transmission at speeds of 100 Mbps and more for the first mile,
- realization of the CzechLight experimental network for the access to GLIF and GN2 testbed,
- cooperation on development of new applications using GLIF.

We paid special attention to low-cost technologically advanced facilities which should enable extending the CEF networks, increasing the number of endpoint workplaces and their gradual deployment in developing countries.

Within the scope of the activity, the CESNET Association became a research workplace which also supports development of foreign CEF networks. Supporting the CESNET2 CEF network had become commonplace in the *Optical Networks* activity. Making GLIF accessible for all those workplaces in the Czech Republic that are able to participate in relevant international application projects and experiments, as well as its use as a national testbed for further international research cooperation (e.g., in the GN2 JRA4 where a new international fibre and lambda testbed is being built), are the long-term goals of the CzechLight network realisation.

The research results are being verified and used both in laboratory environment and in wide-area experimental networks, and later also in production networks (e.g., CESNET2, AMREJ, and GN2). In some cases we found out an advantage of passing from a common commercial relationship with fibre lessors (when one must be able to specify one's requirements of fibre lease and to acquire offers at acceptable prices) to a collaboration in the research and development field, which allows acquisition of optical lines of hyper-standard quality, frequent experiments on the line setup (e.g., changes of length and parameters of test lines, changes of the G.652 and G.655 fibre length ratio), testing an equipment developed for in-line use, etc.

The research team collaborates on the verification with network designers and operators in various countries, with widely varied conditions. The activity involves the participation in the EU project *GN2 – Multi-Gigabit European Academic Network* (the SA1, JRA3, and JRA4 activities) and in one grant project. Making ready for participation in the EU *SEEFIRE* project, the *CzechLight Extension* international project (R&D collaboration with a hardware supplier) and participation in another grant project is another result of the 2004 work.

The GN2-SA1 *Procurement* activity brings new routes and technologies for the GÉANT2 pan-European production network. The GN2-JRA3 activity researches the current state and further development of the Bandwidth Allocation and Reservation Service (in other words: "Bandwidth on Demand", BoD) in its connection-oriented end-to-end version.

The GN2-JRA4 research activity gathers knowledge about new network-building concepts and about interconnection of European national test networks, as well as testing new transmission technologies.

A goal of the EU *SEEFIRE* project is a study of network infrastructure availability and possible strategies in regional NREN development in south-eastern Europe. It should help involve those countries in the eInfrastructure community and increase their technological competence to cooperating internationally. The technical core of the work is the preparation of long-distance and international dark fibre connections and selecting low-cost advanced technology for lighting them.

The *CzechLight Extension* international project prepares the extension of the CzechLight experimental network both in the geographical and functional senses. Transmission and switching Cisco equipment for CEF networks will be developed and verified with the manufacturer's support and their applications will be tested within the project.

A grant of the Grant Agency of the Czech Republic, started in 2004, is focused on *Optimizing the data transmission at 10 Gbps over G.652 fibres with respect to maximum transmission distance without deploying in-line EDFAs.* A newly acquired grant of the Information Society programme targets the *TDM-pumped Raman fibre amplifiers.*

3.2 Supporting the CEF network development

In 2004, the *Optical Networks* activity started supporting development of foreign CEF networks. This support is usually based on the principle of mutual advantage. The EU (*SEEFIRE* project) supports us to faster deploy the project results in south-eastern Europe in 2005. This activity has also selected the program of the *CEF Networks* seminar attended by many international participants and has established the international mailing list for its participants. Besides, collaboration of the activity research team on acquiring fibres and verifying transmission systems for the CESNET2 network has become commonplace.

Independently, the leader of this activity was asked in January 2004 to give an overview lecture on deploying dark fibres in European NRENs at the *TERENA Networking Conference 2004;* he also became a member of the GN2 Procurement committee project. Within the frame of the GN2 preparation, the activity research team won the leadership of the *Technology testing* task in JRA4 and became an important part of JRA3.

At the *Customer Empowered Fibre networks* seminar which took place in Prague on 25th and 26th May 2004, 46 participants from 20 European NRENs, Canada and the USA took part. 17 lectures were presented about the CEF network deployment in the participants' countries and about the most important trends in this area. It has been found out that the results and concepts of the *Optical Networks* activity project team belong to the most advanced all over the world in the relative fibre deployment scope and in the use of advanced transmission equipment. A large number of participants appreciated the organisation of the seminar and they expect us to continue.

The CEF networks are characterised by the fact that it is their users themselves who operate them. These users only rent a fibre (alternatively, they have it laid) and they themselves acquire the hardware which transmits data over the fibre. Thus, they have the fibres – or a right to use them – and at the same time, they choose the way of building the network (especially its optical transmission system) and network management. As the users of customer empowered networks, often an R&D workplace staff, have specific requirements of transmission parameters and prices, the CEF networks are "tailor-made" according to the actual user needs.

The seminar participants came to the conclusion that the CEF networks are now successfully implemented in several countries, including the Czech Republic, within the NRENs. They also recommended further international cooperation which would mainly focus on continual exchange of the following information on the CEF networks in near future:

- experience of acquiring and deploying dark fibres within NRENs (National Research and Education Networks),interconnecting the NREN nodes close to national borders using dark fibres,
- a building kit of transmission equipment and a CEF network design cookbook,
- reference to emerging transmission technologies, equipment for fully optical networks, etc.,
- advanced transmission systems for long-distance optical lines,

- feasibility of PC-based WAN CEF networks, design of custom-made transmission equipment for CEF networks using optical modules and programmable hardware,
- possibilities of sharing very long dark fibres between several NRENs, DANTE, Internet2, Canarie, research institutions and other non-profit organizations (shared using, e.g., the lambda services),
- near future of CEF networks,
- other topics important for CEF network design and deployment.

At the seminar, a discussion took place about the feasibility of building the GN2 pan-European production network as a CEF network, which has turned out to be very important for further development of the GN2.

Currently, CESNET is probably the most important organization worldwide in the sphere of long-span CEF optical network design and operation. This is the result of some four-year development supported also by the former and current research plan, by universities, the Academy of Sciences and by almost all of the dark fibre owners in the Czech Republic.

As one of the first organizations, CESNET took over the development of CEF networks rather early – at a time when this trend was hardly supported by anyone; in 1999, CESNET prepared a 323 km, 2.5 Gbps route Prague-Brno using leased optical fibres and started its operation in February 2000. As a result, gigabit transmission lines of the CESNET2 production network consisted not only of leased dark fibres terminated with transmission equipment maintained by the CESNET staff, but also of leased gigabit transmission services maintained by telecommunication operators. It was found out that leasing the dark fibres should be strongly preferred for cost reasons. Moreover, using one's own transmission equipment brings about very important advantages concerning the future network design and management. These networks offer not only the "best effort" services but also those needed for real-time applications (connection of distant expensive or unique research equipment, remote presence, remote collaborative environment, etc.).

Since 2002, intensive efforts have been made to convert the Czech Republic CESNET2 NREN to dark fibres. In contrast to other contemporary CEF networks worldwide, we opted to significantly decrease the number of regenerators and amplifiers which are connected to dark fibres in the field in so-called huts. As a result, instead of commonly used fibre lines with spans between huts of some 80 km, very long fibre segments of 150–200 km or single-span lines of about 300 km are deployed. This hut-skipping technology reduces the operational costs and is very important if lack of highly-qualified optical staff prevails. Consequently, the architecture of NRENs (placing the points of presence within university premises) as well as of other CEF networks can be adapted to minimise the number of huts used.

In 2003, CESNET started to cooperate with the supplier to build optical fibre first-mile lines. The conversion of the CESNET2 production network to customer empowered dark fibres was mostly finished in 2003.

By December 2004, CESNET was using 3,828 km of dark fibres, including 3,310 km within the CESNET2 production network; no domestic gigabit service from telecommunication operators has been rented. Most of these fibres are lighted as long-reach circuits. CESNET operates six single-fibre long-distance lines (over 350 km in total) at transmission speed of 100 Mbps, suitable especially for connecting smaller network nodes. International 1GE dark fibre line Brno–Bratislava for the Slovak NREN SANET connection and 1GE dark fibre line Ostrava–Bielsko-Biala for the Polish NREN Pionier connection are operational.

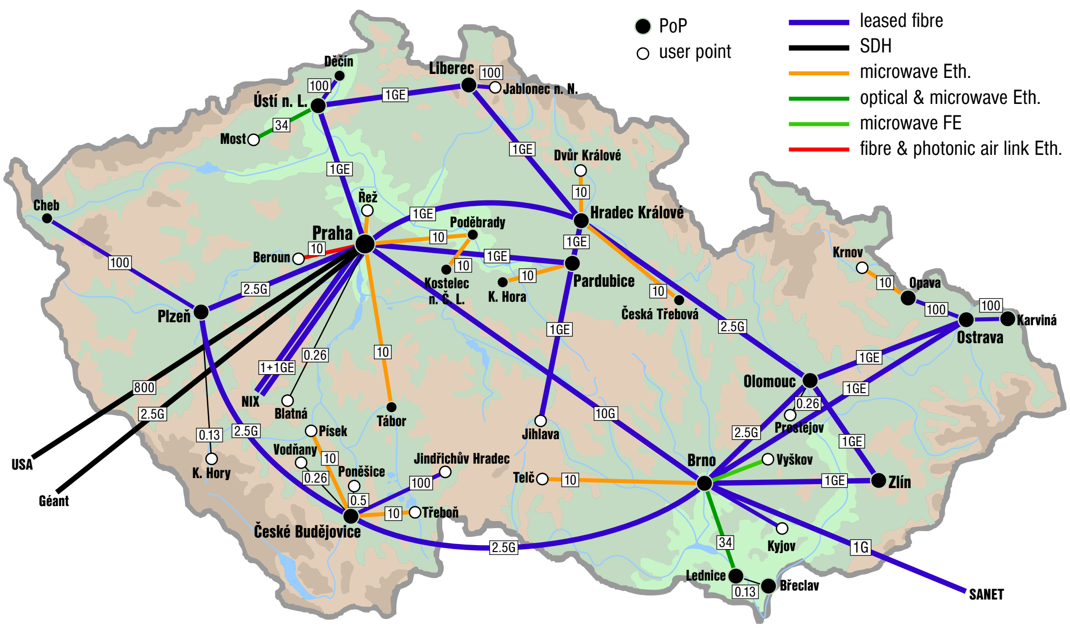

Figure 3.1: Topology of the CEF CESNET2 network as of December 2004

3.3 Supporting the experimental network access and use

GLIF is one of the most important global activities within the networking research and development. Participation in it is essential for the position of the Czech research in the world (50 most important world professionals chosen by the founding organisations participated in GLIF research negotiations). Correspondingly to the GÉANT2 hybrid network and GN2 testbed construction and in harmony with GLIF strategy we suppose that GLIF will not compete with any kind of service offered by these networks but it will investigate more advanced applications and global experiments.

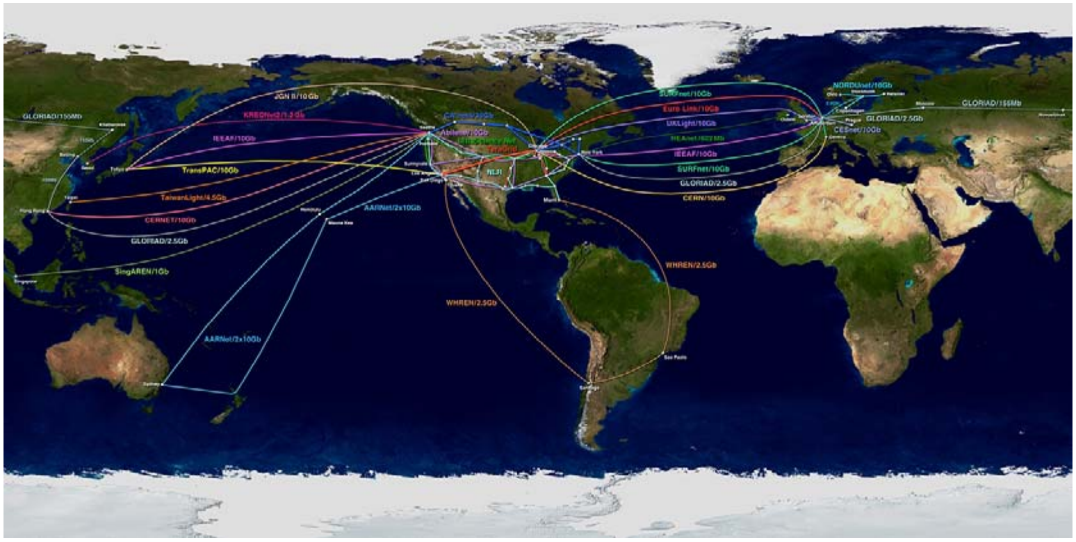

Figure 3.2: Global Lambda Integrated Facility

The Prague-Amsterdam GLIF lambda connection over the Dutch NetherLight experimental network was at 2.5 Gbps speed since 2003. The access was upgraded to 10 Gbps on 1st September 2004 – at a time when NetherLight changed from Cisco switches to Nortel switches. Despite this change, the connection worked well. The position of CzechLight within the GLIF network (and consequently within an American TransLight node) thus reached an adequate level; the possibilities of international experiments widened and the interest for the cooperation with the Czech Republic abroad increased. The results were presented at the world GLIF meeting in Nottingham in September 2004.

The CzechLight network is used for GLIF access and as a testbed for further tests and for accessing other networks (e.g., the GN2 testbed). The use of CzechLight therefore is and will be of the same character as the use of GLIF and testbeds: enabling the experimental development of networking and development of new and more advanced applications in the way which is unacceptable for production networks or at a time when it is not yet possible with production networks.

For the users from various branches of research, the CzechLight experimental network makes possible qualitatively new solutions of their requirements and needs which emerge during scientific and research cooperation. In the Institute of Physics of the Academy of Sciences of the Czech republic (FZÚ) in Prague 8 (Na Slovance 2), the *Regional Computing Centre for Particle Physics* was established. The Centre was opened on 1st November 2004. It provides computational

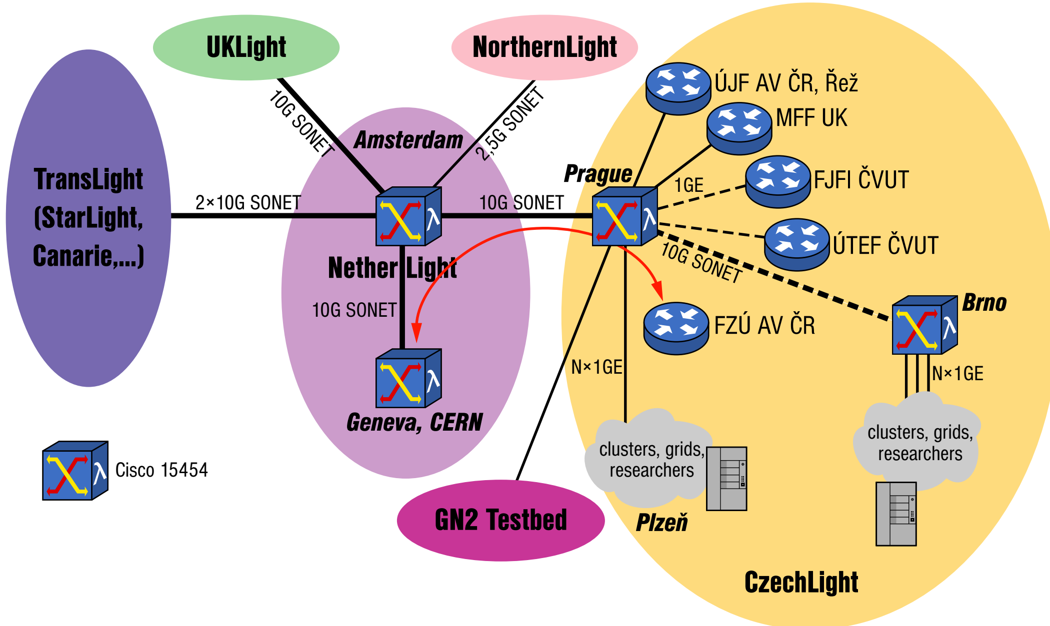

Figure 3.3: CzechLight network

and storage capacity for demanding calculations for the D0 experiment on TEVATRON accelerator in FERMILAB and for the ATLAS and ALICE experiments on LHC accelerator at CERN which is under construction. Among the cooperating workplaces in Prague are the Faculty of Mathematics and Physics of Charles University (MFF), the Faculty of Nuclear and Physical Engineering of the Czech Technical University Břehová 7 and Trojanova 13 (FJFI), the Institute of Technical and Experimental Physics of the Czech Technical University (ÚTEF) and the Nuclear Physics Institute of the Academy of Sciences of the Czech Republic, Řež (ÚJF). Realization of the CzechLight access for these institutes is under way. So far, we have connected three of them by means of dedicated dark fibres (ÚJF, MFF, FZÚ). The connection tests have been successfully carried out at all the institutes. In collaboration with the CWDM project of the CESNET Development Fund, the GE lambda connection over PASNET for FJFI Břehová is already prepared using the FWDM mux/demux technology for 1310 and 1550 nm wavelengths. By the end of 2004, after the rest of technical transmission equipment is delivered, the interconnection of the workplaces will be tested as one unit. The ÚTEF and FJFI Trojanova will be connected in the beginning of 2005. Next important step from the viewpoint of application development is to set up another optical connection from the above-mentioned institutes to other important international centres – e.g., RAL in England, FNAL in the USA, TAIPEI in Taiwan, etc.

The particle physics applications belong to those in the world which initiated the creation of lambda networks and hybrid networks and they are also one of the first to use the CzechLight. Of course, the intention of CzechLight use is much

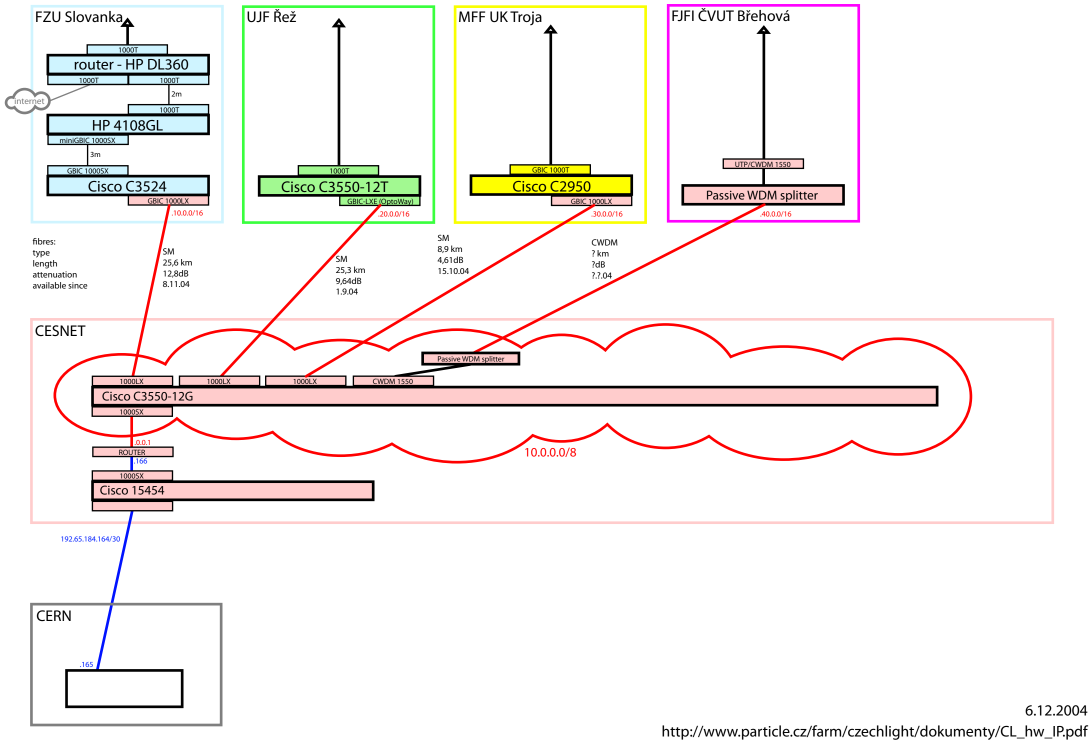

Figure 3.4: Current connection of particle physics workplaces to CzechLight

broader. Within the Optical networks activity, we now offer collaboration on the CzechLight connection to groups from various fields when they are preparing applications needing the GLIF. During the realization, direct participation of the application researchers in the Optical networks activity or collaboration with another activity or another project organised by CESNET – according to the situation – is essential. Several first applications are thus of pilot character and they will be used as an example for other applications.

An application or its part may later move to the production network if it is necessary (e.g., because high availability is required) and feasible. Having the first mile solution – e.g., connecting the workplace over optical fibres which are now realized for the CzechLight connection – will be necessary even at a time when deploying the international and national transmissions at 10 Gbps and more over hybrid production networks providing lambda services is possible.

The accessibility of GLIF and CzechLight for applications depends on manual planning and resource allocation now. Although the resource allocation (mainly of transmission capacities) will later become programmable and therefore also faster, it will be generally considered as a time-limited allocation. But at the first stage of development, it is usually more than sufficient.

In 2005, the work on making the CzechLight accessible in the Czech Republic will continue for experiments on computer networks (such as international transmissions for the 6NET project), for experimental data transfers in the field of particle physics, for interconnecting the super-computer clusters, for remotely operated experiments and measurements and for accessing costly equipment (first tests on accessing the Spirent AX/4000 generator/analyzer with 10GE ports have been carried out), for medical projects and other applications. The aim is to connect all research workplaces capable of testing the use of lambda services for their international collaboration but unable to do this without the CzechLight. It will also be used for national GN2 testbed expansion within the GN2 JRA4 framework.

To make the CzechLight connectivity accessible in Moravia, its Brno node will be complemented by a 10GE switch. Its connection to the Prague node still has several variants: the suppliers of Prague–Brno fibre line will either manage to lower the attenuation to the 65 dB they promised, or the transmission error rate will be lowered by our using more sensitive receivers and filters, or we will use one in-line optical amplifier in each direction. Other workplaces in Bohemia will be connected with GE or 10GE using fibres from Prague (fibres to Plzeň have already been prepared). Moravian workplaces will use fibres from Brno.

3.4 Methods of data transmission over CEF networks

We focused on 1 Gbps (1GE) and 10 Gbps (10GE, SONET/SDH) NIL transmission testing in particular. Using CWDM GBIC, we successfully transmitted two 1GE channels over 325 km with sufficient margins. During these experiments we used an EDFA booster, Raman fibre amplifier and optical tunable filter for channel separation and noise suppression.

We extended the 10 Gbps experiments by testing 10 Gbps DWDM SONET Cisco ONS 15454 equipment. Transmission over a 290 km G.652 fibre is an important result of this testing. In this configuration, we used the following equipment: EDFA booster, Raman laser, two EDFA preamplifiers, four optical filters, and four DCF modules altogether.

Further tests were performed on G.655 fibres which we acquired in May 2004. With these fibres, the maximum distance was 290 km as well. In contrast to the G.652 link, using only one EDFA preamplifier, three filters and one DCF module was sufficient. Last group of tests was performed on a combination of G.652/G.655 fibres which has a considerable practical importance. Some lines for both CESNET2 and CzechLight networks are composed of these fibres. The most important result is an error-free 302 km/65 dB transmission where 10G DWDM SONET line cards were deployed and the line was composed of a 50 km

G.652 and a 252 km G.655 section. The maximum distance when the ONS 15454 system was still operating was 313.4 km/67 dB but in this case, the bit error rate was too high and unacceptable for practical deployment. One of the most important findings from our testing the G.652 and G.655 fibres is as follows: the best properties of any line with regard to maximum transmission distance were reached when both ends contained at least a 15 km G.652 fibre section. The reason is a larger effective cross section and the resulting possibility of launching higher optical power. On the other hand, the G.655 fibre is preferable due to smaller chromatic dispersion. All these results were utilized for design and deployment of a 10G CzechLight line from Praha to Brno.

International cooperation started especially with colleagues from the Irish and Slovenian NRENs who expressed a serious interest in deploying optical amplifiers which are being developed in CESNET, and in deploying 10 Gbps NIL transmission.

We also continued our experiments in 10GE signal transmissions (Cisco Catalyst 6503) and we were able to overcome a line length of 287 km (the line consisted of 202 km G.655 and 85 km G.652 sections). We have also successfully tested the transmission of 2×10GE on this line where the maximum distance, when composed exclusively from the G.652 fibre, was limited to 252 km. A significant improvement is expected from deploying the DWDM XENPAKs where the receiver sensitivity is higher than that of 10G DWDM SONET/SDH line cards.

Figure 3.5 demonstrates the possibility of covering the Czech Republic territory using the Cisco ONS 15454 system and NIL method. It is obvious that the most important line Praha–Brno remains the biggest problem.

We were able to start the experiments in the 1310 nm band amplification thanks to the loan of praseodymium amplifier (PDFA) from FiberLabs and later purchase of two samples. Exploiting a very low chromatic dispersion of G.652 fibres in this band, especially for bit rates of 10 Gbps (and higher in the future), will bring advantages. With NIL concept in mind, we extended the transmission distance for 10GE XENPAK modules from 40 km up to 120 km, for 1GE LXE GBIC transceivers from guaranteed 30 km up to 125 km. With one inline amplifier, the maximum transmission distance increased up to 160 km, or 175 km. In addition to PDFA, we have also tested other amplification techniques in the 1310 nm band. We used a Raman fibre laser to counter-directionally pump the transmission fibre to obtain the distributed Raman fibre amplifier. Deployment of Raman amplification in the 1310 nm band is relatively new, we found only one vendor of this technology. It is important to keep in mind that the attenuation of a 160 km G.652 fibre is approximately 60 dB. We have plans to test 1GE with DFB lasers (longer transmission distances are expected) and above all other 10GE adapters (S2io, Chelsio) which are available with 1310 nm transceivers only. One Czech operator has shown particular interest in these results.

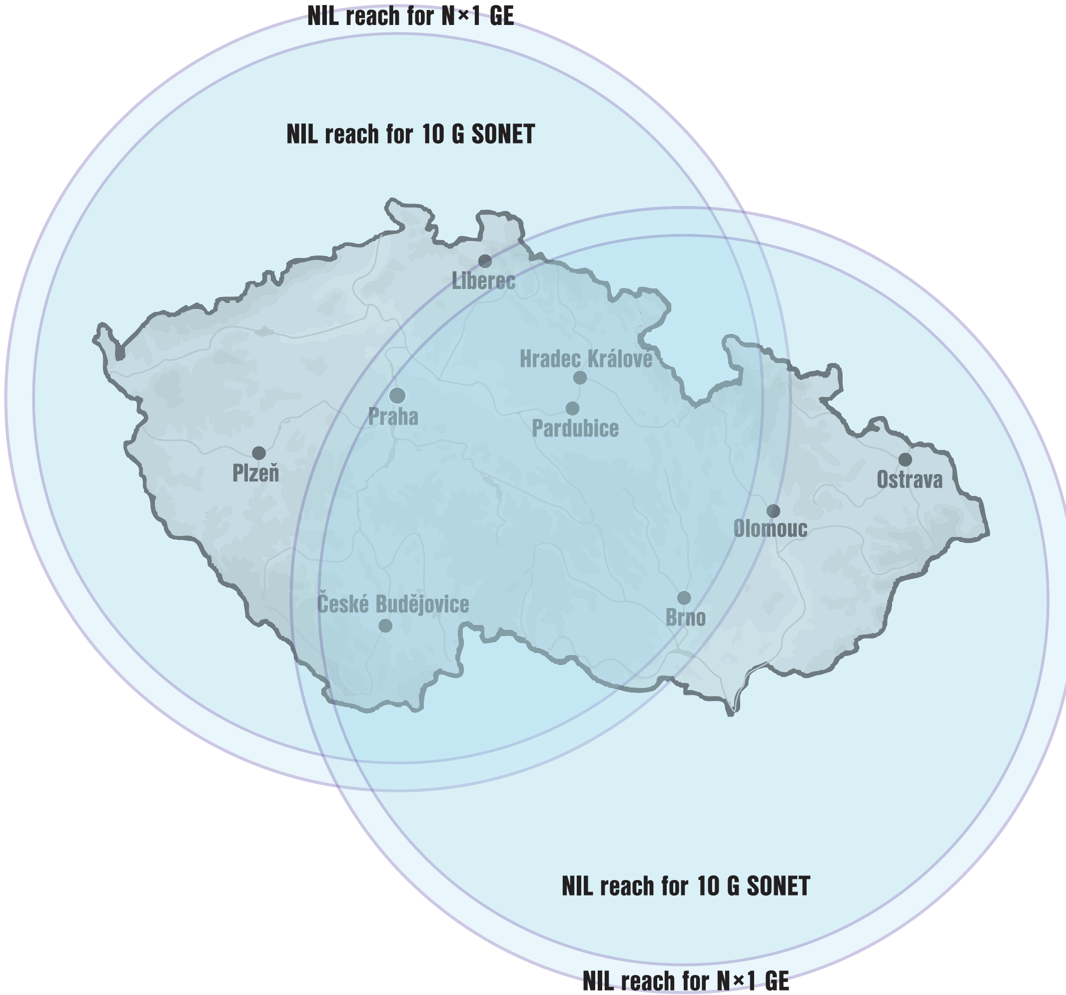

Figure 3.5: Coverage of the Czech Republic using Cisco ONS 15454 in NIL deployment

We investigated, both theoretically and experimentally, the possibility of stabilizing the gain in a cascade of three Raman fibre amplifiers. We have been using an eight-channel DWDM test system purchased from grant resources of the GA ČR project. Simultaneously, we started theoretical analysis and experimental verification of broadband time-division multiplex pumped Raman fibre amplifiers optical characteristics. The ÚRE AV ČR institute in cooperation with CESNET succeeded in obtaining a project within the framework of Information Society programme. Results of these projects will be used in future building of fibre networks and, possibly, also in the GÉANT2 and SEEFIRE international projects.

We applied the acquired theoretical and practical experience particularly to the extension of the CzechLight network. The point of presence in Brno was established in planned configuration with its 10 Gbps connection to the point of presence in Prague and realised as NIL but the actual error rate of this link is intolerably high. The main reason is the high attenuation of the line. The attenuation promised by the fibre provider for this line of 298 km composed of G.652+G.655 was 65 dB. At the time of handover, the attenuation of the line was 74 dB and after several adjustments by the lessor, current attenuation is about 67 dB. A laboratory line with the attenuation of 65 dB (302 km fibres on spools) used for data transmissions at 10 Gbps worked error-free. The lessor promised to further reduce the attenuation of the line and another improvement can be done on our side, too (tunable fibre gratings for compensating the chromatic dispersion, low-noise amplifiers based on the PC Light, improved optical filters for noise suppression).

The results of our research in this area were published at international conferences and in prestigious journals. A full list can be found in the Annex of this publication.

3.5 Transmission equipment for CEF networks

Within the PCLight activity, a prototype of fully remote-controlled optical fibre amplifier PCLight 2in1 was constructed as a part of PC-based network equipment called PC Light.

The core of PCLight 2in1 equipment is an EDFA module containing two amplifiers. The first is designed as a booster amplifier and the second as a pre-amplifier with a very low noise figure. Thanks to this construction, one can use the PCLight 2in1 amplifier on lines where optical amplification of the signal behind the transmitter and in front of the receiver is necessary, and this is possible both on single-end amplified shorter lines as well as on longer lines, including those with chromatic dispersion compensation. During the laboratory experiments with this amplifier, overcoming a distance of 225 km of G.652 fibre using just a booster at 1GE signal transmission, and distance of 300 km using both the booster and pre-amplifier was possible. At coincident fibre pumping by a Raman laser, the reachable distance has increased to 325 km. The PCLight 2in1 amplifier was successfully deployed in testing operation on a CzechLight 1GE experimental line Prague-Plzeň (length 159.4 km, attenuation 36.7 dB). It was also tested on a CESNET2 production network line Prague–Hradec Králové (150.4 km, attenuation 35.69 dB) which is being prepared.

Positive response not only from inside the CESNET organization led us to develop a new version which will use two EDFA modules in one case of 1U height. It will provide significantly higher reliability parameters thanks to a backup power supply, GSM modem for out-of-band management and important operational parameter monitoring (optical power outputs, power supply voltages, amplifier and power supply temperatures, fan rotational speed). The prototype is nearly finished, we are only waiting for replacement of supplied defective power sources.

Two types of PC 1GE LAN adapters for PCI-X bus have been developed for simple and economical connection to experimental networks (e.g., the CzechLight). The first type uses standard two-fibre CWDM transceivers. In laboratory environment, a maximum reachable distance of 125 km over G.652 fibre at transmission speed of 956 Mbps was achieved. This transmission speed corresponds to maximum achievable speed of a direct PC to PC connection with attenuators. We expect that the reachable distance should reach up to 140 km when newer transceivers, which have lately appeared on the market, are used. The second type of GE adapters is designated for economically effective full-duplex optical transmission over a single fibre. The first direction uses 1510 nm wavelength, the second direction uses 1590 nm. The span reached in laboratory was 105 km of G.652 fibre at a maximum transmission speed of 956 Mbps.

The interest in PC Light shows that the current component basis for optical transmission systems allows constructing significantly better/cheaper transmission equipment than that offered on the market. That in itself would not be a sufficient reason for building such devices within the Optical networks activity, but even more important is the opportunity to use these and similar devices for verifying the principles of building optical and opto-electronical networks. In 2005, we intend to extend the current optical workplace to a laboratory testbed (with remote lambda access later on). This laboratory testbed will be designated to research, develop and verify new optical networking facilities. This way, we expect to influence the research, development and deployment of CEF networks towards lower prices, higher technological level and higher transmission speed (40 Gbps and more). Optical switches will also be one of the construction elements tested in 2005. In contrast to Calient switches tested in Starlight and NetherLight, we wish to aim at using planar-based components. The possibility of easy integration and higher mechanical resistance of planar switches is very beneficial.

3.6 Free Space Optical Transmissions at 100 Mbps and more

While building the CEF networks, we may find that laying fibres in some locations may be difficult or expensive although the span may be rather short (e.g., hundreds of metres). This is typical mainly for the connection of end users (so-called "first" or "last" mile). In such cases, a link based on the WiFi wireless technology (802.11b or 802.11g) is usually chosen but this choice offers a maximum transmission speed of 6 Mbps or 20 Mbps, respectively, and it has frequent interference problems. However, CEF networks usually need 100 Mbps to 10 Gbps transmission speeds for their first mile. Optical transmission sets at 2.5 Gbps are already available from suppliers and there are promises of 1 Gbps microwave transmission sets. But broad application in CEF networks (they will become "CE networks" then) will also depend on low production and operational costs, and for the purpose of experimental networks building, the possibility of modifying and developing appropriate hardware is also necessary.

The development follows up with the considerable experience of the CZFree network with development and deployment of low-cost 10 Mbps FSO (Free Space Optics) facility which enabled many university and secondary school students and other applicants including teachers to obtain connection at 10 Mbps from their homes, which would be too expensive if bought as a commercial service. It is very important that thanks to this, high-speed Internet access has been spreading fast which would not be possible in a common commercial way. We are therefore searching for real possibilities of using low-cost facilities for CE network building, where also higher transmission speeds will be necessary, and we are comparing them to commercial offers of corresponding devices.

In a Beroun locality, long-term testing of an operating 10 Mbps FSO connection to the CESNET2 network and its mechanical construction had been performed. After evaluating the results, we made some changes in the mechanical construction and we upgraded the FSO. We also attempted to use 100 Mbps electronics but the sunshine suppression necessary for APD photodiode in the receiver was not sufficient.

We developed a new mechanical construction for FSO electronics which can operate at higher transmission speeds (100 Mbps and more). We presented the aspects connected with the development of the 100 Mbps FSO electronics and mechanical constructions at the *Optical Communications 2004* conference. At the same time, a professional article dealing with the criteria for FSO evaluation and possible solutions to construction problems was published in the Proceedings volume. Before the end of the year, we tested basic functional electronics samples at 100 Mbps with an APD photodiode and VCSEL laser on a 250 m long route. The tested route was equipped with low-pass optical filter which cuts off the wavelengths from 790 nm upwards. Moreover, we will use an interference filter which should limit the interference outside received wavelength window of 30 nm. We have upgraded the current 10 Mbps FSO and prepared it for possible use of 10 Mbps and 100 Mbps electronics, respectively. This equipment will be used for accessing the CzechLight from some of the workplaces. It is a low-cost facility (roughly 2,000 Euro) which will allow another community of applicants to access the GLIF and high-speed networks.

For better comparison, we use technical and pricing information of commercially offered devices. Carrying out user tests or deploying such equipment is even more important. In 2004, we had a very good experience with a Laserbit laser system installed between the University of West Bohemia campus and the Borská Student Hostel. The system operates as so-called media convertor. It is modular and an appropriate module is always selected for the installation, according to transmission line length and required speed – the price depends on that as well. This system is attested for the use in the Czech Republic and its operator does not have to apply for any kind of licence or permission to operate. For our purpose, we chose the LaserBit LB-1500 E 100 model which is designated for up to 1500 m span. Its laser output is 70 mW in class 3B, it operates on 785 nm wavelength, and according to technical specification, it reaches the 100 Mbps full duplex speed. The system offers an Ethernet UTP 100 Mbps interface; another optical interface can be chosen instead. The price of a pair of these transceivers was 9,300 Euro without VAT at the time of our tests. The producer guarantees proper system operation in any kind of weather including fog, rain, and snow. The manufacturer also supplies 100 Mbps laser modules for the distance of 150, 200, 500, 1000, 1500, 2500 and 5000 m and 1 Gbps modules for 200, 500 and 1000 m.

We were able to test the laser link operation also in bad weather. Even heavy rain accompanied by thunderstorm or ordinary fogs did not affect transmission speed in any way but the connection failed during thick fogs. The level of fog thickness that may influence the connection functioning depends on local conditions of each line. Our line runs above a field (40 m above the ground) and so the fog there is often much thicker than that in built-up areas within a city. During the five-month operation when LaserBit was connecting the Borská Student Hostel network to the campus network in routine operation, we have noted four network failures during very thick fogs. No failures occurred outside foggy weather. But even including the fog-related failures, the overall system availability reached over 99.5 %. Every minute, a 20 MB test file is transmitted over the line and the results of this long-term transmission measuring correspond to the tests that have been carried out. A backup line (e.g., WiFi) may be necessary for continuous operation should local conditions prove unsatisfactory for a laser link.

We are considering to test the FSO LaserBit connection over a distance of 2.5 km, evaluate the WiMAX technology possibilities and so-called Gi-Fi (Gigabit Wi-Fi), and investigate into other technological possibilities of gigabit free space transmissions in 2005. The interest for these possibilities is also documented by their inclusion into relevant TF-NGN international activities. At the same time, we will continue developing and testing low-cost optical connection transceivers at 100 Mbps and researching other possibilities of further speeding-up while keeping the prices relatively low.

3.7 Parts of International Projects and Grants in Optical Networking Activities

In 2004, the activity participants became engaged in the following parts of international projects and grants.

3.7.1 GN2 SA1 Procurement

The SA1 activity deals with transmission capacity procurement, locating PoPs, facilities, facility maintenance and network operation for transferring or replacing present interconnections between NRENs within GN2 by qualitatively new lines.

The aim is to choose and recommend optimum lines and transmission technologies based on tenders with respect to technical and price levels and availability, and to sign contracts with selected suppliers.

3.7.2 GN2 JRA3

Primary aim of this activity is to map-up the BoD (Bandwidth on Demand) users and their requirements, and to elaborate a comprehensive study on the current state of technologies for the BoD service support.

Secondary aim is to elaborate a detailed BoD service specification. Owing to the fact that the BoD development and deployment is quite complex, this will be realized gradually within four levels according to the growing level of difficulty: single-domain manual provision, multi-domain manual provision, single-domain automatic provision, and finally multi-domain automatic provision.

The third aim is the service implementation itself, where instead of developing new solutions, current solutions will be integrated. The last aim is to test and evaluate the service in real environment.

3.7.3 GN2 JRA4

The JRA4 research activity of the GN2 Multi-Gigabit European Academic Network project gathers knowledge of new experimental network conceptions and interconnects the national testing networks to test new transmission technologies for the GÉANT2 network.

This research activity is focused on testing new services and transmission technologies for the GN2 network in the framework of NRENs and between individual NRENs which have a highly developed testing network based on dark fibres and are experienced in advanced transmission technologies.

The aim is to connect the research activities of European networks and interconnect national testbeds based on the experience in dark fibre acquisition, on the latest transmission technology deployment and on operating such optical lines. Under JRA4, new experience with new types of experimental networks will be gained. These experimental networks will be fully optical, based on dark fibres, using long-distance transmission (LongHaul and UltraHaul), multi-lambda transmissions between end users, etc.

3.7.4 SEEFIRE

There are three basic groups in project goals. The first group sets up strategic goals for the development of regional NRENs, justification and defence of regional NREN roles, identification of countries where governmental support will be necessary for dark fibre acquisition, and spreading the project results outside the region, mainly towards emerging NRENs in the rest of the world (South Africa, Latin America, the Mediterranean, Asia).

The second group of goals involves the creation of the current list of potentially available dark fibres in the region including their types and owners and the documentation of existing technical and administrative experience in fibre infrastructure in the region (on metropolitan, national and regional levels).

The last group of goals involves an identification of suitable technical solutions of optical transmission systems with respect to their technical levels while keeping the prices acceptable (CESNET), finding the companies which are experienced in laying new optical cables, and finding out the conditions and prices of this cable laying with special respect to last miles.

CESNET will be responsible for fulfilling the goals concerning the transmission technologies suitable for the south-east European region.

3.7.5 CzechLight Extension

The CzechLight Extension international project attempts at extending the CzechLight experimental network both in the geographical and functional senses. Cisco transmission and switching facilities for CEF networks will be developed and verified during the project and their applications tested. The nearest step is the change of the original project with respect to current conditions and facilities. Thanks to the fact that the financing conditions have been solved, the project can start successfully.

3.7.6 The Czech Republic Grant Agency

The aim of the common CESNET–ÚRE–FEL ČVUT *Optimisation of data transmission at 10 Gbps over G.652 fibres with respect to maximum transmission distance without deploying in-line EDFAs* project is the analysis of the possibilities of NIL transmission optimisation over G.652 and G.655 fibre routes at 10 Gbps using Raman pumped transmission fibre and signal amplification by erbium-doped amplifiers. The results of numerical analysis will be verified experimentally under laboratory conditions. Use of Bragg grating for GVD compensation to substitute the DCF modules will be experimentally investigated as well. For laboratory experiments, a Cisco ONS 15454 SONET MSPP system with two OC-192 cards (10 Gbps transmission speed) will be used, too. We expect that the simulation and laboratory test results will be used in the CzechLight experimental networks (and elsewhere in case of interest, e.g., in the GN2-JRA4).

3.7.7 Information Society

The aim of the common CESNET-ÚRE *Time division multiplex pumped Raman fibre amplifiers* project of the Information Society programme is a theoretical analysis, experimental realization and quality verification of wideband Raman fibre amplifiers with time division of pump sources. The theoretical analysis will be based on the creation of TDM RFA numerical large-signal model proceeding from numerical solution to a set of bound partial differential equations describing all important phenomena occurring in TDM RFA. After the set-up and tuning of numerical programs for TDM RFA behaviour simulation, a detailed analysis of the properties of this type of Raman amplifier will be done and the properties will be compared to the optical parameters of continuously pumped RFAs. We would like to test the simulations and tests results also in the CzechLight, or maybe in other experimental networks.

4 Programmable hardware

This activity emerged as an extension of the original *Liberouter* project which aims at developing a PC-based IPv6 and IPv4 router. The COMBO6 hardware accelerator, thanks to its modular design and electronic components used, turned out to be useful not only for forwarding and filtering IP datagrams. The *SCAMPI* project (see chapter 4.4) decided already in 2003 to use the COMBO6 platform as a basis for development of a special network monitoring adapter. In 2003 we also started the development of a two-channel optical repeater for Gigabit Ethernet. A new task was added to the above list in 2004 – development of an autonomous network monitoring probe capable of generating data in the NetFlow version 9 format.

The *Programmable Hardware* activity was established at the beginning of the year 2004 with the primary goal of coordinating the development effort mentioned above, and, at the same time, engage new developers (mainly students) and provide them with all necessary training so that they can be effectively integrated into the team and work on new projects. The number of team members grew to 69 in 2004. The new developers are, for the most part, students of three universities in the Czech Republic (Brno University of Technology, Masaryk University in Brno and Czech Technical University in Prague). We now have altogether 53 students on board. Such an intensive involvement of students certainly has its caveats and risks but it seems to be the only way how to finish all the projects in time. On the other hand, the students benefit greatly from cooperating within a large team and working on real-life problems. Some evidence of this important side effect is seen in the general success of the bachelor, master and doctoral diploma works stemming from the project.

4.1 Organisation and management

Administering and managing such a large team also poses a number of nontrivial challenges. In 2004 we re-organised the team management into a hierarchical structure with seven relatively autonomous workgroups and gave the workgroup leaders significant competences and responsibilities. A new group – System Support – was founded with the intention of integrating important support tasks such as administering the ever-growing pool of servers and workstations, developing our web site[1], etc. During 2004 we also organised three seminars in order to give the distributed team an opportunity for face-to-face meetings and also to promote mutual cooperation among the workgroups.

[1] *http://www.liberouter.org/*

4.1.1 VHDL workgroup

The VHDL workgroup deals with firmware design and has 29 active members, 24 of them being students and 11 newcomers. The sheer size of the group and multitude of tasks brought about further structuring of the group into four subgroups (Liberouter, SCAMPI, NetFlow, Testing). Each subgroup has a leader responsible for integration and proper firmware functionality of the given project.

As the group and its subgroups became more autonomous, it became apparent that the previous ad hoc documentation practice was insufficient. We thus designed a new documentation system based on XML which enables us to use the same informations in many different ways, e.g., as a detailed technical documentation or as a summary on project web pages.

Six bachelor theses and a six doctoral theses are under preparation within the VHDL workgroup.

4.1.2 System software workgroup

The system software group has 11 active members, 6 of which are students. Three developers work on various drivers and the others on various modules of system and user-space software. Application programmers of the software group work on integrating the whole system.

Three master theses and a doctoral thesis are under preparation within the software group.

Moreover, three students who are not yet official team members work on related non-essential topics such as graphical representation of nanoprocessor computations. This cooperation usually has a form of a tutoring student's bachelor thesis.

4.1.3 Formal verification workgroup

This workgroup currently consists of eight students. Three of them were hired in 2004 with the goal of applying further verification methods, namely the creation of abstract formal models of programmable hardware components suitable for verifying the temporal properties.

Workgroup members spend most time in communicating with hardware developers. In order to formalise this communication, we created an interface of so-called *asserts* that allow specifying required properties of VHDL designs directly in the VHDL code (in natural language). The members of the verification team then formalise these asserts by means of temporal logics and translate the VHDL code into the Cadence SMV language in which the formal verification is performed. Verification results are fed back to the VHDL developers via verification reports that are presented on the project web. As an aid to this process, we are developing a suite of scripts named *Verunka*. It is described in the Technical report [TR05/04].

Two master theses and one PhD. thesis are under preparation within the formal verification workgroup.

4.1.4 Netopeer workgroup

This group develops the *Netopeer* software system for configuring routers and entire networks. The group had six active members by the end of 2004, five being students. One of the students finished his bachelor thesis already in 2004. Two master theses and one PhD. thesis are under preparation.

4.1.5 BIRD workgroup

This is the newest and smallest workgroup in the project, consisting of only two active members. The main object of their interest is the BIRD routing daemon. In 2004 they ported this software to the NetBSD and FreeBSD operating systems, now are working on extending its functionality.

4.1.6 Testing workgroup

This workgroup develops an independent testing suite by which most hardware, firmware and software development results (including documentation) are scrutinised. For this purpose, the group uses a specialised network tester Spirent AX/4000 and a set of open source programs.

In the previous years, the core of the testing workgroup was formed by students of the Czech Technical University. Most of them left the team in 2004 and so we had to substitute them by new students – three of them from Masaryk University and one from the Czech Technical University.

4.1.7 System support workgroup

This work provides support to the team members in the following areas:

1. Administration of public and private web pages and servers for email, CVS, bug tracking, etc.;

2. Documentation and presentation activities;

3. Management of accounts, access permissions and related personal agenda;

4. Administration of servers and workstations used by project developers.

We introduced a content management system (CMS) on our web server[2] and generally consolidated this important medium. The web pages are now partly generated dynamically from CESNET databases (LDAP, publications). The private part of the web also underwent substantial changes where we launched several administrative applications like the inventory of COMBO cards and their users, allocation of MAC addresses for interface cards, reporting and planning systems, etc. In cooperation with the VHDL workgroup we also created documentation tools for firmware designs based on XML.

We also introduced the *Mantis* bug tracking system that helps in systematic monitoring and resolving firmware and software bugs and other issues. Through this system, the support workgroup also accepts requests from the team members.

Electronic mailing lists remained essential for team collaboration – we manage nine lists currently. Another crucial tool is the system for distributed software development, CVS[3].

4.2 The family of COMBO cards

The hardware development of COMBO communication cards continued in 2004 as previously planned. Descriptions and pictures of all cards can be found on the project web[4]. Probably the single most significant achievement is the activation of a two-port 10-Gigabit Ethernet interface card COMBO-2XFP (see Figure 4.1).

While this card is primarily intended for the SCAMPI project, it will be used in other projects covered by the activity Programmable Hardware as well.

As the COMBO cards gradually reach the technological leading edge, it becomes increasingly difficult – despite vendors' promises – to get all components with required parameters in time. In the second generation of COMBO cards, which are now being manufactured, we thus attempted to minimise the number of components used by capitalising on the advantages of the new generation of FPGA chips, namely the Rocket IO circuits that are part of VIRTEX II PRO FPGA, or, alternatively, to replace some components like the PCI bus interface by IP core.

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[2] *http://www.liberouter.org*
[3] *http://www.liberouter.org/cgi-bin2/cvsweb.cgi/*
[4] *http://www.liberouter.org/hardware.php*

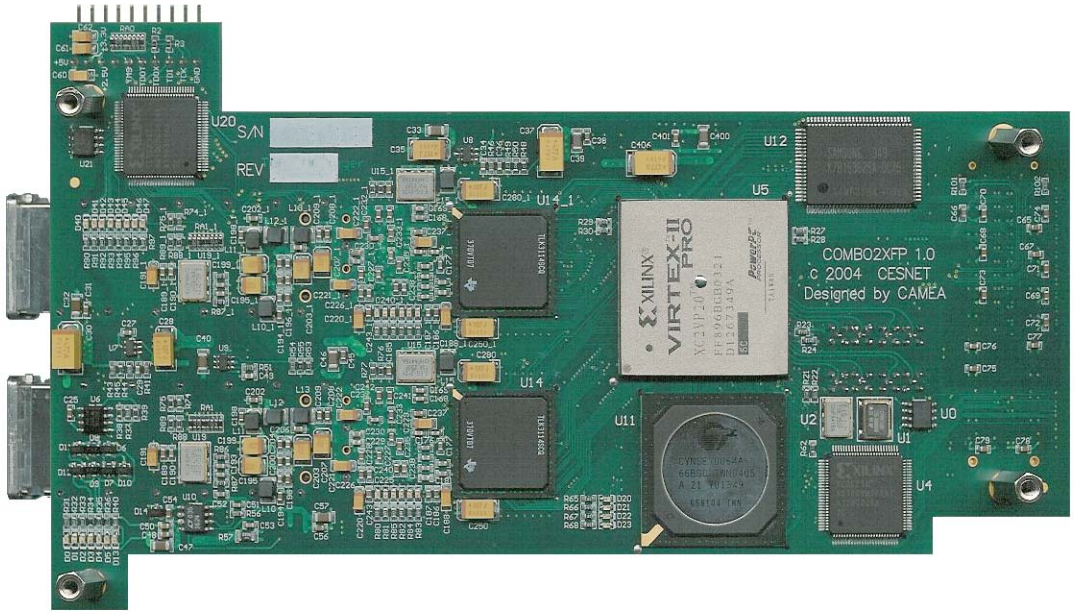

Figure 4.1: 10-Gigabit Ethernet interface card COMBO-2XFP

The first card of the new generation is the COMBO6X motherboard that is intended as a replacement for the original COMBO6 card. The COMBO6X card benefits from the features of VIRTEX II PRO by introducing serial communication also between circuits on the COMBO6X card and attached interface card. The PLX 9054 PCI controller used on COMBO6 was replaced by the VIRTEX II PRO gate array together with a PCI core implementing the PCI-X bus on 133 MHz. In addition, the VIRTEX II PRO chips also contain embedded PowerPC processors – COMBO6X has three of them. This will allow us to move parts of the algorithms that have been previously handled by the host PC to the COMBO6X card.

Another successor of COMBO6 has also been designed under the name COMBO6E. Its architecture is similar to COMBO6X, but instead of PCI-X it is intended for the new bus standard Express PCI. For this purpose, COMBO6E will use the Rocket IO circuits and a corresponding IP core.

In the process of developing the COMBO-2XFP interface card (2 ports of 10GE) we encountered problems with heat dissipation in the serial/deserial circuits (TLK3114SC and LXT12101) that are moreover difficult to obtain. The new version of the card – COMBO-2XFPRO – is thus based directly on VIRTEX II PRO with Rocket IO-X. An additional advantage of this solution is that it directly supports not only the 10GE standard but also SONET OC-192.

By the end of 2004 we also finalised the hardware design of the COMBO-4SFPRO (4 ports of GE) which is a replacement for the COMBO-4SFP card. Again, serial/deserial circuits will be replaced by Rocket IO. The card will support either the Gigabit Ethernet (with VIRTEX II PRO) or SONET OC-48 (with VIRTEX II PRO-X).

To summarise the status, the COMBO family currently consists of the following cards:

1. **COMBO6:** Motherboard, in the production phase, to be replaced by COMBO6X and COMBO6E in 2005.
2. **COMBO6X:** New motherboard for the PCI-X bus, the card is being activated.
3. **COMBO6E:** New motherboard for the Express PCI, in the stage of PCB design.
4. **COMBO-4MTX:** Interface card 4×GE with metallic ports, in the production phase.
5. **COMBO-4SFP:** Interface card 4×GE with SFP transceivers, in the production phase.
6. **COMBO-2XFP:** Interface card 2×10GE with XFP transceivers, prototype to be replaced by the new card COMBO6-2XFPRO soon.
7. **COMBO-4SFPRO:** New version of the interface card 4×GE with SFP transceivers, PCB is being manufactured.
8. **COMBO-4XFPRO:** New version of the interface card 2×10GE with XFP transceivers, PCB is being manufactured.
9. **COMBO-PTM:** Source of ultra-precise timestamps, developed by the SCAMPI project, in the production phase.
10. **COMBO-BOOT:** This card can be connected to an interface card instead of the COMBO6 motherboard. This allows for embedded devices (without a host PC). This combination is used in the optical repeater, see section 4.5. The card is in the production phase.

4.3 Liberouter project

The Liberouter project, which is also part of the international project *6NET*[5], aims at improving PC/Unix-based routers in the areas where they lag behind their commercial counterparts:

[5] *http://www.6net.org/*

- throughput and packet forwarding/filtering performance,
- configuration interface.

Due to the unsatisfactory status of the two common Unix routing daemons – *GateD* and *Zebra/Quagga*, we also decided to contribute to the development of the BIRD[6] daemon, originally a student project at Charles University, Faculty of Mathematics and Physics. In this area we focus on implementing the PIM-SM protocol for multicast routing.

During 2004 we decided to concentrate the efforts of all workgroups on finishing a functional prototype of PC router with better performance than a purely software solution. A demonstration of such a device is being prepared for the review of the 6NET project in February 2005.

An important feature of the Liberouter, apart from supporting the latest IPv6 standards, will also be its open design. By publishing the complete firmware and software documentation we hope to attract other parties (both academic and commercial) outside the original project team to carry on the development.

4.3.1 Firmware

The main task of the Liberouter firmware is fast routing and filtering of IPv6/IPv4 packets using resources on the COMBO6 card. These functions are concentrated to several programmable gate arrays (FPGA) that handle packet reception from an input network interface, process the header data, decide about the appropriate action and, finally, send the packet to an appropriate interface. Firmware architecture that has been described in last year's report remains essentially valid.

In the year 2004, we concentrated on finishing and debugging individual components and integrating them to the whole design. The functions of HFE (Header Field Extractor), LUP (Look-Up Processor) and PQ (Priority Queues) have already been tested in the FPGAs. The remaining components have been checked only by software simulation. We finished the first version of firmware for analysing packet headers and ingress filtering on all four interfaces. Its architecture is shown in Figure 4.2.

The depicted components have the following functions:

IBUF (Input Buffer): checks whether the incoming packet is corrupted (CRC) and temporarily stores the whole packet before passing it to HFE processing.

HFE (Header Field Extractor): dissects the headers of incoming packets and produces a fixed data structure called *unified header (UH)*.

[6] *http://bird.network.cz/*

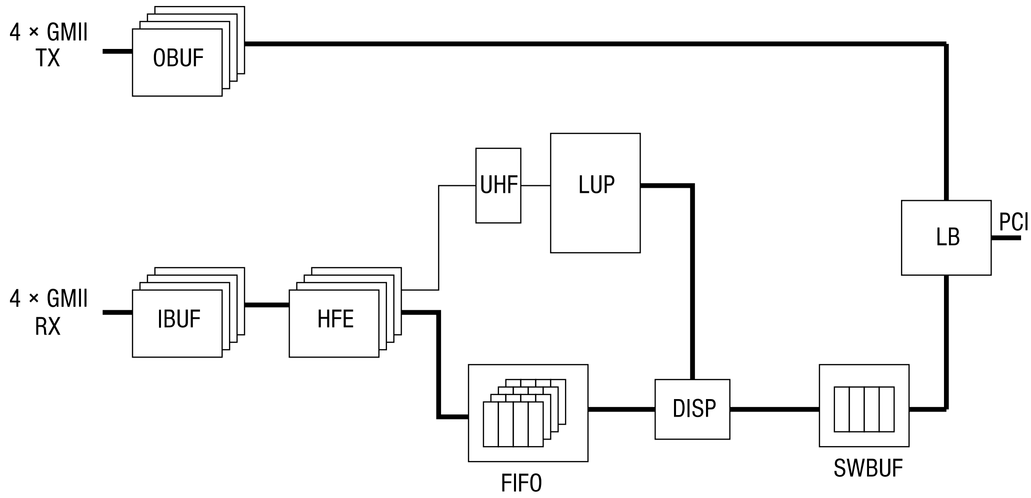

Figure 4.2: Current diagram of firmware architecture

LUP (Look-Up Processor): classifies the packets according to the data in UH.

DISP (Dispatcher) : controls further packet processing based on LUP classification. In particular, it can drop the packet or pass it for software processing.

SWOBUF (SW Output Buffer): maintains buffer space for packets intended for software processing and controls packet transfer via PCI bus.

OBUF (Output Buffer): controls packet transmission via output interfaces.

Compared to the original firmware design, the current version is simplified in that it does not store the packet payload directly on the COMBO6 card. However, the input part (packet header analysis and packet classification) exactly follows the original architecture already. In order to implement the remaining parts of the firmware architecture, we intend to apply the principles of hardware/software co-design: functions will be gradually added into the existing firmware, while the remaining components are implemented in software.

4.3.2 System software

Software support of COMBO6 card is being developed for the NetBSD and Linux operating systems. Porting to FreeBSD is planned.

Software for COMBO6 can be divided into two basic categories:

1. COMBO6 drivers allow basic communication with the card (firmware upload, handling internal memories and registers, etc.).

2. Support for packet acceleration, the *combod* daemon.

The driver enables access to the COMBO6 and interface cards. In the operating system environment it is represented as a set of character devices */dev/combo*. Tools for initialising cards and firmware upload have also been developed. In order to simplify testing and debugging, we have prepared a set of control utilities *hfectl*, *lupctl*, and others. They allow reading and writing registers and memories of nanoprocessors as well as controlling the behaviour of nanoprocessors.

The driver also provides access to COMBO6 network interfaces. The interfaces behave like usual network interfaces and allow configuring by means of usual operating system tools, e.g., *ifconfig*.

Support for packet forwarding and filtering acceleration is the main task for the *combod* daemon. It is designed to make the special features of COMBO6 opaque to the operating system. The operating system kernel keeps the information about routing, address resolution (ARP), packet filtering (firewalling), and possibly also *tcpdump* setting in a set of tables and other kernel structures. COMBO6 should forward and filter packets in exactly the same way as the operating kernel would, only faster.

LUP, the lookup processor implemented in COMBO6 hardware, uses a special data structure for packet classification. It exploits content addressable memory combined with lookup instructions stored in static memory. The task of the *combod* is to keep the structure synchronised with the operating system tables.

Currently, a feature-limited version of the design is available. It behaves as a network adapter with hardware ingress filtering on source and destination ports and addresses. Extending filtering possibilities is an open research problem. The most promising approach for lookup structure compilation is to distribute the packet filter setting to relevant parts of the routing table.

4.3.3 Formal verification

We have verified VHDL programs for the packet edit engine, concentrating on the communication of this module with the DRAM scheduler. Modules UH_FIFO and ASYNCHRONOUS FIFO have also been tested. The results are available from the verification reports at the formal verification section[7] of the project web.

The key contribution to the development of verification technologies was the verification of the asynchronous queue where the problem of formalising VHDL design with multiple clocks was solved. The problem and its solution is described in the Technical report [TR04/04].

[7] *http://www.liberouter.org/formal_verification/*

4.3.4 Netopeer configuration system

The Netopeer software system deals with configurations of IPv6 and IPv4 routers and entire networks. Its basic setup is shown in Figure 4.3: Configurations are created on the manager station which stores them as XML documents in the configuration repository and also – if instructed to do so – converts them into the native configuration language of the target router and installs them there.

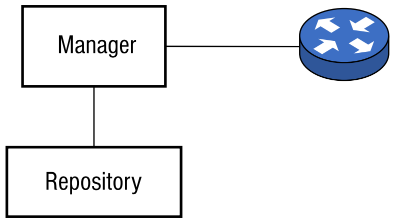

Figure 4.3: Basic setup of the Netopeer system

For the most part, the Netopeer system is a set of programs running on the manager station. The overall architecture is shown in Figure 4.4. Its upper half contains front-ends that realise the user interface, transform user input into an XML document, and store it in the repository. For translation into the language of the target router, front-ends use an appropriate back-end which is available to them as a library function.

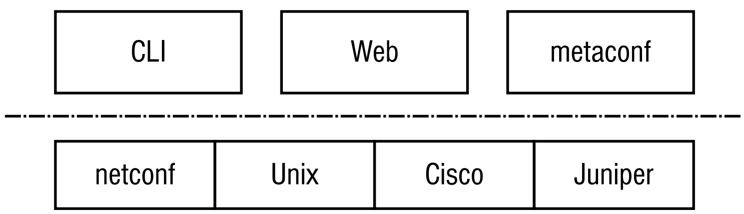

Figure 4.4: Software architecture of the manager application

In 2004, our focus was to finish a functional prototype suitable for configuring PC routers in production networks. To this end, it was necessary to improve especially the command line interface (CLI) that is considered the primary configuration tool, and also the Unix back-end for translating configurations from XML to Linux and BSD scripts and configuration files and installing them in the PC router.

Substantially changed was also the XML scheme defining the data contents of XML configurations. First, we migrated to another language for XML schema description – RELAX NG. Compared to the previously used DTD language, RELAX NG allowed including a significantly larger extent of syntactic and semantic constraints directly in the XML schema. The RELAX NG scheme currently represents configuration of network interfaces (including tunnels and VLANs), basic system configuration (DNS, NTP, etc.), packet and route filters, static routing and three major routing protocols (RIP, OSPF and BGP).

The CLI front-end is now in the beta stage and essentially usable. Its syntax is derived directly from the XML scheme. This is very useful since every change to the XML scheme is immediately reflected in the CLI, but in some cases it makes the CLI syntax rather clumsy. We thus plan to adjust the scheme and also intersperse hints for front-ends throughout the scheme (in a special XML name space). These hints will help the front-ends in mapping the XML structure into an easy-to-use CLI syntax.

The web front-end was changed in a similar way: now it generates its HTML forms dynamically from the scheme and this has similar pros and cons as in the case of CLI. The system of hints in the scheme should help in this case, too. The architecture of the web front-end is described in the Technical report [TR06/04].

The Unix back-end currently allows configuring PC routers running Linux and the Zebra routing daemon. This platform can thus be configured via the command line interface.

An interesting addition to the system is the *Netconf* module based on the Netconf protocol that is being developed in IETF [Enn04]. This protocol is also based on XML and so fits very well into the Netopeer architecture. The implementation of the Netconf over the BEEP[8] transport protocol was the topic of a master thesis finished in January 2005.

A considerable progress also marked the development of the *metaconfiguration* application which enables configuring entire networks based on higher level information. This application will automatically generate low-level configurations of individual routers in the Netopeer XML. We created a special scheme (also in RELAX NG) covering all fundamental areas (addressing, routing and filtration) and also designed a graphical user interface. The results are described in the Technical report [TR27/04].

4.3.5 BIRD routing daemon

The BIRD routing daemon is the highest software layer represented in the Liberouter project. Its main task is to set up routing tables for unicast and multicast routing (IPv4 and IPv6), based on information exchanged with neighbouring routers by means of routing protocols. The dynamically generated routing tables are passed to lower layers of the operating system kernel and through it also to the COMBO6 card.

Our contribution so far was the port of BIRD to the NetBSD and FreeBSD operating systems (the original version runs on Linux). The unicast forwarding kernel

[8] *http://www.beepcore.org/*

is complete and debugged as well as the implementations of the BGP, RIP and OSPF routing protocols. The development of the multicast kernel is finished and implementations of DVMRP and PIM-SM are under development. We are also working on implementing a module for network interface configuration.

4.4 SCAMPI monitoring adaptor

The SCAMPI network monitoring adaptor is also based on the COMBO family of cards and benefits from their modularity, which allows several combinations of a motherboard (COMBO6, later COMBO6X or COMBO6E) with an interface card (COMBO-4MTX, COMBO-4SFP, COMBO-2XFP, COMBO-2XFPRO, COMBO-4SFPRO). The only card that was specially developed for the SCAMPI project is COMBO-PTM, the source of precise time stamps. SCAMPI adapters are thus currently available in three variants:

1. SCAMPI-4MTX: COMBO6, COMBO-4MTX, COMBO-PTM
2. SCAMPI-4SFP: COMBO6, COMBO-4SFP, COMBO-PTM
3. SCAMPI-2XFP: COMBO6, COMBO-2XFP, COMBO-PTM

Additional variants will be tested as soon as new versions of motherboard (COMBO6X and COMBO6E) and interface cards become available.

4.4.1 Firmware

The basic roles of firmware in the SCAMPI project are: handling packet reception from input interface, assigning a precise timestamp for each packet, and performing packet analysis and classification. According to the classification result, it is possible to collect statistical information, perform packet filtration and sampling and detect specific patterns in the payload of selected packets.

Up to 256 different statistics on length and intervals between packets are supported. The current design contains 16 sampling units that can be configured in three sampling modes:

- Deterministic sampling – every n-th packet is passed to the unit.
- Random sampling – packets are passed to the unit with a specified probability.
- Byte-oriented deterministic sampling – the packet that contains every n-th byte is passed through the unit.

The firmware is able to detect up to 512 different patterns at a 3.2 Gbps rate. The maximum rate is determined by the speed of TCAM memory.

The design also contains firmware for the COMBO-PTM card which controls the generation of precise timestamps and their transfer to the COMBO6 card.

Firmware development was divided into two phases. The first one covers the implementation of a monitoring adapter for data rates up to 1 Gbps. The firmware architecture is shown in Figure 4.5.

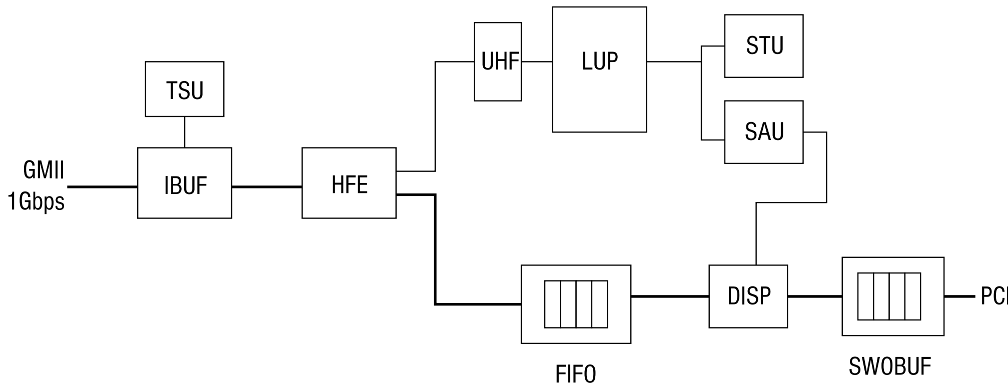

Figure 4.5: Architecture of 1 Gbps monitoring adapter (phase 1)

The depicted components have the following functions:

IBUF (Input Buffer): checks whether the incoming packet is corrupted (CRC) and temporarily stores the whole packet before passing it to HFE processing.

HFE (Header Field Extractor): works almost exactly the same as in the Liberouter design – reads packets data from the input buffer, dissects its headers and produces the *unified header*.

LUP (Look-Up Processor): performs packet classification based on information in the unified header.

FIFO (Packet FIFO): temporarily stores the packets (implementation of a delay line).

STU (Statistical Unit): collects statistic information.

SAU (Sampling Unit): performs packet sampling.

DISP (Dispatcher) : controls further packet processing based on LUP classification. In particular, it can drop the packet or pass it for software processing.

SWOBUF (SW Output Buffer): maintains buffer space for packets intended for software processing and controls packet transfer via PCI bus.

The second development phase now focuses on data rates up to 10 Gbps. As the throughput is much higher, the design for the second phase differs in several ways from the design described above. In particular, IBUF and DISP units are completely different. Several components (HFE, FIFO) have been replicated and the whole design has been partitioned between the COMBO6 and the interface card. The architecture of monitoring adapter for 10 Gbps is shown in the Figure 4.6.

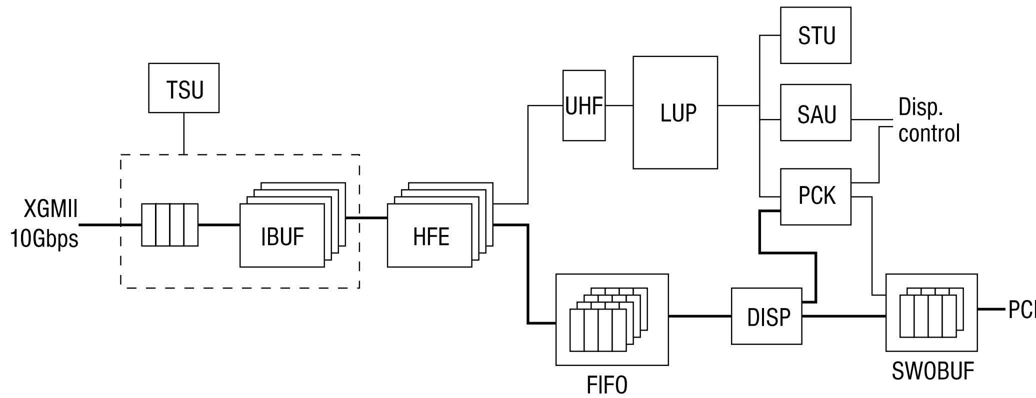

Figure 4.6: Architecture of 10 Gbps monitoring adapter (phase 2)

4.4.2 System software

System software for the SCAMPI project consists of COMBO6 drivers and a library to transform packet filtering rules into a form that is acceptable for the hardware.

Drivers provide low-level access to the COMBO6 internal registers, memories, and counters. Large parts of the driver have been adopted from the Liberouter project, the only SCAMPI-specific driver modules are those for the statistical (STU) and sampling (SAU) units.

Requirements for packet capturing functions are defined by MAPI (Monitoring API). MAPI uses the *Scampidump* library to upload the filter to the card. *Scampidump* accepts rules expressed in a language which is a subset of standard BPF (Berkeley Packet Filter) syntax. The rules are analysed, compiled into the form of a nanoprogram for LUP, and uploaded to the COMBO6 card.

Currently, only a single rule can be used. A version of *Scampidump* supporting more rules is under development and the compilation techniques are under extensive study. Handling the overlapping rules has to be solved. The approach we are testing is based on representing the rule sets as SB+ trees and partitioning them into non-overlapping segments.

4.4.3 Formal verification

The following modules have been verified in the SCAMPI firmware design: DISP, FIFO, STU, and SAU. Formal verification of the FIFO module discovered a deviation from the specification. This result will lead us to correcting the specification – it turns out that the implementation is valid under additional assumption that is fulfilled in all practical cases.

While discussing detailed requirements for the abstract model of the SCAMPI design, we also identified parts of the design that are problematic from the viewpoint of time constraints. The cooperation of the verification workgroup with VHDL developers can thus be very useful even in the design phase.

4.5 Optical repeater

The two-channel optical repeater was designed as a simple application that employs the COMBO-4SFP interface card. In 2004 we completed its development by adjusting it for the 2U rack-mount chassis.

The repeater can also be deployed as an embedded system thanks to the COMBO-BOOT card. Apart from providing power supplies, this card also handles device booting and uploading the firmware to the interface card.

4.5.1 Firmware

The firmware is relatively simple. It is placed in the FPGA on the COMBO-4SFP interface card and consists of two processes that copy incoming octets from one port to another. This firmware will also be ported to the COMBO-2XFPRO card as soon as it is finished.

4.5.2 System software

Control software for the COMBO-BOOT card is written in the C language. We created a simple monitor program that communicates with the controlling workstation via the serial RS-232C interface and implements the basic functions such as uploading the firmware to the interface card and monitoring power supplies.

4.6 NetFlow probe

In 2004, CESNET became a partner of the GN2 international project. One of the significant contributions of CESNET to this project within the JRA2 activity (Security) will be the development of hardware devices for network traffic analysis. The task for the first two years of the project is an autonomous probe generating NetFlow version 9 data which will again be based on the COMBO cards. As opposed to standard router-based NetFlow implementations, this probe will operate as a Y-splitter – inserted in a data circuit, the probe will carry pristine data traffic in one branch while at the same time copying the data to the other branch for analysis.

Version 9 of the NetFlow protocol allows for defining data contents of its records by means of so-called templates. We intend to utilise the flexibility of the FPGA technology, enabling to change the templates and data contents on the fly. Such a function is not available for common NetFlow implementations since the templates are hardwired in their ASIC circuits. We spent a good deal of the second half of 2004 discussing the architecture of this NetFlow probe. The initial design was reviewed by other GN2 partners and the result is recorded in the following CESNET Technical reports: [TR08/04], [TR14/04], and [TR15/04].

4.6.1 Draft hardware architecture

The initial NetFlow probe architecture is constrained by the features of the COMBO cards. The device has to use the existing card resources for maintaining as many NetFlow records as possible. In this phase, the target performance is set at 1 Gbps. Security also has to be seriously considered, e.g., information about data flows must not get corrupted, be it accidentally or as a result of an attack.

The NetFlow probe will analyse incoming packets, select important information and collect it into a NetFlow protocol header. This header then serves as input for the 19-bit and 45-bit hash functions that compute an address where the flow data should be added (if it is a new flow) or where the existing data should be updated. SSRAM memory is the best candidate for storing NetFlow records on COMBO cards. The Figure 4.7 shows memory organisation utilising SSRAM memory for a maximum number of records.

The first static memory performs matching by using a 19-bit hash function. This memory stores just a pointer to a corresponding NetFlow record and a 45-bit value of the hash function. The latter is used for reducing the probability of flow collisions while at the same time keeping the advantage of a constant-time search. The collision occurs when two different flows are mapped onto the same record. The probability of collision increases as the memory fills up. Therefore, the memory has to be filled relatively sparsely. It is also crucial to save as many

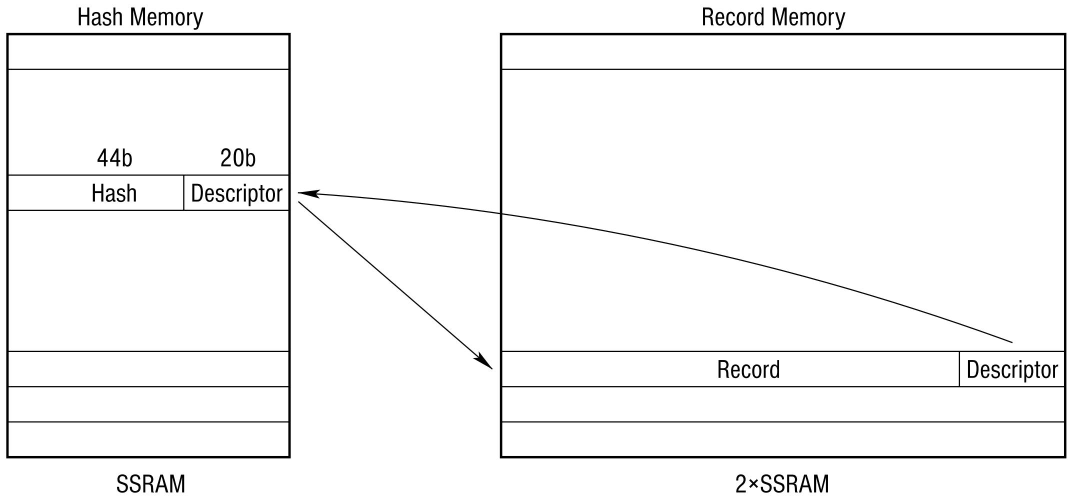

Figure 4.7: SSRAM memory organisation of the NetFlow probe

memory resources as possible and so the NetFlow records will be stored in separate memory banks.

The architecture of the NetFlow probe is shown in Figure 4.8. Each packet is received from the input interface to the input buffer (IBUF) where a timestamp from TSU is added. The packet then continues to the header field extractor (HFE) which analyses its header, collects important information and writes it into the NetFlow record. The hash block (HASH) uses this record for computing the 19-bit and 45-bit hash functions used by the hash search component (HSRCH) for fast NetFlow record matching. The matched record is then updated by the storage controller (SCTRL) component. If the flow is identified as new by HSRCH, a new record is added. The communication between HSRCH and SCTRL is controlled by the manager unit (MAN) which takes care about adding and releasing records.

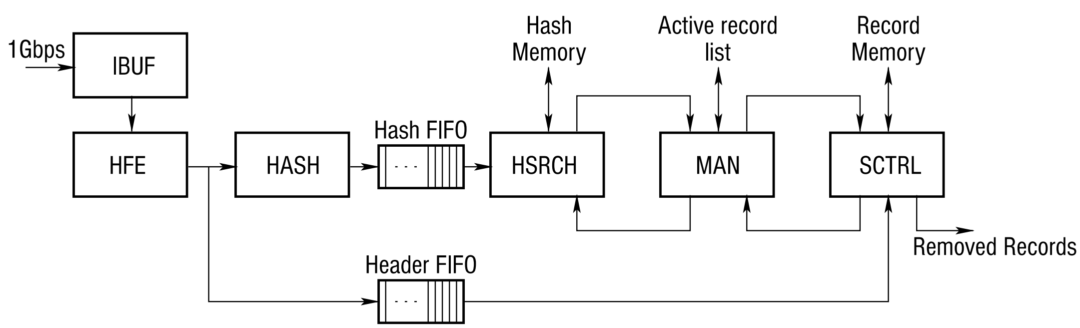

Figure 4.8: NetFlow probe firmware architecture

Active flows listed in a linear list are sorted by the timestamp of last update. Inactive flows are released by removing items from the beginning of the list according to the current time. Free records are also kept in a linear list whose items are reused when a new record is added. For capacity reasons, both lists are stored in the SSRAM memory.

5 Network and traffic monitoring

5.1 Introduction

Starting points of monitoring system design depend on current state of the art and trends in networking, network services and applications. The characteristics of current networks are undergoing most significant changes in the following two fields:

- The structural elements as well as the structure of networks change rapidly. Originally, networks used to be relatively “readable”. The hierarchy of their layers was definite and within the scope of each layer, the networks looked quite uniform from the technological point of view. Current trends lead to hybrid infrastructures, distinguished by varied mixtures of technologies as well as by enormous variability of particular layers and their hierarchy (including recursive encapsulation). The network infrastructures become more and more complex and complicated units with non-trivial internal logic often dynamically changing in time.
- The way the networks are used is changing. Originally, they used to be built almost for a single purpose; instead, they are representing a multi-functional communication and informational environment with the potential to adopt gradually almost all known applications and services. Data, voice, computing or video/TV services available through a single network interface is a partly real (technical scope) and an expected outcome of technology progress and its large scale application in near future.

This continuous progress must be systematically projected into development of monitoring methods, tools for primary data retrieval, processing as well as visualization, because the foremost goal of activity in this area is an ability to analyze events and explain them - not only identifying them.

5.2 Network Infrastructure Monitoring

The plan in the network infrastructure monitoring area for 2004 was to start analysing our formerly developed and operated systems and follow up the results with first designs and tests of components which should later become a core of a new system called G3. While designing and verifying the functionality of particular tools, we have concentrated especially on the following parameters:

Large-scale and continuous monitoring: The system should be able to provide large-scale as well as continuous infrastructure measurement in a selected area. This assumption implies use of relatively common technologies for primary data retrieval and searching for specific highly efficient alternatives of their implementation and further data processing.

Recording the dynamics of events and processes: Recording the dynamics with at least some statistical probability while providing large scale monitoring is a necessary condition for qualified analysis of the network behaviour. We need to catch the dynamics with accuracy corresponding to the communication characteristics of services and applications currently used (of course, the hard limits are determined by the measurement method used).

Convergence to human understandable information: This objective concerns two areas. Firstly, we need to bridge over the natural gap between the human perception of network infrastructure and logical structure of active network devices on the one hand, and their technologically defined structure given by the specific (and/or available) methods of their measurement which may differ from vendor to vendor on the other hand. Secondly, we need to provide aggregated information. As mentioned above, the infrastructure becomes more and more virtual and complex and there is no chance to embrace it all at the level of primary information about it (within the scope of measurement). Aggregation as a result of processing multiple primary values (even in the range of multiple instances of devices or their components) may help to get overall view while keeping the detailed information.

Automated adapting to device reconfiguration: We want to ensure that reconfiguration of a device will reflect in the measurement part of the system immediately or after a relatively short delay (given by configuration) without any need for user action. This "discovering" functionality is built-in within our current system as well but it is driven by a configured fixed time step. It should be made more flexible in the new system – driven also by results of actual measurement step.

5.2.1 Development of the G3 System

G3 should become our network infrastructure monitoring system based on standard measurement methods (mainly SNMP in this case) with non-standard measurement timing and specific data processing to satisfy the objectives described above. It may be the successor of GTDMS-II monitoring system which is being used in the Czech Republic NREN but first of all it should help us get new ideas and points of view on network infrastructure and the importance of various types of information about it. Although its primary purpose is measurement of large-scale networks, the system should be relatively small and should allow fast and easy installation for ad-hoc measurements without any specific needs for hardware resources or software packages.

The plan for 2004 was to begin with basic design of fundamental parts of the core components. Each idea was experimentally verified using an ad-hoc built tool when possible. First, the measurement core was built and tested. We need a very efficient and flexible but reliable mechanisms of SNMP data retrieval for the new system. We started with a small, relatively unified and version independent API to standard SNMP mechanisms (snmp-get, snmp-walk and bulk requests when available) to find a set of suitable measurement strategies. We continued with elementary architecture and process management. Currently, the measurement core is functional in its basic form and appears stable. Its data acquisition performance seems to be much faster when compared to the currently used GTDMS-II system.

We had several ideas about object identification on the data processing layer. It should be independent on the native indexing (mainly SNMP and therefore relatively dynamic). We implemented a strategy where identifiers are derived from measured values (optionally processed in a way given by configuration) of selected key items which are significant from the human point of view (interface descriptions, interface IP addresses and similar). This should allow us to follow the "travelling" items with the same meaning (human view) across the network device or even among several devices. Design and implementation allow us changing the set of key items without affecting the measurement core. Regardless of the SNMP interface indexes, we must be able to select all interface instances and corresponding time windows for any exclusive identification given by any combination of descriptive item values to construct both technology dependent courses (e.g., "POS 2/1", "GE 4/0") as well as the purpose dependent (e.g., "GEANT connection", "University XYZ").

To be able to measure short duration peaks effectively, we designed and tested a mechanism where the strategy of measurement time step can be configured in an unlimited way. It may be any combination of constants or parameters implying pseudo-random or random time step generation. The length of sequence is unlimited. This mechanism does not limit recording the dynamics of network behaviour (there are always some limits given by the basic measurement method, of course) and in addition, it allows us to keep the frequency of measurement within acceptable (non-destructive) limits.

Long-time experimental measurement of basic items at a small number of devices confirmed that the measured average values match those measured by other systems. There is a significant difference in envelope curves which indicate the network traffic dynamics. This is thanks to the timing mechanism described above. But reaching the optimal and safe configuration values as well as finding the limits of the time parameters will probably be an object of further research.

Another feature which had to be designed and tested is the controlled strategy of the “best value” selection. Some measurement alternatives to get a specific information exist. After certain kinds of processing (summaries, limits, algorithm), a group of several particular items may produce a single one. Typical examples are the 32-bit and 64-bit counters of the same meaning, but many others exist. Generally, we are interested in “best” values, but on the other hand, keeping the original sources and observing all the source items as well as the result may be useful under some conditions. Therefore we implemented a mechanism which enables both. Making items “virtual” is an effective strategy when giving overall summary views and may be useful in the future as the networks become more complex, virtual and abstract.

We started to work on one of the most important parts of the new user interface – the navigation scheme. Its mechanism must be complementary to object identification at the data processing layer described above. The currently being built tool we are testing allows us to configure and modify the structure of view (template) interactively. The template can contain any combination of key items in any hierarchy. The native (i.e., template content independent) attribute of the real navigation tree is aggregation. It means that every navigation object holds information about all real measured objects which have identical descriptive value (even a result of some future processing, e.g., substitution) within the scope of a particular template item. E.g., it enables to display a single navigation object (and later a single summarized result) for all interfaces having concrete IP address configured in requested time window regardless of its “travelling” across different interfaces of the device or (more often) interface SNMP index changes given by reconfiguration or booting. Navigation aggregation is not limited to single device data, so that one can reach, e.g., a single aggregated view on interface with specific description even if it had moved from one device to another or to a summarized view over the whole device.

Although the system in its current state can provide continuous measurements, we must point out that the set of items which can be measured is minimal and measurement itself is provided first of all as a prerequisite of its further development and long-term stabilization of its partially tested components.

5.3 Traffic Monitoring

Traffic monitoring is concerned with developing tools for efficient processing of specific elementary information about network traffic – the flows. Massive growth of network traffic in current networks leads to distributed systems with efficient classification and filtering and intelligent storage. We would like to offer an overall long-term view as well as particular network interaction analysis of the IPv4 as well as IPv6 traffic.

5.3.1 FTAS System

We focused on implementing and experimental operation of the FTAS (Flow Based Traffic Analysis System) in 2004. Its design notes and internal architecture are described in Technical reports 14/2004 and 15/2004. We implemented the system and started to operate it. Our preliminary experience shows that it is stable and functional. Currently, two separate instances of the FTAS are operating. The first one consists of seven multi-purpose collectors distributed among six servers for the CESNET2 backbone traffic monitoring. The second one consists of two multi-purpose collectors running on a single server. It is used as a test bed for optimizing parameters of specific long-term statistics which are running on the primary instance and as an information base for knowledge of traffic structure in this type of network. We are analyzing the experience with FTAS and making ready for next steps of its development. It seems there are two areas for possible improvement. We would like to shorten the response times (especially summary, non-filtered, aggregated requests for relatively long time intervals), decrease interactive work requirements and allow running all actions by single off-line requests. This added functionality of user interface will be a part of system development in 2005 which corresponds to the long-term research plan.

Within the scope of our plan, other sources were added to the existing FTAS infrastructure in 2004. The most important action was installation of a dedicated collector-host for input processing of flows from the primary border router between the CESNET2 backbone and global Internet. We have also reconfigured the system several times to reach better balanced load among available resources. This means that processing the incoming as well as redistributed flow streams moved from some collector-hosts to others. We regarded as a success that all these configuration changes have been made through the administrative interface only, without crashing any component of the system and without interrupting the data processing.

In autumn, almost all available capacity of this activity was consumed by practical use of FTAS. We observed a significant wave of DoS and DDoS attacks from/to nodes with Microsoft-based operating systems. With help of FTAS we were able to analyze and explain all incoming requests as well as validate or discard complaints of our internal sources. These conditions were also optimal for system stability tests under heavy load and for aggregation parameters optimization.

6 Performance monitoring and optimisation

This research activity investigates theoretical and practical aspects of end-to-end performance in high-speed long-distance networks. We concentrate particularly on monitoring their performance, studying the protocol behaviour and optimising their operation. This activity is associated with the SCAMPI and LOBSTER research projects and with the GN2 project JRA1 activity.

In the following sections we summarize the most important results achieved in 2004. More information about our publications, software and conducted experiments can be found on our web page[1].

6.1 Scheduling, processing and presenting the performance monitoring tests

When data traffic passes through a network, it experiences various performance characteristics, such as throughput, delay, packet loss rate, jitter, etc. Many performance monitoring tools have been developed to measure these characteristics or to check the current state of the network in order to verify that the required performance characteristics can be achieved. Performance monitoring tools are indespensable for locating fault points and performance affecting points, and to observe trends in network operation.

Different characteristics require different measurement methods. Also, different monitoring goals require different result processing and presentation. Tests can be started on-demand or scheduled regularly. Measured values need to be appropriately aggregated. Consequently, for a comprehensive view on various performance characteristics, a set of different tools is needed; this implies a need for an extensible framework for scheduling individual tests and for processing and presenting their results.

As part of our participation in the GN2 project JRA1 activity (Performance measurement and management) we developed a pilot version of the test scheduling and result processing framework. It allows us to acquire experience with various tools and observe their behaviour when used simultaneously between specified points in our network.

[1] *http://www.cesnet/english/project/qosip*

6.1.1 Test specification

Complete information about which tests should be run as well as the measured and processed results are stored in a MySQL database; its structure is illustrated in Figure 6.1.

The `test_type` table includes one record for each test type. The `tests` table includes one record for each test instance which can run between certain end points. The `attributes` table includes parameters of test instances, such as the IP addresses of end points. Measured values are stored in the `mvalues` table and aggregated according to instructions in the `aggregations` table. The database also includes information on graphs presenting the results and constraints about which tests cannot run at the same time because they would influence each other.

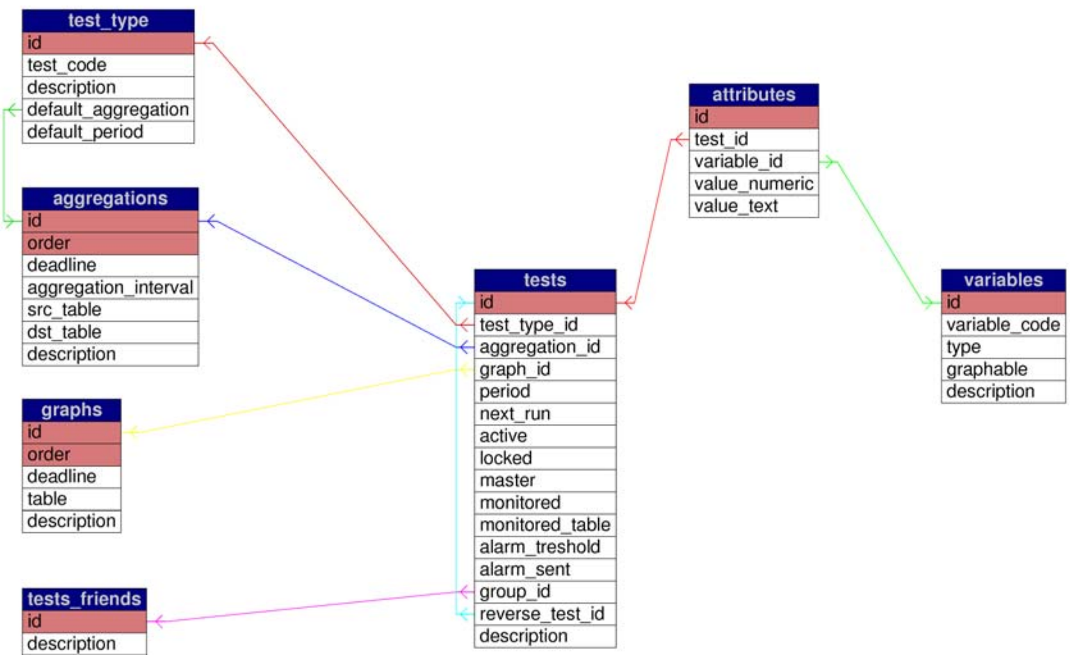

Figure 6.1: Database structure

6.1.2 Test scheduling and data aggregation

The test scheduler is implemented by a script which reads the `tests` table and executes tests at specified times. The script checks if particular tests can be started in parallel or if they must not overlap. Execution of tests at remote sites is done by NRPE. A remote site executes another script which wraps the particular test command (e.g., iperf) and translates its output to an appropriate format which is processed by a child process started from the scheduler and written to the database.

Aggregation is performed by another script (usually specific for each test type) executed periodically approximately every 10 minutes. There is no link between data aggregation intervals and the interval in which the script is executed. Aggregation intervals are specified in the `aggregations` table. The script aggregates and deletes individual measurements older than the current timestamp minus the `deadline` field.

6.1.3 Test result presentation

All measured results from all tests are available in a uniform web-based user interface illustrated in Figure 6.2. The user can click on any graph to display it in a larger resolution as illustrated in Figure 6.3. A set of graphs for different time scales is generated automatically.

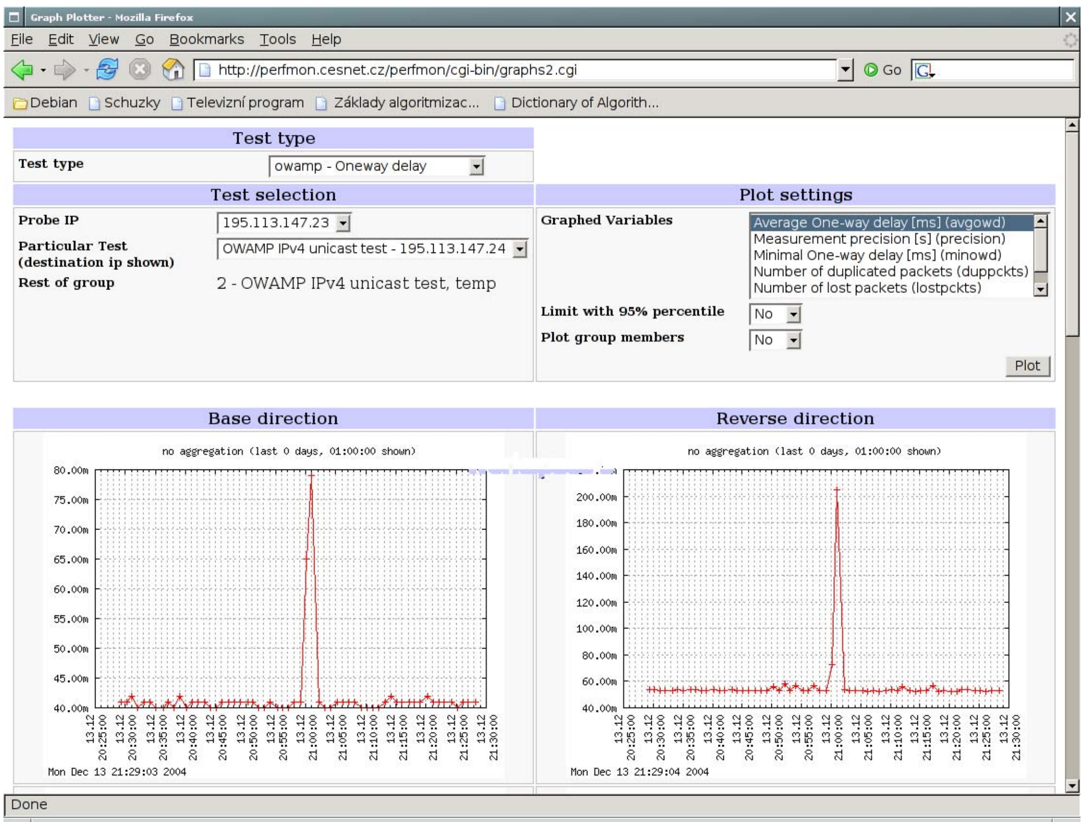

Figure 6.2: Test result presentation

Users first select the type of test. Currently we use three types of tests – bwctl (wrapper around iperf) for active throughput measurement, owamp for active one-way delay measurement, and reading router interface byte counters via SNMP for instantaneous link load measurements. We plan to add further tests as needed. The system finds all test instances of the selected type automatically.

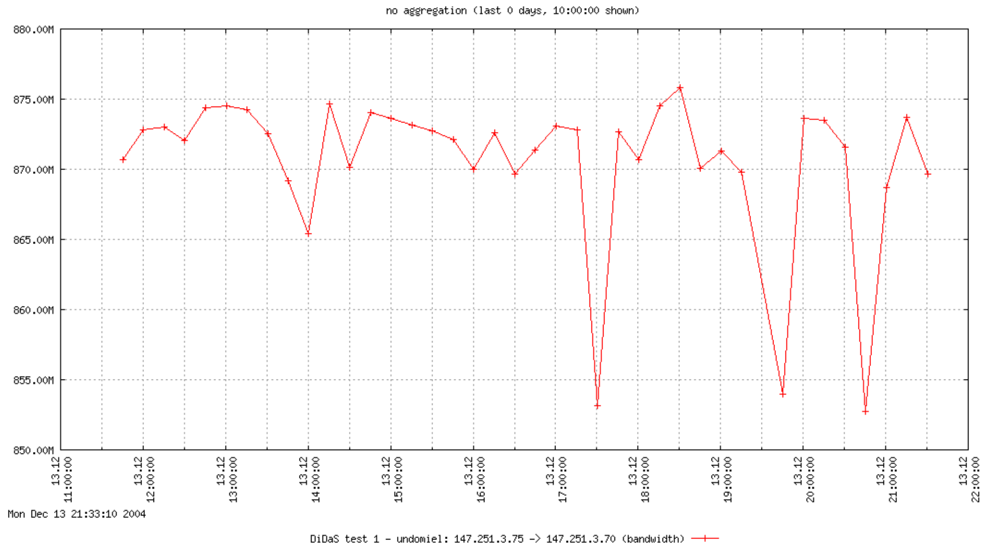

Figure 6.3: Enlarged graph of throughput measured by bwctl

In the next step, users select a particular test instance by specifying its end points. The system automatically finds all performance characteristics measured by this test instance. Afterwards, users choose one or more performance characteristics to be plotted in graphs using different colors and line styles.

Finally, users can choose if values exceeding the 95 % percentile should be omitted from graphs. This allows utilizing the graph space to display most values in finer detail – otherwise, several excessive values might compress most values to a small portion of the graph space. The user can also select plotting several test instances in the same set of graphs for easy comparison.

6.2 Congestion control monitoring and optimisation

Most network traffic is currently carried by the TCP protocol which provides reliable data transfer. TCP uses several congestion control mechanisms. Their task is adjusting the transmitting speed according to the current available bandwidth and trying to exploit it as much as possible. TCP was designed at the beginning of the Internet development when network lines were slow. Some of its mechanisms do not provide optimum performance on today's high-speed long-distance networks with high volume of outstanding data sent by the sender but not yet acknowledged by the receiver.

Many performance problems are caused by improperly set parameters of the TCP congestion control mechanisms. In order to optimise these parameters, we need a monitoring system providing real-time information about TCP internal runtime variables. We also need a tool to configure these parameters.

6.2.1 Bulk utility

We developed a utility called *bulk* for active throughput measurement (done in a similar way to the well-known *iperf* tool) which allows synchronous monitoring of TCP runtime variables. *Bulk* uses standard `setsockopt()` and `getsockopt()` system calls, particularly for the `TCP_INFO` socket option to set and get parameters of TCP connections. The utility includes mnemonics for many known socket options; however, their numeric codes can also be used. In this way the tool can be used with any newly added socket options in new operating system kernel versions.

For instance, we may want to measure the performance using ten parallel data streams and a 10 MB sender socket buffer. Wishing to check if the initial connection handshake (during which also the TCP window scaling factor is agreed upon) went properly, and also wishing to observe the TCP runtime variables `rcv_ssthresh`, `rtt` and the actual size of receiver socket buffer, we can use the following command:

```
./bulk -v -m -c50 -sSO_RCVBUF,10000000 -b10000000\
  -gwscales%Scales:\ ,rcv_ssthresh%Recv\ thresh:\ ,rtt%RTT:\
  -gSO_RCVBUF%Real\ RCVBUF\ size:\ >outfile_r.txt
```

The output may look as follows:

```
...
[5] Scales: 16 Recv thresh: 81919 RTT: 10000 Real RCVBUF size: 131070
[5] Scales: 16 Recv thresh: 81919 RTT: 10000 Real RCVBUF size: 131070
...
```

6.2.2 AIMD patch

We also developed the *AIMD patch* for the Linux operating system (available for both 2.4 and 2.6 kernels). This patch allows us to set the aggresivity and responsiveness of AIMD (Additive Increase Multiplicative Decrease) – the primary TCP congestion control mechanism. Standard TCP uses AIMD (1, 0.5); this increases sender congestion window (cwnd) by one MSS segment each RTT and decreases cwnd to 0.5 of the current value when packet loss is detected. These settings are normally fixed values in a TCP implementation and do not allow utilizing the available bandwidth in high-speed long-distance networks with high volume of outstanding data.

This patch also permits switching on/off and monitoring the CWV (Congestion Window Validation) and CWR (Congestion Window Reduction) activity. All these options can be configured and monitored individually for each socket connection. This is a significant advantage over similar existing tools which can only operate on all socket connections. This patch implements two new socket options `setsockopt()` and `getsockopt` – `TCP_AIMD` and `TCP_COUNTERS`; these are also supported by the *bulk* tool.

As an example, if we want to modify TCP congestion control just for the connections of the current application to AIMD(2, 0.75), we can use the following code fragment:

```
struct tcp_aimd aimd;
struct tcp_counters counters;

aimd.slope=200;
aimd.ratio=75;
aimd.cwven=0;
aimd.tqcwr=0;

setsockopt(sockfd, SOL_TCP, TCP_AIMD, &aimd, sizeof(aimd));
getsockopt(sockfd, SOL_TCP, TCP_AIMD, &aimd, &wsize);

printf(”AIMD members: Slope: %d, Decr: %d, CWV: %d, CWR: %d\n”,
       aimd.slope, aimd.ratio, aimd.cwven, aimd.tqcwr);
```

The sender congestion window will then proceed as illustrated in Figure 6.4. The volume of transferred data is given by the space below the cwnd curve. Of course, filling the available bandwidth more aggresively may affect other connections and may increase packet loss, thus influencing the throughput of all connections. For optimum results, the AIMD parameters need to be adjusted for particular network conditions.

6.3 Parallel scp and parallel socket library

One way to achieve higher throughput for transfers of large data volumes is to use several connections in parallel. This allows us not only to utilize several

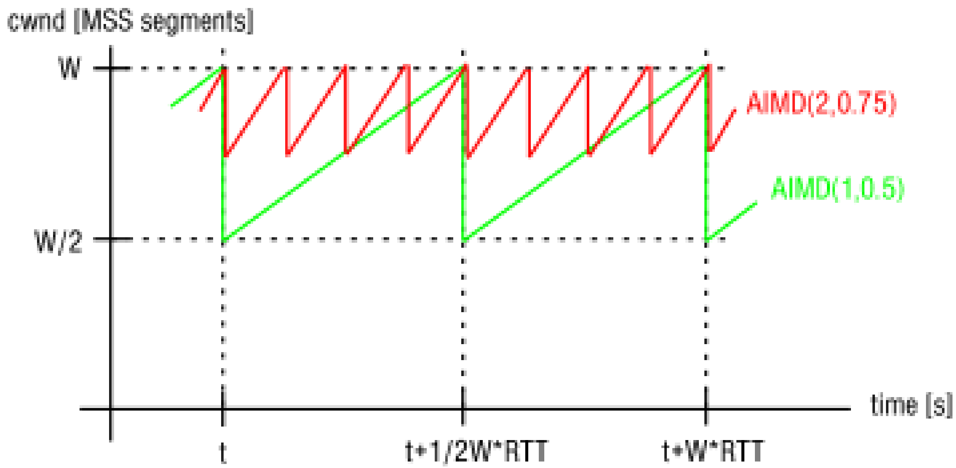

Figure 6.4: Congestion window development for different AIMD parameters

parallel physical paths, but also to better utilize the bandwidth available on a single high-speed network path. The latter case is an alternative to modifying the AIMD parameters. The advantage is that we do not need to modify operating system kernel; all changes can be done within the application.

We developed two implementations of parallel transfers. The first implementation is *pscp* – a parallel version of the well-known *scp* program for secure remote file copying. *pscp* operation for two parallel connections is illustrated in Figure 6.5. Each connection uses one instance of an underlying *ssh* program which does not need to be modified. An important feature is that we can use the standard *sshd* daemon on the server side whose modification would require root access.

Results of performance measurement from copying a 100 MB file over two network paths through the GÉANT2 network are summarized in Table 6.1. PC1 was *ezmp2.switch.ch* in Switzerland and PC2 was *tcp4-ge.uninett.no* in Norway. Both sending and receiving socket buffers were large enough so that they did not limit communication. We tried 1, 2, 5, and 10 parallel connections. The table indicates the number of seconds needed to copy the file. We can see that parallel communication generally reduced the time needed to copy the file. In certain cases the performance stopped improving or even dropped with higher number of parallel connections. This can be caused by several reasons – sending or receiving machine may have been overloaded, or the maximum achievable throughput given by the current background traffic had already been reached and more streams just increased the processing overhead.

We also developed the first release of *psock* – parallel version of a standard socket library for network applications. The advantage of the *psock* library is the possibility to use parallel transfers with any application which needs

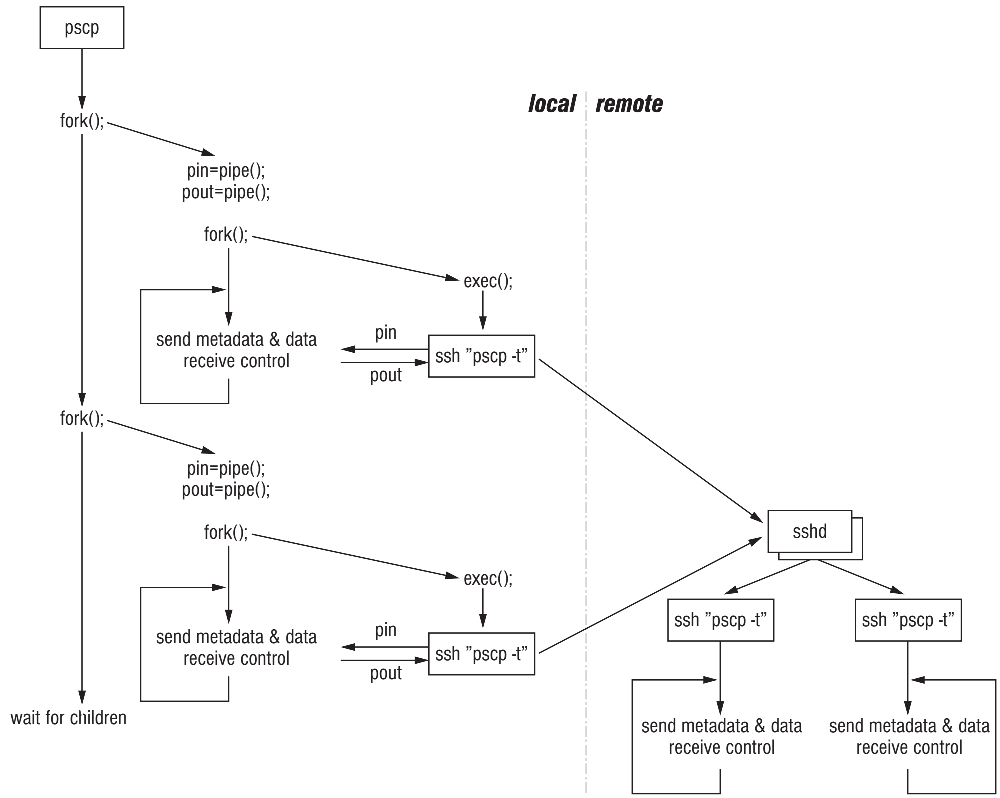

Figure 6.5: pscp (parallel scp) operation

Connections	Cesnet–>PC1	PC1–>Cesnet	Cesnet–>PC2	PC2–>Cesnet
1	21.6	28.5	43.9	36.7
2	12.1	14.2	41.2	25.8
5	12.9	9.2	34.3	25.8
10	14.8	9.4	32.8	28.0

Table 6.1: Duration of file copying using pscp

only small modifications. The library also permits using different algorithms for distributing data among parallel streams, thus adjusting the transfer to conditions of individual connections and allowing experiments with different techniques. We are currently enhancing the *psock* and measuring the performance.

6.4 PERT

PERT (Performance Enhancement and Response Team) is an emerging international initiative attempting to create a technical and organisational structure to assist users in solving network performance problems.

At the present time a pilot PERT project is underway. The European NRENs take turn in weekly shifts to work on open performance problem cases. The knowledge acquired during problem investigation is stored in a database for futher reference. PERT day-to-day operation is documented in an electronic diary.

Typical problems investigated by PERT are sudden drops in throughput during communication between two points in European NRENs, increased packet loss or strongly asymmetric performance (particularly throughput) between some points. The PERT case database is illustrated in Figure 6.6.

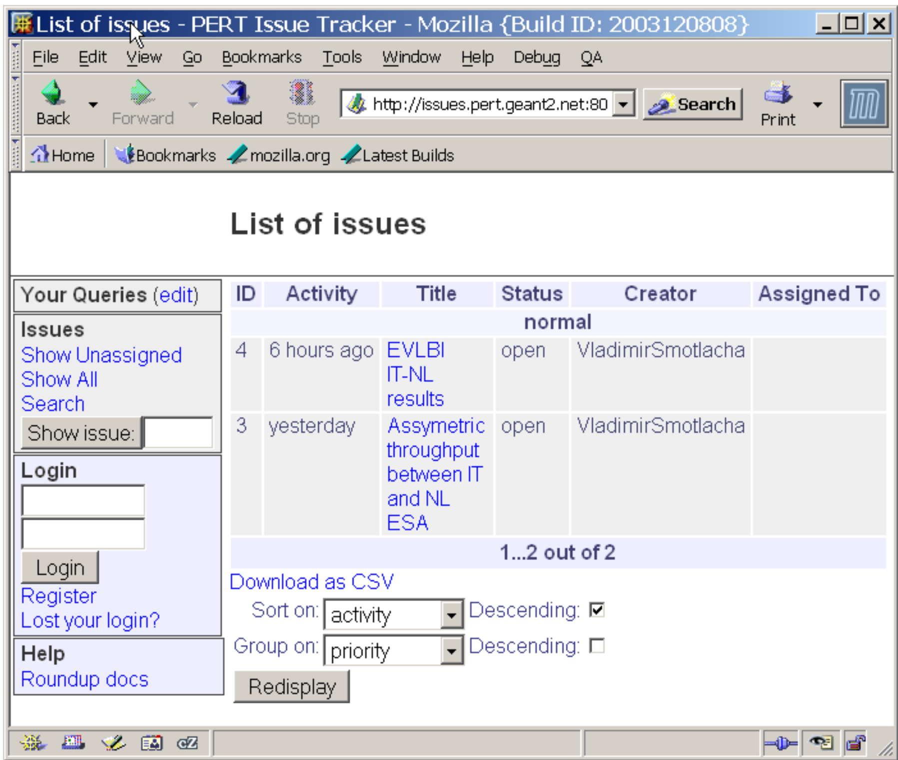

Figure 6.6: PERT case database

6.5 Time synchronisation

Network monitoring requires assigning precise timestamps to all observed events, such as sending a packet, receiving a packet, reading registers of network devices, etc. These timestamps can then be used to compute certain important communication characteristics, such as one-way delay, round-trip time, jitter, etc.

Timestamps should comply with two requirements:

- Accuracy, i.e., the deviation from the absolute time, must be lower than certain specified limit
- Resolution, i.e., the step of the clock generating timestamps, must be sufficiently small so that any two events generate distinct timestamps

When monitoring high-speed networks, the required accuracy might reach several microseconds and the resolution should not be over tens of nanoseconds. To achieve these requirements, the system clocks in measurement points are synchronised usually using GPS receivers. There are several computers in CESNET premises that must have their clocks synchronised. This is why we developed and installed a distribution unit which can send the signal from one GPS receiver to eight computers using standard twisted-pair cabling. We plan to install a second unit in January 2005. The installation in some of the other locations of the CESNET2 network requires either a long cable from a GPS receiver to the computer or an optical coupler inserted in the connection for safety purposes. For these locations we ordered customised RS-232 to RS-422 converters suitable for outdoor installation.

6.6 Remote access to network generator/analyser

In cooperation with the *Optical networks* CESNET research activity we tried experimental long-distance access to a 10 Gbps network generator/analyser (Spirent AX/4000) at physical layer (L1). These generators/analyser are useful but expensive devices and the experts would welcome if they could share access to them using remote connection. The experiment configuration is illustrated in Figure 6.7.

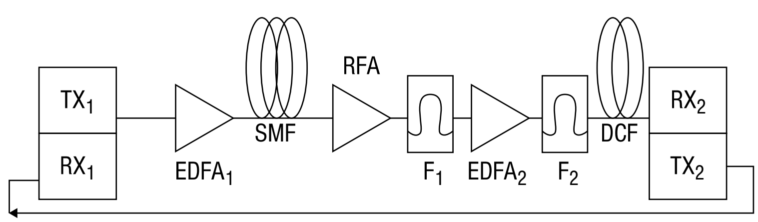

Figure 6.7: Experimental remote access to network generator/analyser

We verified that using this device over the distance of 210 km was possible and we expect that this distance could be extended up to 252 km in another configuration. However, the equipment (optical amplifiers and filters) needed to access the device was expensive and would render remote access ineconomical. We plan to do more experiments with remote access at higher layers (L2 and L3), which should be less expensive but it would probably introduce some limitations on accessible functionality of the generator/analyser.

6.7 Future work

In our future work we plan to concentrate on the following topics:

Firstly, we want to continue researching the congestion control mechanisms in high-speed long-distance networks. Secondly, we plan to continue our work in performance monitoring. We want to install a pilot version of a performance monitoring system in the CESNET2 network and to contribute to the JRA1 activity of the GN2 project by integrating the SCAMPI passive monitoring platform with the emerging JRA1 infrastructure. Next, we plan to work on low-level user data anonymisation within the LOBSTER project. Finally, we plan to contribute to the PERT initiative by setting up a pilot PERT in CESNET.

7 AAI and Mobility

7.1 AAI and Mobility

The research activity *AAI and Mobility* aims at creation and development of a generic *Authentication and Authorization Infrastructure (AAI)*. This infrastructure would serve as an authentication and authorization service provider to users and resource owners of the CESNET2 network, thus eliminating the need to register every user for every service. The concept assumes using authentication services operated by individual institutions – every user is registered within his/her own home institution which has established identity verification mechanisms. A proper user categorization may even be used as one of the authorization decision inputs.

This ambitious aim requires deployment, development and standardization of communication interfaces of institutional authentication systems not only at the national but especially at the international level. Close bounds to international development in this field strongly affect the advance of the national level solution.

Even in the international context, the generic AAI has been prepared mainly as a theoretical concept so far. In addition to it, several projects are developing their own specific authentication and authorization infrastructures. One of the most importants is the RADIUS-based infrastructure operated by the eduRoam project.

7.1.1 The eduRoam.cz project

In accordance with the international context, an essential portion of our resources was devoted to the development of services for mobile (roaming) users. The *eduRoam* project started within the TF-Mobility working group of TERENA and later was included in the GN2 project JRA5 activity. It enables users from the individual participating institutions to connect to a (usually wireless) network operated by any of the participating institutions and get that way Internet connectivity and, optionally, access to some other services provided by the hosting network. The user is always authenticated by his/her home institution. The communication channel between the authentication service and the user is created in one of the following ways:

1. 801.1X + RADIUS hierarchy (the preferred way)
2. VPN tunnel
3. WWW application + RADIUS hierarchy

AAI for eduRoam consists of a hierarchical tree-like structure of RADIUS servers organized basically in three levels. The institutional-level servers provide

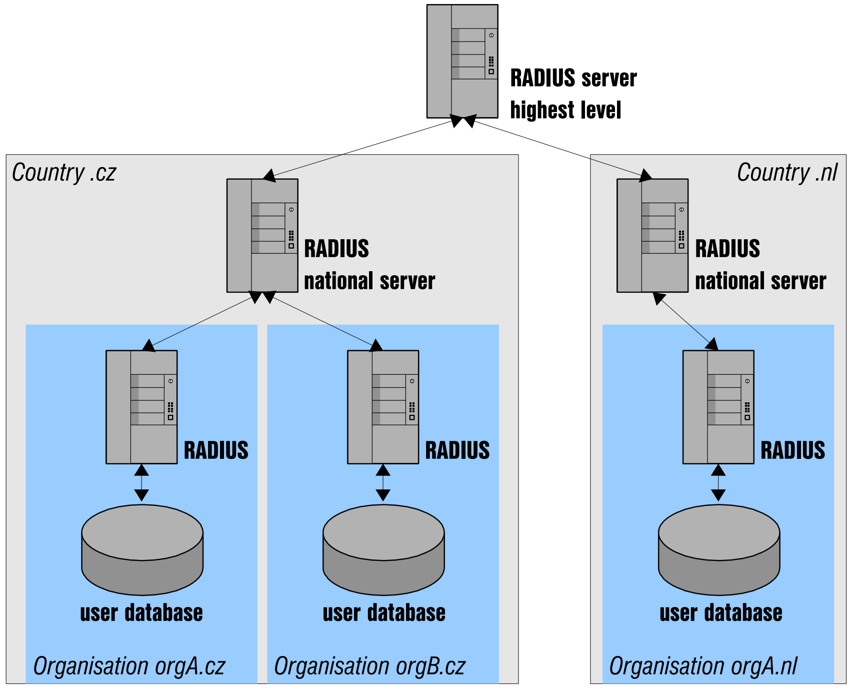

Figure 7.1: AAI in eduRoam

authentication of local users – usually they serve as front-ends to local user databases. When confronted with a request to authenticate a non-local user, the server forwards the request one level up to its national RADIUS server. Every national server maintains a list of participating institutions and their RADIUS servers within its region. If the incoming request is asking for authentication of a user from any institution registered at the national server, it is forwarded to the corresponding institution's server. All other requests are forwarded to a top-level server. Top-level servers maintain lists of participating national networks and their RADIUS servers and forward the requests accordingly.

Participation of the Czech Republic in the eduRoam project is coordinated by the *eduRoam.cz* national project. Its pilot started in the second half of 2004 and was much appreciated by Czech academic institutions. Nine sites from eight institutions were connected by the end of 2004:

- CESNET, Prague
- Charles University
  - Faculty of Pharmacy, Hradec Králové
  - Rector's office, Prague
- Faculty of Electrical Engineering, CTU, Prague
- Technical University of Liberec
- University of Hradec Králové

- Jan Evangelista Purkyně University in Ústí nad Labem
- Institute of Chemical Technology, Prague
- University of West Bohemia, Pilsen

The eduRoam.cz pilot goal is to prepare and verify technical and organizational preconditions for roaming among Czech academic networks as well as their cooperating with other eduRoam networks. The pilot addresses four main tasks:

- verification of functionality, reliability and compatibility of the RADIUS hierarchy
- verification of 802.1X devices functionality for users, recommended configurations, documentation
- coordination of authentication VPN tunnel configuration
- roaming policy formulation

Current information, documents, guides and software are available at the pilot portal *www.eduRoam.cz*.

Link to the other parts of the eduRoam infrastructure is implemented by two national RADIUS servers *radius1.eduRoam.cz* and *radius2.eduRoam.cz* running the RADIATOR[1] software by the Open System Consultants (none of the open source RADIUS servers met the projects requirements). The communication channel security is increased by mandatory IPsec implementation.

For non-802.1X enabled devices, a *Scaa* WWW authentication gateway was developed within the project. It consists of a firewall controlled by a WWW application using the RADIUS protocol to authenticate users. The Scaa gateway is being used in CESNET offices LAN as an alternative to 802.1X authentication. The software is available at the project portal *www.eduRoam.cz*.

The pilot will be evaluated in the second half of 2005. We expect that the outcome will contribute to creation of a standard roaming environment in the CESNET2 networks. We plan to continue the international cooperation in development of eduRoam-NG, i. e., the new generation of the roaming infrastructure which should rectify some of the current system imperfections based mainly on the RADIUS protocol and its mode of usage. We assume that our experience with IPsec-secured infrastructure operation will be a valuable contribution to the eduRoam development community.

[1] *http://www.open.com.au/radiator/*

7.1.2 Generic AAI

In spite of our original assumptions, standardization of AAI interfaces among European NRENs has not advanced very much during 2004. The GN2 project which deals with AAI and mobility in its JRA5 research activity has only been started in the fourth quarter of 2004; TF-EMC2 – the new AAI-oriented TERENA workgroup – has also been established only in the autumn. Most of AAI-oriented human resources from all NRENs seem to have taken part in preparing for these two forums.

The direction of the future advancement being kept open, we concentrated on development of the local AAI elements (user databases – LDAP, individual authentication systems, PKI). Integration-oriented tasks were postponed until key compatibility issues are sorted out. Our researchers actively participate in both groups mentioned above. As a result, we are not only informed about their activities but we can also influence their decisions.

7.1.3 PKI

In 2004, the CESNET CA continued its services. In addition to routine operation (more than 200 active server certificates and more than 80 personal certificates have been operating by the end of the year), we modified the server certificate profile to make it acceptable to common 802.1X clients.

At the same time, the preparation to root keys changeover was started. Current root certificate is going to expire at June 27, 2006. Because the end entities' certificates are valid for 12 months, the last end entity certificate in current configuration can be issued at June 27, 2005. EUGridPMA (the body most influencing the CESNET CA policy) is in the process of changing its minimal requirements on CAs. The discussed changes define a new value for maximum validity period for a root certificate and some other certificate profile parameters. We plan to use the changeover as an opportunity for a principal system change to make full use of the new minimal requirements and to deploy professional Entrust Authority CA software which would increase user and operator comfort while providing maximum security and credibility.

8 IP Telephony

IP telephony is an application running on packet switched data IP networks. Compared to a channel switching based telecommunication system, IP telephony is a more effective and advanced technology using up-to-date voice coding methods and communication protocols. The IP telephony project, started in mid 1999, allows this advanced method of voice communication to run within the CESNET2 network. In general, this activity aims to support the CESNET members in connecting and using the IP telephony network built by the CESNET Association. A research part of this project tests and develops the IP telephony applications and components.

8.1 Current state

By the end of 2004, 21 Association members became involved in this project with a total of 31 voice gateways. During 2004, the CESNET2 IP telephony network interconnected more than 1.3 million phone calls totalling over 4 million minutes. Fifteen percent of calls were toll-free internal calls within the CESNET2 network. The rest was routed to the PSTN and incurred costs were charged to the appropriate Association members. During 2004, the fifth year of the IP telephony project, the members' interest in IP phone calls reached its peak. Figure 8.1 illustrates the duration of phone calls in hours made during past three years.

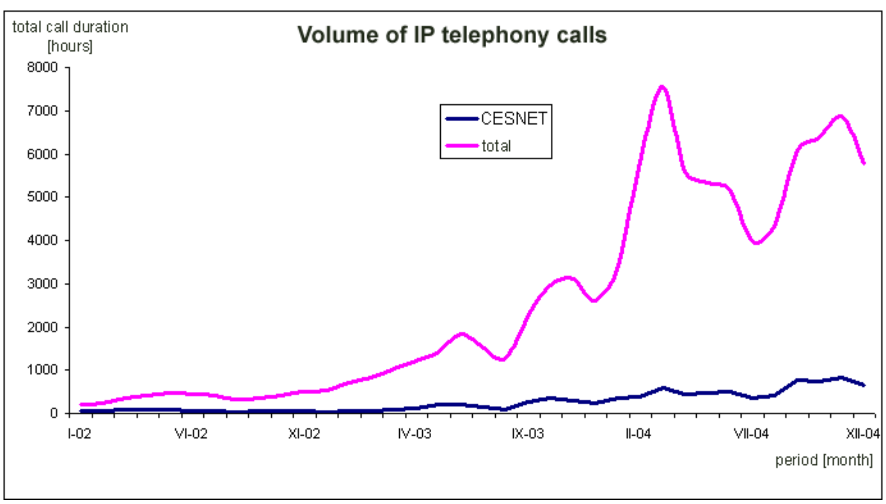

Figure 8.1: Duration of phone calls in hours between 2002 and 2004

A list of currently connected institutions can be found at the Project web site [1] together with their prefixes and foreign peering.

8.2 Gatekeeper

Kerio, the supplier of the border gatekeepers deployed in the CESNET2 network, decided to terminate the VoIP product development and support. As a result, one of our goals in 2004 was replacement of the Kerio gatekeeper with a suitable alternative. We chose an open source solution based on the Debian/GNU Linux platform. We examined the current state of open source Linux gatekeeper applications by evaluating the following projects:

- The **OpenGK** at *www.openh323.org* is an operational but unfinished project. The latest update was published in mid 2004 and no further development is under way. It can be configured using the web but still we decided that this GK project is of no interest to us.
- The **GnuGk** at *gnugk.org* also uses the OpenH323 attribute. After testing it thoroughly, we chose this solution, bought two PCs and installed version 2.0.7 in mid 2004. Version 2.2.0, released in October, is used in the CESNET2 network now.
- The **Asterisk** (*www.asteriskpbx.com*) is a Linux project of a software private branch exchange. We are interested in this project as it supports both the H.323 and SIP protocols. We plan to investigate the Asterisk during 2005. Current version is 1.0.

We deployed two GNU GK gatekeepers in the second half of the year. They can be accessed using the *gk1ext.cesnet.cz* and *gk2ext.osanet.cz* domain names. Servers are deployed at topologically and geographically distant locations: the *gk1ext* is located within the CESNET Association premises in Prague, while the *gk2ext* resides within the premises of the Technical University in Ostrava. Static records for all voice gateways in both gatekeepers were created and reachability of all gateways was checked. The H.323 endpoints wishing to communicate with their CESNET2 counterparts may register in these gatekeepers. This is of concern mainly for foreign research and educational institution gatekeepers, gateways and terminals. These two border gatekeepers allow them to connect only to the CESNET2 network; PSTN connection attempts are rejected. Two internal Cisco gatekeepers located also in Prague and Ostrava route local calls to the PSTN. The Gatekeeper diagram is shown in figure 8.2.

[1] *http://www.ces.net/project/iptelephony/calling.html*

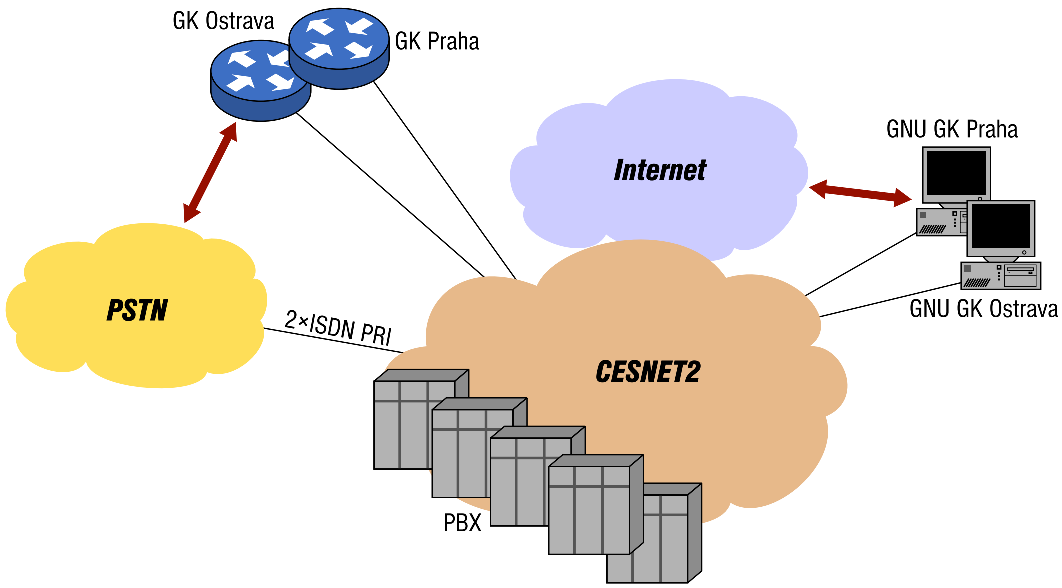

Figure 8.2: CESNET2 network Gatekeeper schema

Originally, connections were set up using a new IP2IP GW, but problems occurred at the H.245 level: only connections using the FastConnect method were set up correctly by the IOS. This method has been supported optionally since H.323v2, however, some applications (e.g., the NetMeeting) use H.245 explicitly. In the end we chose static routing in the border gatekeepers. Final setup of border gatekeepers should bring automatic redundancy. Turning off one of the GKs generates a URQ message and a subsequent RCF message to be sent to all endpoints. The URQ message requests for re-registration and the RCF message presents a list of alternative GKs. As a result, redundant mode is attained. Currently, experiments with DRC, GRX and Proxy mode are under way in the Ostrava GK. Therefore, only the *gk1ext* running in GRC mode is fully operational.

8.3 QoS research in the CESNET VoIP network

An IP phone monitoring application using the SNMP protocol has been developed. This allows IP phone MIB2 database lookups and receiving traps. Results are stored in the MySQL database and can be visualized using PHP scripts. Compared to SNMP, the ITU-T H.341 standard offers much better monitoring potential but unfortunately, almost no IP phone manufacturers implement it. Primarily, the SNMP monitoring application allows gathering packet loss information and

IP phone network adapter status. This project was developed under the Linux OS using the following components:

- Apache
- MySQL
- PHP, PHP-MySQL, PHP-SNMP
- UCD-SNMP

In the second half of 2004 we targeted call quality measurements using the R-factor which was calculated using the new E-model. The Surveyor software analyzer was used for this purpose - the only one capable of R-factor measurement in mid 2004.

The R-factor is described in the ITU-T G.107 recommendation which defines a computing model known as an E-model. The R-factor is a well-tried tool for transmission planning and for determining the combined impact of various transmission parameters which influence the call quality. All appropriate transmission parameters are put together to calculate the R-factor as follows:

$$R = R_O - I_S - I_D - I_{E-EFF} + A$$

where

R_O: is the basic signal-to-noise ratio,

I_S: is a sum of all impairments occuring during speech transmission,

I_D: is a degradation factor representing all impairments caused by the voice signal delay,

I_{E-EFF}: includes packet loss,

A: is an advantage factor (permitted range is from 0 to 20)

Two sorts of R-factor were identified during measurement: Network R-factor comprising the device impact and User R-factor adding the susceptibility effects. Currently, the MOS parameter is mostly used for quoting the connection quality value; therefore, converting the R-factor to MOS is important. Our analyzer immediately converted the values measured to MOS. The VoIP connection parameters withing the CESNET2 network using different codecs were measured and the results were published in a report available at this web site[2].

As an example, the value of the MOS parameter of a phone call to the Louisiana State University reached 3.71. This roughly corresponds to the maximum MOS

[2] *http://homel.vsb.cz/ voz29/files/voz49.pdf*

value achievable using a cell phone. The value of MOS during a call to the Hungarnet VoIP network reached 4.23 – this is the maximum value achievable during a PSTN call. These results prove that even the international calls made by the VoIP technology can be of excellent quality.

8.4 Numbering scheme

In the mid 2004, prefix 950 0 was assigned to the CESNET Association as its VoIP network access code by the Czech Telecommunication Office. As a result, CESNET acquired 100,000 assignable phone numbers. These numbers can be reached from public telephone network via the Technical University Ostrava and Czech Technical University Prague PBXs; this is a part of an experiment agreed to by the GTS Czech operator. These numbers should be available especially for IP phones and videoconferencing applications. Unfortunately, termination of these numbers from PSTN to the CESNET2 network is not yet possible. Number termination should be a part of voice service provider selection procedure.

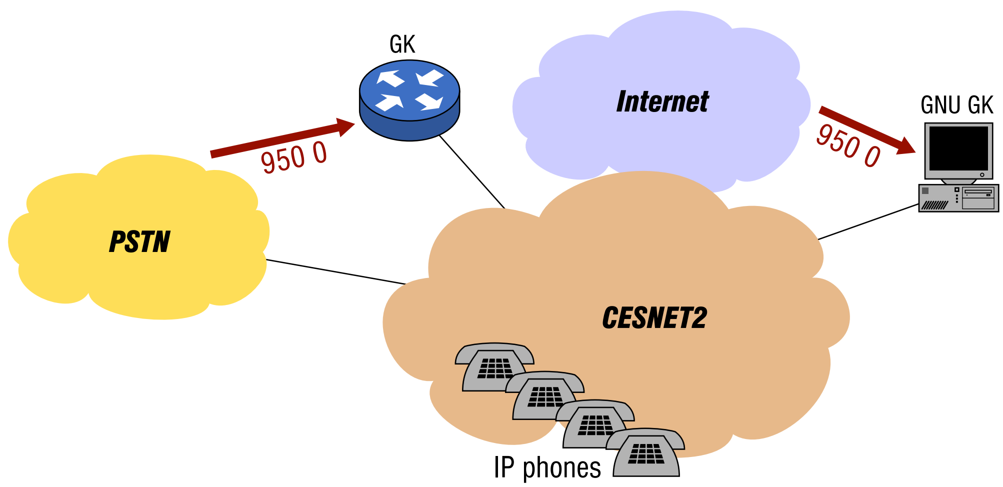

Figure 8.3: The 950 0 access code assignment

The IP telephony prefix will be used for accessing the CESNET2 network not only from PSTN, but also from the Internet where especially the use of the ENUM protocol is expected.

8.5 Alternative call exits using CESNET VoGW

A voice gateway Cisco 2651-XM equipped with 2×ISDN/PRI was bought and installed in May 2004 in Ostrava where an alternative connection of the CESNET2 network has been deployed. The prices for the Moravian-Silesian and Prague telephone districts (TDs) are equivalent. Another exit into the Brno TD should be added in the first half of 2005. The interconnection agreement has not been signed yet.

8.6 Cisco Call Manager

During 2004 the Cisco Call Manager system (CCM) was upgraded from version 3.3 up to version 4.1.2; this brought significant interoperability improvement between the CCM, H.323 and SIP elements. System redundancy based on two hubs continues: the publisher (primary server) is located in Prague, the subscriber (spare server) in Ostrava. Because of these changes, compatibility problems arose on ICM 5.0 which is a fundamental part of the IPCC. This problem can be circumvented by using the IPCC Express version (CRS 3.5.1); however, this impacts the available functionality.

Configuration of several coexisting numbering plans within one CCM cluster has been tested successfully. This way, several device groups were set up and each of them could be assigned specific rules independently of the others. This coincided with solving the communication problems between the CCM and various gateways as well as with setup of codecs. Currently, this type of communication has been tested with C26xx, C1751 and M3810; this service will soon be ready for the Association members (accessing the network using the 420 950 0 prefix, connecting the members' IP phones). The Undefinite Messaging system represented by the Cisco Unity 4.0 and its interoperability with the CCM is being tested. Tests with SIP elements are being prepared. Initially, the Lotus Notes were used; however, this software did not meet our requirements and was replaced by the MS Exchange 2000. We were also concerned with the security issues – we used a newly installed independent experimental CCM server to test the service security parameters as well as communication security.

8.7 SIP

The main parts of the SIP infrastructure are represented by two SIP servers running the IPv4 as well as IPv6 protocols. These servers can route calls to the

PBX gateways of the Association institutions, registered clients as well as remote IP phone domains, e.g., MIT (SIP.edu), SANET, NASK. We have advertised the general accessibility of our IP telephony network within the TERENA TF VVC and we have already detected several calls from the SANET network.

Accessibility of the SIP servers is supported by advanced DNS resource records. A basic method uses SRV records which provide service point propagation (server address or name and port of the target service). The SRV records also support load-balancing and service backup methods. In addition to the SRV records, we can also use the NAPTR records which provide a more advanced mechanism for locating the services. This way, users can determine which types of service the domain provides as well as the priority of services, and only then they will query the service point stored in the SRV records. So far, only several applications support the resolution of the NAPTR records. Should SRV records be resolvable but resolution of NAPTR records unavailable, the solution can be regarded as unsatisfactory. Experiments with these kinds of special records are going on to reach better service availability, simpler interdomain routing and easier client configuration; this should bring faster and easier IP telephony client deployment and administration.

The process of integrating SIP components into the AA infrastructure has advanced. A need to upgrade the existing LDAP modules of the server to provide at least secure communication (LDAPS) has been confirmed. We are testing the third version of our authentication module extension using a newly set up testing LDAP server. We also continued testing the SIP server and his advanced services but this system is not yet available for user registration. We postponed this phase because a new release of the SIP server scheduled for beginning of 2005 brings changes in functionality and module interface. We are working on upgrading modules for the new version and we are testing new server configuration.

We tested a Polycom Sound Point IP 500 SIP phone with very satisfactory results. Compared to Cisco phones, this device is equipped with advanced functionality like instant messaging, presence and interesting pricing. Its firmware is undergoing rapid development and we plan to continue its tests within the large IP clients' test planned for 2005. We also tested a complex audio-video client Wavethree Session which is used by the SIP.edu initiative members. The open source world was represented by the Linphone client which supports the IPv6 as well as the ENUM resolution, although in a rather nonstandard way. Its major problem is unsupported SRV record resolution. In the second half of 2004, we made basic tests of the Xten eyeBeam, Minisip, and SJPhone clients. In spite of qualitative improvement, these clients do not satisfy our needs in some areas (DNS SRV, etc.). We also made some basic tests of the GnomeMeeting client whose current version supports only H.323; however, its new version supports resolution of SRV records according to H.323v5 Annex O which is a very rare function. We also stored the SRV records for the H.323 service in main CESNET2 DNS servers for further testing.

Our newly installed test gateway allows us also verifying the IPv6 support. Results from our test show that Cisco gateways do not yet support the SIP signaling over the IPv6 protocol.

8.8 ENUM

A national ENUM domain (0.2.4.e164.arpa) has been delegated to the CZ.NIC Association. Based on our previous discussion with the CZ.NIC Association, we expected some progress in this field during the first half of 2004 but there was none. As a result, we continued our tests within a private E.164 domain within *cesnet.cz*. We are dealing with various possibilities of storing, converting and administering the records. The development version of the SIP servers can query several ENUM domains concurrently.

During the CZ.NIC's technical workshop we presented the need of testing delegations before the registration system starts operating. These test delegations were enabled during the third quarter of 2004. Active delegations for the 234 680 and 950 0 ranges, used directly by the CESNET Association for IP telephony applications, have been set up within the 0.2.4.e164.arpa domain. Most of these ranges are served by the CESNET main name servers, while testing subranges are delegated to the test name servers where the experiments with the records are going on. So far, the records are administered by hand because the results of our experiments influence the record layout. Experiments within the public tree significantly influence the general behavior of the query system, e.g., the total response time needed for queries sent from remote zones. The quality of ENUM support in Cisco gateways has not changed yet; this means that the gateways support only the old record format and can not assign calls to signaling protocols correctly. Therefore, we considered using TCL scripts and an auxiliary RADIUS server for external resolution.

9 METACentre

The primary focus of the METACentre activity is a development and production support of the distributed infrastructure – the national Grid which connects computing and data resources and provides a solid foundation for advanced applications using the computer network.

The METACentre activity is closely coordinated with work on the EU 6th Framework Program project EGEE (see page XY). This close collaboration of both groups is also a strong guarantee that results and achievements of the international project are immediately deployed within national infrastructure and at the same time it provides a forum where the METACentre results can be presented and may be used in the international environment.

For the year 2004, the METACentre activities were split into the following areas:

1. Production operation of the METACentre infrastructure
2. Establishing user support, including a full reconstruction of the METACentre portal
3. Research and development of new grid monitoring infrastructure
4. Security in the Grid environment

Research and development in the field of resource scheduling has not been a part of METACentre activities mostly due to the budget restrictions. In the long term we expect to use the results of research (conducted at the Masaryk University in Brno) as a part of the research plan of the Faculty of Informatics and Institute of Computer Science.

9.1 Production operation

Clusters of personal computers are the main METACentre computing facility. We take care of three sites – at the University of West Bohemia in Pilsen, in the CESNET premises in Prague and at the Masaryk University in Brno – where some 262 CPUs have been operating by the end of 2004. All these clusters use Intel Pentium CPUs (ranging from Pentium III at 700 MHz to 3 GHz Pentium 4 Xeon dual core processors) with the Debian Linux operating system. Nodes within some clusters are also connected through the high-capacity low-latency Myrinet network which provides up to 2 Gbps duplex transmission speed. The Myrinet-based clusters are used for computations with very high requirements on speed, latency and throughput of the network connecting individual cluster nodes. However, users can access alternate computing environments, most notably the 64-bit systems by the IBM (based on the Power4+ processors) and by the AMD (based on the Opteron processor). Both these 64-bit systems run under the SuSE Linux operating system to provide an environment as similar as possible to the one used on more conventional 32-bit clusters.

In cooperation with the University of West Bohemia, Charles University and Masaryk University, the METACentre also operates high-end systems by the SGI and HP. The SGI servers provide almost 100 MIPS CPUs in Brno and Prague, the HP/Compaq AlphaServer in Pilsen is equipped with EV7 processors. The METACentre also operates a high-capacity tape library providing 12 TB of uncompressed space. This library is used to backup all METACentre sites, as the CESNET2 network throughput is sufficient to transmit even the high volume backups. The service is also offered to universities and other academic institutions. The continuous backup of the CESNET videoarchive is an example of the extended service – more than 1.5 TB of digital video material is currently archived. The tape library is served by the NetWorker system by Legato (or rather IBM, which has bought Legato recently), backups are kept for three months.

More detailed information about METACentre hardware and software is available at the METACentre portal, *meta.cesnet.cz*.

Despite budgetary restrictions, the METACentre computing capacity has been upgraded during 2004. For the purchase, we considered both the 32- and 64-bit architectures, but after evaluating all the proposals and taking into account the current state of compilers, development tools and environments for 64-bit architecture, we decided to stay with the proved IA-32 architecture. We purchased a new cluster with 70 Intel Pentium 4 Xeon processors with 1 MB secondary caches and working at 3 GHz frequency. The cluster uses dual CPU nodes, each with 2 GB of RAM and one 80 GB ATA disk. The cluster is currently located in the CESNET premises in Prague where it should gradually replace the dated SGI cluster with Pentium III processors.

However, the cluster purchase and installation has been just one of the activities related to the METACentre infrastructure operations. The group also participated in the following activities:

- Deployment of process accounting on all cluster nodes. This service provides detailed data about use of all programs installed in the METACentre. The statistics are available on the METACentre portal, and will be also gradually used for scheduling decisions, to provide a fairer resource sharing among METACentre users.
- Software maintenance, specifically the maintenance of scheduling systems. During 2004 the PBSpro scheduling system license has been extended to cover all the METACentre nodes. This unification of scheduling systems simplifies the situation both for system administrators and for end users – they will not have to become acquainted with different job management and submission systems. The narrowed focus to just one scheduling and batch queue management systems allowed to get better knowledge of its implementation and to be able to modify it to suit better

to our purposes. This led, e.g., to our identifying and correcting the cause of unexpected end user job aborts. During the year, all the nodes were also upgraded to a new version of operating system used.

- Cluster management, including tools for cluster monitoring. Nowadays, end users can monitor the state of their jobs through a portal where all the commonly needed information is available: cluster node state, state of individual queues, state of individual jobs (see *http://meta.cesnet.cz/cs/state/resources/index.html* and Figure 9.1.).

- The most commonly used applications were ported to the environment with non IA-32 architecture. Results of this work will be immediately available outside the METACentre, e.g., users of the National Centre for Biomolecular Research will use the AMD Opteron ported versions on their new cluster, purchased near the end of the year and consisting of 8 dual 64-bit AMD Opteron nodes.

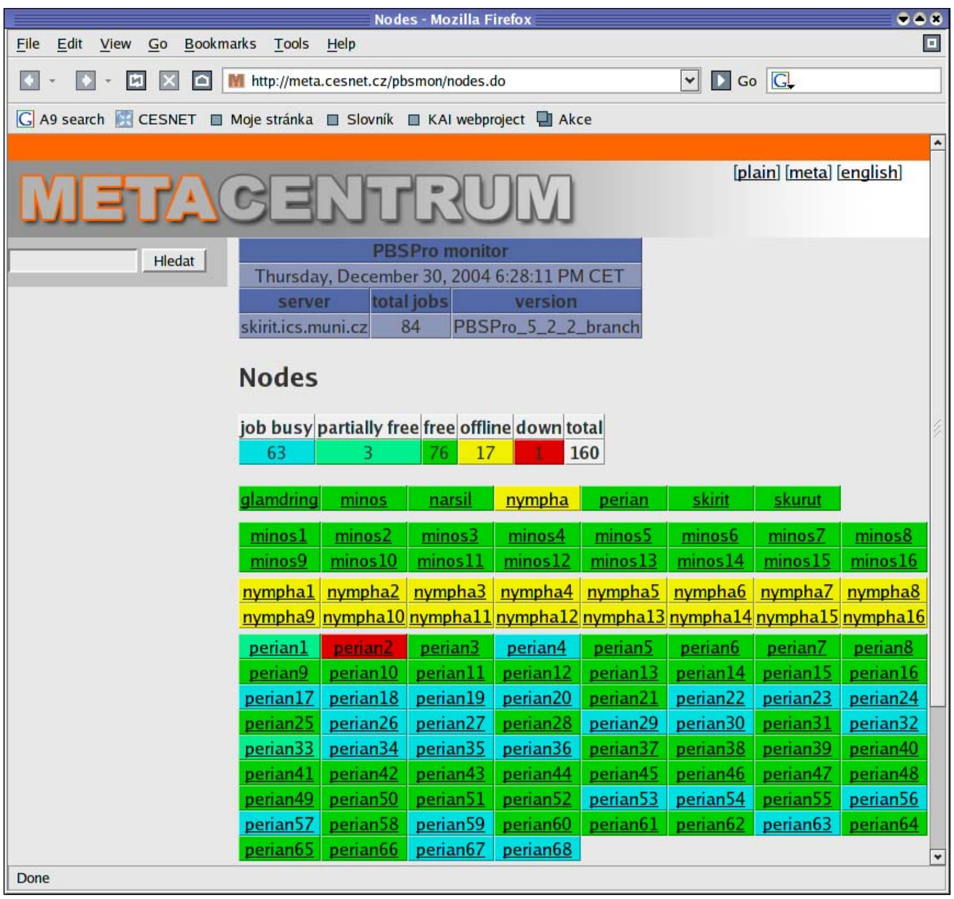

Figure 9.1: METACentre machines and their state

The METACentre manages and further develops the Perun system which has been designed during the previous research period. The Perun system takes care of managing the information about users and some Grid components and extensively simplifies administrator work. The system has been enhanced to support the PKI authentication (the basic METACentre authentication system is based on the Kerberos). We extended the corresponding data schema, development of appropriate CLI (Command Line Interface) tools and we also made available a gridmap file service (generating the authorization information). The Perun system is built on top of the Oracle database which we upgraded to version 10. In the following period, the Perun system will be used outside the METACentre for managing our resources used within the EGEE project. We prepared a first independent distribution of the Perun system including an installation guide.

All user-visible applications were integrated into the METACentre portal.

In 2004 we designed and developed a completely new subsystem for notification handling. Various events in the database are watched and processed with a set of customizable scripts which evaluate them into notifications – currently email messages. The covered events are either parts of standard workflow, e.g., arrival of a request for an account (the responsible person is notified to perform required action as soon as possible), approving a registration or creating an account (the requesting user is informed), or abnormal conditions, e.g., repeated failure in communication with a managed computer. Currently the notification subsystem runs on top of the production database.

The Perun system has been presented also at the international workshop in Cracow in December (A. Křenek, Z. Sebestianová: Perun – Fault-Tolerant Management of Grid Resources, Cracow Grid Workshop 2004).

The Masaryk University in Brno successfully defended a project DiDaS (*Distrubuted Data Depots*) in the second half of 2004. This project resulted in a distributed data storage accessible through the IBP protocol (Internet Backplane Protocol). Some 15 TB of disk storage is available at 7 sites throughout the Czech Republic. All the data depots are directly connected to the CESNET2 network backbone (see *didas.ics.muni.cz*).

As all the original project partners are CESNET members, usually directly involved in the METACentre activities, further development of the distributed data storage will become a part of the METACentre activities. We will take care of finding new use for the capacity which is currently available as a temporary data storage for data intensive computations (extensively used, e.g., during digital video transcoding). It is also used as a temporary storage for large data volumes (hundreds of GB and more), e.g., unpacked archives, large intermediate results, redundant copies of often used read-only data processed at many different clusters, etc.).

9.2 User support and portal

A new concept of presenting information about the METACentre and its activities has been created during 2004. The METACentre portal has been completely refurbished – transformed from the original version based on (undocumented) combination of static HTML pages, PHP and Perl scripts to a new, modern framework. Static content is managed with the OpenCMS system (Content Management System), interactive pages are built using the J2EE technology (Java 2 Enterprise Edition).

The portal is available at *meta.cesnet.cz*; it is gradually filled with contents in both the Czech and English language versions.

The portal is a gateway to new services through which we increase user friendliness when dealing with the METACentre. The public interactive part of the portal has been completely redone. It includes parts that deal with registration to the METACentre, access to end users' personal data stored in the system, management of application and activation of end user accounts at individual METACentre machines, and also one part that deals with submiting yearly reports. In collaboration with other groups within the METACentre activity, we also enhanced the interactive part of the portal with the status pages where end users have access to the information about state of the METACentre resources, including information about actual load on individual nodes; information from the PBSPro batch queuing system is presented in a concise graphical form.

Near the end of 2004 we also implemented a notification service to announce information about planned and unplanned failures and blackouts of all the METACentre data and computing resources and services.

To deal with user requests and to support better communication between end users and METACentre system administrators, we started to deploy a standardized request tracking system. We selected the RT system, as it is widely used in CESNET for tracking network-related requests and its expert support was available locally. We purchased primary and backup RT system servers shared with the management and operation of the CESNET2 network. We use RT system version 3 and we are building a local electronic (virtual) helpdesk which is shared with the EGEE support. This helpdesk will be fully integrated into the METACentre portal during 2005.

9.3 Grid Infrastructure Monitoring

Grid Infrastructure Monitoring is the major research activity of the METACentre. However, during 2004 the work has been still focused mostly on activities associated with supporting the Grid management and the actual research has been performed within the EGEE project.

Cluster node activity monitoring has been switched to the *ganglia* system, we focused mainly on its modifications and enhancements. We extended the set of sensors, but the using the "old" (classical) system, which is not adequate for production use. To create a better support, a bachelor degree thesis has been completed to specify new interfaces for adding sensors and also to register hooks into the central core of the *ganglia* system. This will allow storing the monitoring data to other formats than the RRD – the natively supported format. End users will be able to specify selection constraints for stored data, which could be sent to an SQL database (mainly the MySQL), to a socket or to a pipe. This will allow connecting the *ganglia* system directly with notification services that need a simple data input (here provided via the socket or pipe). The *Ganglia* web interface can be found at *https://lindir.ics.muni.cz/ganglia*, however, the access requires METACentre user authentication. We plan to integrate the *ganglia* outputs into the portal during 2005.

The actual research has been focused on the design and development of a new model for Grid monitoring architecture (GMA). Near the end of the year we presented (at the Cracow workshop) the *Capability based Grid Monitoring Architecture* (CGMA). This is a general framework where different monitoring infrastructure components can coexist and cooperate while staying relatively independent. This is both origin and requirements independent, i.e., the components can be implemented by various people or groups with no tight cross-synchronization, and the purpose they are supposed to serve could be quite different (this also includes possibility to add components that do not have interfaces introduced and used by previously introduced components). Requirements that are contradictory could be served by different components, but all components share a common framework which removes any unnecessary duplication within the infrastructure.

The principal idea of the CGMA is the introduction of data attributes and component capabilities. These are meta-descriptions of data handling constraints and rules on one side and meta-descriptions of capabilities provided by individual components. These meta-data are, together with other information about the data and components, stored in an enhanced registry which serves as a mediator between data requirements and component capabilities.

The data meta-descriptions – called *attributes* – are in fact constraints for data handling and use. Examples are "cautious handling" (use persistent elements only), "secret" (handling allowed only through the components that provide trust at the specified level), or "priority" (speeds up their processing, e.g., by sending first from any queue). Examples of the complementary meta-data descriptions of the components – the *capabilities* – are "reliable" (no data are lost), "secure level X" (trusted element at the specified level), or "fast and volatile" (data are transmitted with as little overhead as possible, however, they can become lost).

In order to describe the essential CGMA functionality, we use an analogy with the Quality of Service (QoS) concept in networking. The attributes of an event can be thought of as its QoS requirement, and the task of the infrastructure is finding an appropriate path for the event, using the desired QoS tags and the knowledge about component capabilities.

The research and development of the CGMA concept continues in 2005, including a prototype implementation for the EGEE project.

Integrating the monitoring and information services is another part of our research activities. The METACentre portal does not distinguish between these two services (i.e., no distinction between monitoring services and information services exists any more). The portal provides unified and uniform access to integrated information without distinguishing how they were collected.

Internally, the infrastructure of directory services is used for integrated access to information stored in different parts of the Grid infrastructure. During 2004 we designed and deployed a new infrastructure of LDAP servers. It is fully integrated with the Perun system and it guarantees an incremental, almost immediate propagation of changes from the Perun databases into the directory system.

We changed the way how data from Perun to LDAP are fed. Developed technology does not demand any changes on the Perun or other data source side. Perun had already a feature ensuring that after each data change, full table dump can be initiated but only if the predefined time period from last full dump passed. This feature ensures that changes are propagated mostly immediately but prevents too much frequent updates. We developed a method of translating a full dump into an incremental update on the side of the LDAP infrastructure. Each full dump is translated to LDIF data format and compared to current LDIF representation of LDAP server state. As a result, we get an incremental file in a form of LDIF update format which is simply executed by the common LDAP utility ”ldapmodify”.

In comparison to previous update mechanism (nightly full dump based rebuild of directory server content), we get nearly real-time change propagation, no server downtimes (the full rebuild required server to be stopped) and a possibility of using standard replication between the LDAP server replicas (only primary LDAP server is updated by our technology, all replicas can be configured to use standard LDAP replication flow originated on primary LDAP server). The replication is the basis of high availability of the LDAP system.

A second source of data to be presented in the METACentre directory services are data from other GRID services. The LDAP directory is here to allow unified access to basic information gathered by different services in the METACentre. Our partial caching idea is designed for this usage pattern. The LDAP server acts here as a gateway to a primary source of information. It is not only translating service specific data representation and access protocol to LDAP but it can also cache the data. In our design a way exists for the user how to specify if he needs really fresh data (with some time penalty) or if cached information is enough for his usage (getting the advantage of quick response). But this decision is not really free: the fresh data option is available only when posing simple query (returning one directory entry); users always get cached data when queries returning many entries have been asked.

Prototype implementation of partial caching LDAP gateway as an OpenLDAP backend was developed and we are evaluating it on an internal testbed. Implemented proof-of-concept service provides access to user quota and usage information acting as a gateway to the AFS filesystem and METACentre computing clusters home filesystem services (Linux NFS servers). We plan to move it into production use after evaluating the experience with the prototype use.

9.4 Security

For heterogenous distributed systems like the Grid, security plays an ever increasing role. This led to founding an independent Grid security group within the METACentre. This group is responsible for all security related actions. In the medium term we expect closer collaboration with other security related groups and teams already existing within the CESNET organization where we currently use directly only the services provided by the AAI group in relation to the Certification Authority activities. Authentication service interoperability, together with the study of available or new, under development only authorization services, has been the main actual focus of the security group in 2004.

The METACentre uses Kerberos as its basic authentication mechanism and protocol. However, end users are not restricted to Kerberos only when they make the first authentication to the system. We support smooth transition between different authentication services. Outside the Kerberos, the major supported authentication services are PKI with certificates, one-time password and hardware tokens. We implemented appropriate libraries and we are working on a universal cross-authentication service called *credential wallet*. Results of this work has been presented internationally and the security group within EGEE has expressed interest to use them. The one-time password infrastructure research led to a Diploma Thesis (at the Faculty of Informatics, Masaryk University, Brno) entitled “Authentication infrastructure for one-time passwords”. We developed and tested a one-time password generator for mobile phones and PDAs, and attracted interest of the EduRoam group.

9.5 Summary

The METACentre continued developing the national Grid infrastructure in the Czech Republic. The main work has been focused on increasing the user friendliness of the whole system and to make easier the access to resources. This priority led to developing a new portal, redesigning and upgrading its content, unifying the batch queue management, simplifying the administration of end-user information and accounts, and to further research in secure access to the METACentre resources. The portal provides all the relevant information to end users: they can find there all information about individual resources and their state, and also about jobs. Thus the portal removes the need to manually track resources and/or jobs through the whole infrastructure (usually done through logging into the nodes directly). Very important has been also our close collaboration with the EGEE project, both in the development and re-engineering activities and also in the management and operation of the Grid – important part of METACentre resources became a part of the pan-European EGEE Grid.

The research and development activities were focused not only on the portal design and development but also on the area of Grid monitoring and information services. The major result here is the development of the Capability-based Grid Monitoring Architecture, CGMA.

In 2005 we will continue to further support all the above mentioned activities, continuously focusing on increasing user friendliness. We will also work more closely with other CESNET research and development groups. Most notably we have extensive cooperation plans with the security group and with the group working in the area of collaborative services. Both these areas will be also developed as part of the MediGRID project which has been accepted for funding starting on January 1st, 2005 within the Information Society funding program, governed by the Academy of Science of the Czech Republic.

New activity for year 2005 will be close collaboration with the CzechLight, leading to experimental use of optical networks. At the end of 2004 we already purchased a dual-processor AMD Opteron server and two 10 GE network interface card with an onboard TCP hardware accelerator from Chelsio. The server with one of the cards will be used for direct connection to the CzechLight lines and it will support research in the truly high-speed network protocols (i.e., transmission speed above 1 Gbps), using these protocols to support high end parallel computing (in collaboration with, among others, the Louisiana State University in the USA).

10 Virtual Collaborative Environments

The *Virtual Collaborative Environments* activity comprises a number of particular activities united by multimedia transmission over high-speed networks. The activities can be divided into two major areas: synchronous communication infrastructure designed for interactive communication (e.g., videoconferencing), and asynchronous tools where latency requirements are relaxed; these tools are often represented by unidirectional data transmission.

10.1 Synchronous Communication Infrastructure

10.1.1 Reflector

Research in the area of synchronous communication infrastructure followed our previous results in research and development of user-empowered reflector – a tool which replicates data to a group of participants regardless of multicast support in the particular network [ICN04]. The design of the reflector stems from a router architecture for active (programmable) networks; its design is modular so that users can extend it using modules linked in during run-time, thus making it usable not only for simple data replication but also for data processing. Because the reflector works in user-space of the underlying operating system, it can be run by any user without a need for any administrative access to computer or network elements.

A single reflector suffers however from poor scalability – the limiting factor turns out to be number of outbound flows which grows quadratically with the number of connected clients. This problem emerges especially when using high-quality high-bandwidth video formats like Digital Video (DV) [ECUMN04]. Natural direction of further development are therefore reflector networks featuring better scalability and also robustness in terms of both network and reflector outages. We have developed and verified a number of possible data distribution models which provide different ratios between redundancy, robustness, and scalability [ICN05]. To achieve maximum overall robustness, we are prototyping a reflector network that uses JXTA[1]-based peer-to-peer network for organizing the reflectors and for implementing out-of-band control channels.

[1] *http://www.jxta.org/*

10.1.2 Active Networks

As a theoretical base for developing reflector, we have further researched the concepts of programmable router for active networks. During this year we have designed and implemented the Active Router Transport Protocol (ARTP) [ARTP] for unreliable data transmission with guaranteed order of delivery and TCP-friendly flow control based on an AIMD algorithm. The implementation is considered to be a reference one without careful optimizations but still the performance of the protocol is interesting even for gigabit network links, though it does not saturate them totally now. We intend to use the ARTP for transmission of large multimedia streams.

10.1.3 H.323

In H.323 videoconferencing, we have focused especially on building sufficiently scalable infrastructure running in a production mode. A multipoint connection unit (MCU) serves as a basis of multipoint conferences; we have selected and purchased a MCU Polycom MGC-25 and put the device into semi-production mode. We plan to enhance it with SIP signalling support, integrate it with the rest of our H.323 infrastructure, and eventually put it into full production mode in the beginning of 2005 after the whole functionality is properly verified. After finalizing all planned changes in the H.323 and SIP infrastructures, we expect to hand over the whole infrastructure to be used by the Czech academic community in a production manner.

We have enhanced current videoconferencing testbed with powerful videoconferencing clients focusing especially on SIP signalling and collaboration over shared contents. We have further developed our cooperation with the IP telephony group; together we plan to deploy new services for IP clients with the H.323 and SIP signalling.

We have improved the quality of videoconferencing services provided at the CESNET premises. Two new videoconferencing workplaces are available using a fully modular technological solution, so that the workplaces are capable of working either independently or together and provide improved collaboration over shared contents even for larger groups. Thus we respond to an ever increasing demand for videoconferencing services from the academic communities located within the CESNET premises.

Based on requests for high-quality conferencing with strong security, we have prepared several new personal videoconferencing sets. In a first batch, we distributed a fully mobile personal set supporting the H.264 video format, AES encryption, stereo sound and interactivity over shared contents.

10.1.4 AccessGrid and Large Communication Complexes

During the last year, unique mobile videoconferencing node has been created to be used for AccessGrid-compatible conferencing. This activity was funded by the CESNET Development Fund and Masaryk University. Our activity is taking over further development of this node – e. g., by the end of 2004, all audio paths have been converted to balanced cabling to remove noise cumulated on audio paths due to its extremely compact solution and resulting high concentration of all cables including power cables.

We also started building a third AccessGrid[2] (AG) node at the CESNET premises which should serve as another reference AG workplace in the Czech Republic. In the next year, we plan to finish this node and develop further tools for managing large communication complexes based on common client software (web, Java applets, etc.).

10.1.5 Transmission of DV over IP networks

Transmission of Digital Video (DV) over IP networks is standardized in RFC 3189 and RFC 3190; it uses the RTP/UDP network protocol stack. A purely software DV over IP implementation has been implemented by the DVTS[3] project. Since we lacked a working display tool for UNIX platforms, we have completely revamped the *xdvshow*[4] tool which allows displaying DV stream in X11 interfaces and which had not been maintained for quite a long time. Our new version supports displaying using X11 and SDL interfaces with the SDL version supporting also full-screen mode – either an up-sampling based scaled one or an unscaled one which switches the computer screen into the closest matching supported resolution and fills the rest of the screen with black background. The latter mode is suitable for slower computers. In cooperation with Internet2[5], the new *xdvshow* was distributed as a part of the official CD[6] with tools for DV over IP during the Internet2 Member Meeting, Fall 2004. Development of DV over IP tools is further pursued by the DVTS consortium where CESNET is represented by the Masaryk University that can participate as an academic institution for free.

DVTS tools and *xdvshow* were also used for prototyping stereoscopic (3-D) video capturing, transmission, and display (Figure 10.1). Cameras positioned on a stereoscopic tripod head are used for producing separate DV streams for the left and right eyes. The DV is transmitted using an IEEE-1394 (FireWire) interface

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[2] *http://www.accessgrid.org/*
[3] *http://www.sfc.wide.ad.jp/DVTS/*
[4] *http://sitola.fi.muni.cz/ xliska/*
[5] *http://www.internet2.org/*
[6] *http://people.internet2.edu/ bdr/dvts/knoppix_dvts_20040917.iso*

and sent over IP network using the DVTS tools. Both streams are received by a single dual-processor computer which displays them using a dual-headed graphics card. The display part uses two projectors with polarizing filters with perpendicular polarizing planes, a special non-depolarizing screen, and glasses again with perpendicularly oriented polarizing filters.

Figure 10.1: Stereoscopic video transmission using DV over IP and stereo-projection

10.2 Asynchronous Infrastructure for Processing and Distribution of Multimedia

10.2.1 Distributed Encoding Environment

The Distributed Encoding Environment (DEE) [TNC04] was created in collaboration of the CESNET Development Fund and Masaryk University to allow efficient asynchronous processing of multimedia material. The DEE uses Grid computing facilities of the *MetaCenter* project (Chapter 9) for processing, and the storage capacity of *Distributed Data Storage* project for storing the interim data. The parallel transcoding process is based on splitting the input material into smaller chunks that are encoded in parallel and merged into a final file during the last phase. In this activity, we continue developing the DEE environment according to requirements from pilot user groups and we also provide a limited support for deploying DEE at various user sites.

10.2.2 Indexing

We have enhanced the multimedia metadata search engine with support for new formats; as a result, the number of indexed files increased to more than 100,000 – and this number currently covers the Czech Internet only. We have developed a proprietary XML-based format [TR19/04] storing the metadata in the first phase of implementation for the sake of simplicity; we plan a transition to the MPEG-7 format during the next year. Despite the recently announced activities of global portals, our system remains unique because of the way it indexes and searches the data.

10.2.3 Streaming

All our current streaming activities are based on a streaming farm we have built during last several years. This farm is modular, comprising a number of components that together provide all the services visible to our end users. During this year, we have extended the farm with servers supporting streaming of MPEG-1/2/4 and QuickTime formats. Together with existing RealMedia and Windows Media streaming servers, the academic community in the Czech Republic can use all the mainstream streaming formats. Some servers also support streaming using both the IPv4 and IPv6 protocols.

Within our development activities, we have also experimented with transitioning to distributed storage based in the iSCSI protocol in WAN environment. However, it turned out that the latency in current WAN environments hinders deployment of iSCSI-based services.

During December, we have participated in the *MegaConference* event which is a global videoconference organized by the Ohio State University with support of the Internet2 association. Our task consisted of streaming the conference using the Windows Media technology on both IPv4 and IPv6 protocols. In the last year, we have also built three Content Delivery Networks (CDNs) used for live broadcasting of the RIPE 47, RIPE 48, and RIPE 49 conferences.

10.2.4 Announcing Portal

We continued our participation in the TF-Netcast project organized by the TERENA association where we further developed the announcing portal (prenosy.cesnet.cz[7]). TF-Netcast successfully ended up in the Spring 2004 and thus

[7] *http://prenosy.cesnet.cz/*

we are taking part in its follow-up project called TF-VVC (Task Force – Voice, video and collaboration) where we lead the activity E called an Academic Netcasting Channel (Live Streaming Infrastructure). We are also actively participating in other activities, especially in metadata handling. We have enhanced the functionality of the announcing portal (Figure 10.2) with RSS feeds, and started working on an Electronic Programming Guide (EPG) as well as on implementing a new architecture based on separating contents and view. The portal also supports additional languages so that their total number reaches ten. The portal was used to announce more than 150 streaming events.

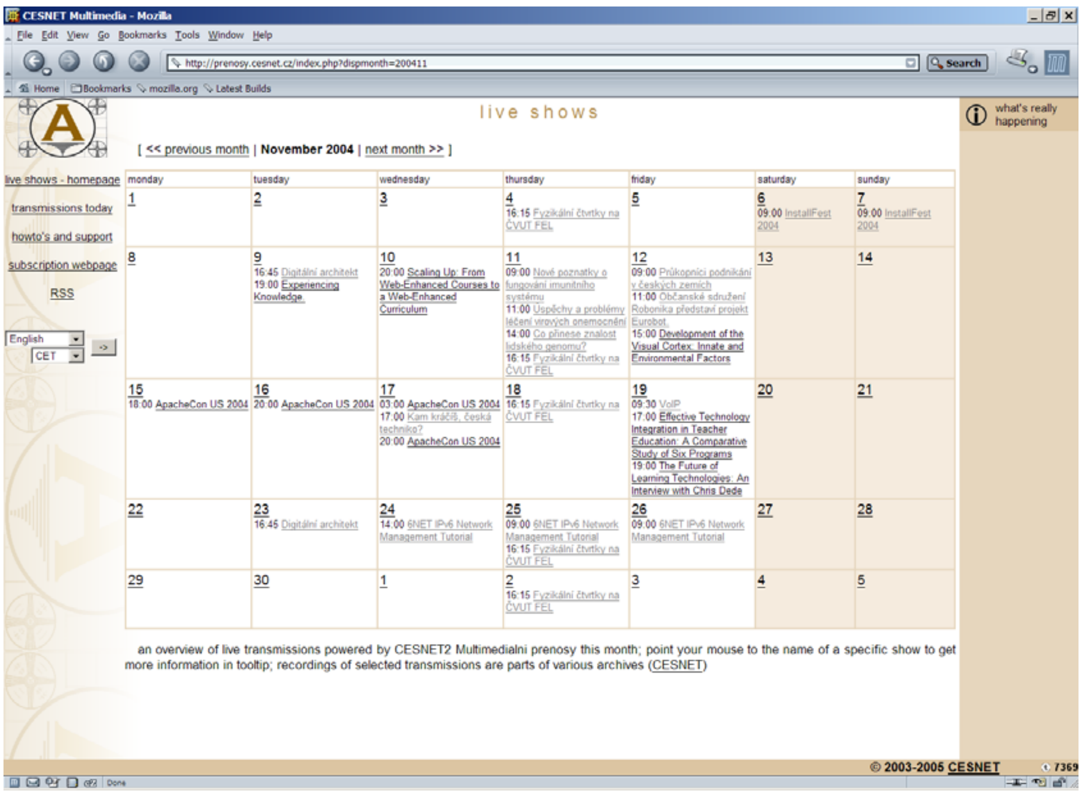

Figure 10.2: Announcing Portal

10.2.5 High-Quality Audio Streaming

We have further developed an experimental system [TR16/04] relying on distributed audio signals in the Ogg and MPEG formats with bandwidths of 128, 192 and 224 kbps. During this year, we have also ceased supporting the MP3 format because of patent-related issues pertaining to this format, better quality achieved by the Ogg format and also sufficient support for the Ogg format in mainstream client software. Higher sound quality has been achieved by using new input signals: we have replaced analog tuners with new digital DVB-S cards and stations ČRo 1, 2, 3, and recently also ČRo 6 and Region are received directly from the Eurobird 1 satellite link. The resulting sound is clearer and more detailed with better separation of channels. Alltogether we are broadcasting the following radio stations: ČRo 1, 2, 3, 6, as well as the Region, BBC, ČRo Pilsen and ČRo Regina.

Since we need to process several DVB-S programs simultaneously, we are using the vls[8] application server. This sever can receive all the streams at once, separate them and then pass them on in the original MPEG-TS format for further processing – e.g., by broadcasting them to specified multicast and unicast addresses. Each MPEG-TS stream is received and decoded into raw PCM format by the vlc client application and further encoded into the Ogg format using the Ices software. Primary encoding servers are located at the West Bohemian University in Pilsen and also at CESNET premises in Prague. All streams are available from the radio.cesnet.cz[9] web pages and also from live streaming pages of the Czech Radio. We support both the IPv4 and IPv6 protocols.

In the future, we plan to concentrate on robustness of the whole system and its resiliency with respect to outages. We expect to deploy redundant configurations of encoding and broadcasting servers with support of automatic reconfiguration in case of network or node failure and also automatic client reconnection to different broadcasting server should some problem occur.

10.3 Direct Support and Consulting

We continue to collaborate with student groups that provide content for our streaming servers. We have evaluated several possible scenarios for acquisition and according to their results we have designed and implemented a mobile and fully digital workspace for contents acquisition. The workspace can capture small-to-medium events as well as support audio and video presentations. Verification of this solution is planned for beginning of 2005.

As a part of our consulting services, we have participated in designing and selecting audiovisual equipment for two reconstructed and one newly built lecturing halls at the Faculty of Informatics, Masaryk University [ITHET04] which are used for automatic lecture recording since Fall 2004. The captured video is further processed using the DEE deployed on dedicated processing infrastructure operated jointly by the FI MU and the MetaCenter (Chapter 9).

We have provided consulting services for reconstruction of two large-capacity lecturing halls at the FEL ČVUT in Prague-Dejvice and we succeeded in cre-

[8] *http://www.videolan.org/*
[9] *http://radio.cesnet.cz/*

ating conditions appropriate for deploying our presentation and conferencing technologies. The whole design is in complete accordance with our experience.

Utilizing our videoconferencing rooms, we have facilitated organization of several tele-presence events for distant education, e. g., recurring remote lectures of Assoc. Prof. Kolář (Computer Department of FEL, ČVUT) for the Tecnológico de Monterrey, Universidad Virtual, Mexico virtual university.

In addition to the events mentioned above, we provide support and consulting to all members of the CESNET Association. We distribute videoconferencing sets, consult purchase of equipment, detect and solve problems even in local networks of our users and we provide support for regular international videoconferences of the CESNET members.

11 Support of Distance Education

The *Support of Distance Education* activity is related to the *Infrastructure and Technology for On-Line Education* project running between 2002 and 2003, and to the *Virtual Collaborative Environments* present activity.

The main goal is a qualitative shift in electronic support of education at university level, maximally utilizing current features offered by advanced network and local digital technologies, such as systems and tools for recording, processing, storing and presentation of multimedia data and tools for remote collaboration.

This activity develops methodology, pilot projects and case studies on using the said technologies in education, so that they can be reproduced within the framework of the CESNET Association. The activity also targets the broad student community at the Czech universities in the areas of technical and natural sciences.

11.1 Maintenance and Extension of the eLearning.cesnet.cz Portal

The *eLearning.cesnet.cz* portal was put into operation during previous activities related to support of distance education. The main objective of the recent period was revitalizing the portal and defining the course for its further development.

The revitalization brought a new structure, design and contents. Selected news have been published continuously. The current state of the portal may be observed at *eLearning.cesnet.cz*.

The portal structure has been divided into several basic sections, the key ones being: *Events* (current news from the eLearning community), *e-zine* (prepared for future implementation of an electronic journal intended for publishing various articles), *Discussion forum*, and *Theory* (overview of basic knowledge concerning eLearning, including detailed descriptions).

At present time we have formulated the basic concept of the portal for the coming year. Its first foundation will be current news about various events in the eLearning community. We have already prepared a system allowing the registered correspondents to publish short news (e.g., about coming conferences, meetings or seminars) on the portal. An extensive network of such correspondents does not exist so far; thus, we believe it is necessary to use relatively good contacts within the narrow eLearning community as well as within the wide academic community. The involvement of correspondents will also have a secondary impact besides their direct contribution to the content, i.e., promotion of the portal. The second foundation is bringing the discussion forum to a new level of utilization. We do not intend to moderate it in the beginning; we assume that the optimum form of the forum will be a result of its evolution after getting some feedback from its users. The strongest innovation should be the e-zine – a casual journal intended for publishing of reviewed valuable articles from the eLearning field.

11.2 Standards in the Electronic Education Support

For each electronic education support, preparing electronic educational materials and distributing them to students is necessary. If the plan offers more than just simply publishing the materials on web pages, using a system created for this purpose – a Learning Management System (LMS) – is advisable. At present, there are dozens of LMS products, both commercial and freely distributable, coming from various companies and organizations (e.g., ClassServer, WebCT, eDoceo, Moodle). An LMS is a local or web-based application managing all educational activities within an organization. The main functions that should be supported by a LMS are as follows:

Administration: This function comprises, e.g., user administration, assigning user roles (administrator, teacher, student, content supplier, etc.), creating and erasing classrooms, assigning students and teachers to classrooms.

Communication between LMS and organization information system (IS): If this communication is set up, lots of work related to user administration are avoided, since any change in the IS is reflected in the LMS (making the same change twice is not necessary). However, this communication is complicated as it must respect not only the structure and function of the particular LMS, but also those of the IS used.

Examinations: Every LMS should have its own tools for preparing tests (not only for examining the students but also for obtaining feedback using course evaluation), as well as appropriate tools for evaluating the tests and, possibly, their statistical result processing.

Online tools: The purpose of these tools is communication between teacher and students or among the students. The said communication may be a real-time one (chat, videoconferencing) or an off-line one (e-mail, discussion forum).

Support for off-line education: This function allows publishing course materials even without an Internet access (e.g., on a CD).

Support of standards: An LMS allows storaging and distributing courses, so it is advisable that it should support specifications for interchange of educational materials, thus allowing insertion of materials prepared in another LMS (the SCORM may serve as an example of such standard). Support for other standards related to eLearning is an advantage, of course. An LMS may also provide other supplementary functions, such as a diary with tasks for every user, team cooperation in projects (e.g., shared file storage, shared workspace), distribution of notices to students (e.g., if their task is currently pending), etc.

If an organization decides to use the LMS functions and chooses an LMS that meets its requirements (not just in the terms of functions, but also with respect to licensing policy, maximum number of requests served at a time, hardware recommendations, scalability, etc.), implementing the system is necessary. If the LMS is planned as a standalone system, integration with an IS is not necessary. However, the LMS is usually built as a part of a complex IS, thus introducing the problem of data interchange between the IS and LMS, ensuring synchronization, integrity, transmission security, etc.

An extensive Technical report number 25/2004 has been prepared that describes this area of interest; is has been published on the CESNET web[1].

11.3 Overall Support of a Sample Course using Online Materials – A Pilot Project

The universities – members of the Association – prepare and operate a wide variety of electronic support tools for various courses at present. Our aim was preparing a detailed methodic example of an overall support of studies "by all available means".

Overall support of education in a selected course is focused on a specific group of students, the 9th semester of the Master study branch of the Telecommunication Engineering, accredited at the Faculty of Electrical Engineering, the Czech Technical University in Prague. From the wide variety of obligatory courses we have chosen one to be supported by prepared comprehensive on-line materials and other supplementary materials within our pilot project. The concept of the project allows most of other courses to join this approach in the future.

[1] *http://www.cesnet.cz/doc/techzpravy/*

With the lecturer's help, on-line materials have been prepared and appropriate links placed on the educational portal *www.comtel.cz*[2] within a section belonging to the pilot course, using some logical structure. The multitude of new streamed lecture recordings (12 basic and 5 special ones) should be pointed out.

This activity was presented to the students as an experimental introduction of distance education. Since the educational materials are available on-line, lectures in the 32PSY course are organized also in a distance form. The evaluation is planned as a survey after the semester terminates, i.e., in Q1/2005.

Technical report number 20/2004 has been prepared on this subject.

During 2005, similar complex support will be completed also in the eLearning support environment at the Masaryk University in Brno where most of LMS functions are provided by the university information system. Complete (video)records of lectures for the course Programming in the Java Language have been prepared, and there are also complex educational materials including problems to be solved individually, examples of tests, rich discussion archives, etc.

In November 2004, an experimental "shared lecture" was presented: the lecturer spoke at the Technical University in Ostrava to the students both in Ostrava and in Prague (Czech Technical University). Transmission of audio and video signals used full duplex over IP. The topic was quite specific and finding an adequately qualified lecturer at both universities would be difficult.

11.4 Audiorecords

The fundamental idea – introduction of audio records as another tool for improvement of education – followed from remarks of students who could not observe live video broadcast or streamed video records because of technological limitations – mainly because of insufficient throughput of their Internet connection; this is a specific situation of those students who do not have direct access to academic network (which is available at school or at the dormitories), thus being forced to use slow narrowband connections in host networks, mainly through the PSTN.

As an answer to this challenge we have developed and implemented a system that enables broadcasting and recording of the lecturer's speech only. The digitized audio signal may be used for real-time transmission even over slow channels; complemented with materials such as electronic presentations, it becomes a comprehensive educational tool.

[2] *http://www.comtel.cz/*

The workplace for audio streaming and recording contains an external sound card, two wireless microphone sets used to process the audio/video stream, sound mixing device (for our purposes: 4× stereo input) and a coder – a PC with appropriate software (Windows Media Encoder) supporting the audio signal transmission and recording. The properties of the audio signal may be set for several output qualities: transmission speed, sampling frequency, mono or stereo can be selected. Since the beginning of the 2004/2005 winter semester, simultaneous audio/video broadcasts have been provided and students can choose one of the streams according to their connection speed – audio/video stream or just an audio stream.

12 CESNET CSIRT

12.1 Introduction

The aim of the CESNET CSIRT project is to achieve a better internal organization of the CESNET2 network security and services provided, as well as improved handling of security incidents reported to the administrators of affected networks/hosts, or discovered by detection systems running here. Another objective is to continue the co-operation with existing international projects in the field of network and services security, such as: TERENA[1], UKERNA[2], FIRST[3].

12.2 Project solution

In 2004, we focused in particular on finding a sensible and feasible programme – identifying the most important insufficiencies of the security incident handling in the CESNET2 network, communication defficiencies between the administrators from individual participating institutions connected to CESNET2 network, and defining the most suitable plan for the upcoming period.

During the year, the activities of the first official CSIRT (Computer Security Incident Response Team) team of the CESNET association showed as the most important ones. By the end of 2003, the cornerstones of the security team were laid down. The team was officially approved by the TERENA Trusted Introducer project at the beginning of 2004 and the CESNET-CERTS team has been added to the list of known security teams (*http://www.ti.terena.nl/teams/teams-c.html*). Contact e-mail address of the team is *certs@cesnet.cz*, fingerprint of the CESNET-CERTS team PGP key is:

341D 3EB0 0160 941F 6A06 4401 F9BF C741 9CAA 8579

At present, the CESNET-CERTS team consists of three members but it should expand in the future. Before this happens, the three existing members of the team guarantee its operation five days a week. Should this team work 24 hours a day in the future, its capacity would require a significant reinforcement.

While establishing the CESNET-CERTS team, the following steps were taken:

- Re-organising the roles of contact e-mail addresses of the form *abuse@* (as used in the registrators' databases and in the international RIPE database) and *certs@*.

[1] *http://www.terena.nl/*
[2] *http://www.ukerna.ac.uk/*
[3] *http://www.first.org/*

- Allocation of the tasks to individual members of the CESNET-CERTS team.
- Definition of the team programme and policy – for example substitution, reaction strategies to reported incidents.

The following areas and activities were dealt with by the CESNET-CERTS team during the year:

1. Searching for and testing appropriate system for the reception, effective administration and archiving of reported incidents. As the CESNET-CERTS team has only three members at present and should expand in the near future, we are considering launching a support system for the reception and effective administration of reportable incidents. Given the number and nature of the solutions, a support system which would for example be able to clearly differentiate incidents according to their stage of processing would be very helpful. This year, we tested several suitable systems – RTIR, Bugzilla, Mantis. So far, the Mantis[4] system seems to be the most suitable for our purposes.

2. Contact information of institutions connected to the CESNET2 network – at present, it is difficult to find the right contact person once a security incident from some IP address (belonging to our autonomous system AS2852) is reported as no reliable database of contact information exists. At first, we considered using the existing RIPE database[5] for this purpose and adding more data into it, then we considered creating our own contact database using the existing LDAP structure. Having mapped the solutions and activities that had been undertaken in this respect in previous years and their results, we have rejected both options as unsuitable and we keep them only as back-up options. (The first difficulties occurred when trying to obtain the primary data, their maintenance, update, accountability . . .). We decided to adopt a set of security policy documents that should induce the participating institutions to establish (not necessarily formal) teams similar to the CESNET-CERTS team. Our aim is to create a hierarchical structure of security teams and to enable these teams to get to know each other and to be able to ask for help when looking for a solution.

3. In 2004, the development of two other systems was included in the project. These two had been separate projects in the past – IDS (Intrusion Detection System) and Auditing system. As regards IDS, it has been fully automated and suggestions of individual administrators have been incorporated (administrators have different views about when, in what for and how often they should receive reports from IDS). The system was set so that the individual requirements could be fulfilled flexibly. As regards Auditing system,

[4] *http://www.mantisbt.org/*
[5] *http://www.ripe.net/*

local administrators of the CESNET association defined the requirements for its functionality and relevant changes should be implemented during 2005.

We have linked up with some other European projects dealing with security of computer networks; in particular with the TRANSITS[6] project operated by the TERENA and UKERNA associations. We took part in organising the successful 5th TRANSITS Workshop which was held in Prague-Pruhonice from November 10 to 12, 2004. Several employees of the CESNET Association took part in this workshop. It is an intensive three-day workshop which is held twice a year and whose aim is to introducej security issues to new and potential members of security teams.

12.3 Plans for 2005

Taking up on what we did in 2004, we would like to define rules for the communication among institutions connected to the CESNET2 network when dealing with security incident. We plan to provide these institutions with guidelines, information, rules and incentives for establishing the security teams. We would also like to focus on improving awareness and knowledge of employees, in particular of the CESNET Monitoring Centre, and on development of other support tools for detecting potential security risks and their prevention (Intrusion Detection System and Auditing System). Furthermore, we would like to develop and expand the activities of the CESNET-CERTS team and deepen co-operation with international projects.

[6] *http://www.ist-transits.org/*

13 Medical applications

Medicine is a source of interesting applications that require high-quality infrastructure and a high throughput capacity. CESNET has been interested in this area for some time. In the second half of the 1990s, many medical videoconferences were held and the CESNET infrastructure was used for transmitting medical image data. As interest in medical projects has been growing, a new independent activity, Medical Applications, was started in the second half of 2004.

The intention of this new activity is to search for and develop further projects in the field of medicine. Many activities (such as Virtual Collaborative Environments, MetaCenter, and Distance Education) were related to medical applications and were undertaken using their general techniques and procedures. Our approach is searching for new projects and extend current programs with specific features required for medical data processing, rather than repeating these general procedures.

The following projects were implemented in the second half of 2004:

- Standard environment of medical applications
- Formalizing and transmitting data on oncology patients
- Videoconference for remote consultations in genetics – telegenetics
- MEDIMED project development
- Searching for new telemedical applications

The staff of the 2nd Medical Faculty at Charles University in Prague and of the Masaryk University in Brno were directly involved in the said activity. In addition, staff from EUROMise (a joint facility of the Academy of Sciences of the Czech Republic and Charles University in Prague), Constitutional Court in Brno, Thomayer Teaching Hospital, Central Military Hospital in Prague, Masaryk Memorial Cancer Institute, the 1st Medical Faculty of Charles University and the IMA Ltd. company joined the working groups in implementing individual projects and preparing joint grant applications for the next grant period. Specialized programming equipment was developed in association with the TATRAMED Ltd. company from Bratislava.

13.1 Standard environment of medical applications

Standardization and transparency of the legal environment which defines the communication between healthcare entities are among the key problems in communication between medical facilities. In addition, harmonizing our legal environment with the EU legislation is crucial in order to avoid working on something that already exists in Europe. Making these issues transparent is essential for acquiring new partners among healthcare facilities because some managers of these institutions are afraid to transmit data outside the hospital walls.

Concerning the area of harmonizing the legislative environment and standards, we have established successful cooperation with the staff of EUROMise and with a lawyer from the Constitutional Court involved in analysing information on legal aspects of maintaining medical records and telemedicine in the EU countries.

A general introduction has been prepared which discusses the concept of the existence and mutual interactions of legal systems, “the national law of the EU member country” vs. “the EU law” vs. “international law”. This general section is important for understanding the principles that serve as a basis for specific legal regulations.

Concentration on more specific problems will follow. In the first place, Czech legal regulations for the maintenance of medical records will be studied. This will involve analysis of the options for the maintenance of medical records in electronic form, including the issues of Act No. 20/1966 Coll. on Public Healthcare (especially Section 67a et seq.), the Electronic Signature Act (227/2000 Coll.) and the Personal Data Protection Act (101/2000 Coll.). The work will also deal with penalties that might be considered in the event of a breach of the duties set forth in respect thereof in the legislation (administrative infractions or, as the case may be, criminal acts).

The next step will deal with the European legal regulation including directives or other legislation of the EU governing the said issues. At the European level, this will include the possibility of transmitting personal data (or information from medical records) between member countries.

We expect that the first complete publication of these materials in the form of a study or article in a scientific journal will be ready by the end of 2005.

13.2 Formalizing and transmitting data on oncology patients

Formalizing the oncology patient data is a brand-new activity. A method has been completed and tested for exporting current and archived data from whole-body gammagraphy of thyroid gland carcinomas. In addition, procedures have been prepared for the conversion of images into a standard graphic format. The objective is further processing of the individual images and their sequences, quantitative evaluation of thyroid gland activity and searching for potential secondary carcinoma foci.

XML presentations of data from history records of the unique database of thyroid gland carcinoma have been created. XML presentations were used to create database structures for SQL database and web forms for effective data input.

This method is used to process two basic data sentences of the carcinoma database: input data of individual cases (a card to be completed during the first meeting with the patient), and longitudinal data to be completed during each checkup.

Establishing this database is required for taking part in future national and international cooperation. One example is the involvement planned in the project of the informational society program titled *Intelligent support for decision-making during diagnostics and therapy in nuclear medicine using Bayes processing of uncertain data and probability mixtures* which is being undertaken by the Institute of Information Theory and Automation of the Academy of Sciences of the Czech Republic.

In addition, a proposal has been submitted for a project for the 6th Framework Programme in the area of Life Sciences, with participation in the Network of Excellence for research in cystic fibrosis.

In terms of further data processing, it is important to establish contacts with the authors of the MEDAL (Medical Algorithms Project) system which includes algorithms of freely distributable programs for medical data processing.

Given the short term of implementation, we do not expect to produce any publications in this area until the second half of the year.

13.3 Videoconference for remote consultations in genetics – telegenetics

We are continuing work on the successful project of videoconferences for remote consulting in medicine focused on genetics, also known as telegenetics. A proposal has been made and testing has been prepared for specialized functions of a communication mirror suitable for teleconference modes and round-table presentations. In addition, the required functions of the client programs have been specified.

In cooperation with EGF, a storage space for digitized video recordings of lectures held in the European School of Genetic Medicine, including accompanying documentation, has been created and made accessible. Statistics and a model example for content-driven pre- and postgraduate medical education are also available.

Together with the University of Bologna, a pilot project for the EU program Leonardo (support of professional education) has been prepared. A project is now available for interconnecting communities of geneticists and hematologists studying thalassemia (genetic hematopoietic disorder) for the 6th Framework Program. The University of Bologna is a partner in education, while CESNET is a partner in infrastructure.

13.4 MEDIMED project development

The MEDIMED project has been extended successfully into a Prague workplace by connecting the Thomayer Teaching Hospital (FTN) in Prague in July 2004. Based on the experiences of production operation, FTN invested approximately CZK 30 million (approx. 1 million Euro) to equip the PACS center and is now interested in establishing the PACS center for the Prague locality. Interconnecting the General Teaching Hospital (VFN) and Teaching Hospital Na Bulovce is under negotiation.

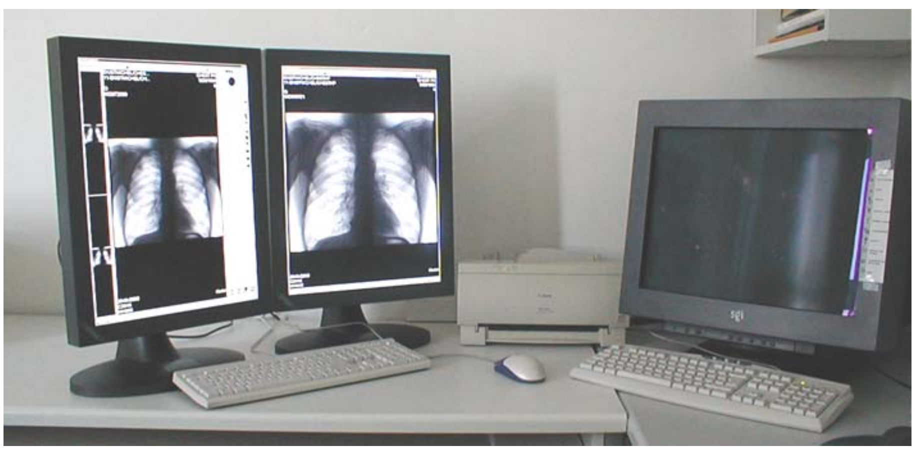

Figure 13.1: A PACS Review Workstation

Anonymizing software for PACS has been created in cooperation with the CESNET Association, MU Brno, Masaryk Memorial Cancer Institute and the TATRAMED Ltd. company. The system is designed for students of medical sciences and for new hospital radiologists. Currently, functionality of the anonymization module, a general version of the description editor, and a module for administrating case studies are being tested in production operation.

After being filled with data, the database of anonymous image studies intended for teaching will be made accessible to students of the Masaryk University Medical Faculty in the classroom belonging to the Masaryk University, Medical Faculty (Biostatistics and Analysis Centre) and Faculty of Natural Sciences. This Centre is equipped with 30 powerful PCs and high-quality LCD monitors and TomoScan licenses. The system may be operated at selected sites of cooperating teaching hospitals, subject to an agreement.

The results of these partial activities were presented at the prestigious IASTED conference in the USA in November 2004.

13.4.1 Developing technical resources of the system

The training system is being developed in cooperation with the TATRAMED Ltd. company. This involves modifying the current commercial concept which is extended to include special components for teaching purposes. The system is designed to meet all the compatibility requirements needed for systems working in production operation.

The key components of the implementation are in particular:

- anonymizing module (all information allowing the patient's identification is removed from an image study)
- editor enabling the addition of an image description in the DICOM Structured Report format
- support of keywords usage (for easy retrieval, etc.)
- extension for creating teaching programs (specialized editor enabling the creation of problem-oriented, specialized case studies with references to image information).

Workstations connected to the teaching system enabling the anonymizing and sending the image studies to the PACS database, have been installed in the Masaryk Memorial Cancer Institute, the Clinic of Pediatric Oncology of the Teaching Hospital of Brno, St. Anne Teaching Hospital of Brno, and the Center for Cardiovascular and Transplantation Surgery in Brno.

13.4.2 Including an image study in the teaching system

Each image study included in the teaching system can be provided with a structured signature (its format follows the international DICOM standard) and with a set of attributes (keywords). The structured signature can be logically divided into several parts, according to the character of the project, as follows:

- description of the image study
- description of the diagnostic procedure used

Basic (technical) attributes of the image study are automatically saved upon inclusion of the image study into the teaching system. The values of these attributes are based on the original image study obtained during the routine operation.

- modality (CT, US, PET/MR, PET/CT, . . .)
- name of the healthcare facility where the examination was performed
- date of examination
- patient's year of birth (actual date of birth is to be transformed, e.g., into 1/1/1964)
- all technical parameters of the examination (distance between sections, number of images, number of series, . . .)

13.4.3 Case study

A case study shall mean a document comprising independent text pages with optional references to image studies such as DAPET. The teaching system will contain tools (specialized, purpose-adjusted editors) enabling radiologists to create their own case studies.

13.4.4 Further development

- Coordination in defining new keywords
- Training users
- The Thomayer Teaching Hospital is taking part in preparing draft contents and development
- Many district hospitals, teaching hospitals and specialized healthcare facilities throughout the Czech Republic are interested in joining the system
- Particular attention is being paid to the fields of oncology, pneumology and cardiology

- Solving security issues (access authentication, hierarchy of certification authorities)
- The system is designed to be open to foreign cooperation.

13.5 Searching for new telemedical applications

As part of activities for the second half of 2004, two new grants of the Informational Society program, announced by the Academy of Sciences of the Czech Republic for a period of up to 5 years starting from 2004, were successfully prepared and defended. The first project is the *MediGRID*, with the 2nd Medical Faculty of the Charles University being the main researcher, and the Masaryk Hospital in Ústí nad Labem and CESNET being fellow researchers. The second project is the *Effective processing of medical image information* with the CESNET being the main researcher and Masaryk University and Masaryk Memorial Cancer Institute in Brno being fellow researchers.

Prospective applications include an international research project in the area of neuroscience, BIRN (Biomedical Informatics Research Network), which enables access to high-performance models and brain examination techniques. The Department of Neurology of the Central Military Hospital Prague has already shown interest in becoming involved in the BIRN project via the CzechLight network. Negotiations on involvement in this project are underway with the Thomayer Teaching Hospital and Teaching Hospital Motol.

A system for supporting highly demanding exchange of image data (microscopy, MR, PET) should be another interesting application of the MEDIMED system for the newly-built Cell Therapy Centre. Once established, this system will connect the Charles University - 2nd Medical Faculty, Academy of Sciences of the Czech Republic (AV ČR), IKEM, and MZLU Brno. Given the research character of this facility, we are considering the use of the CzechLight infrastructure tentatively in the second half of 2005.

Part II

International Projects

14 GÉANT and GN2 Projects

Since 1996, the CESNET Association has been actively cooperating in building a European infrastructure interconnecting the national research and education networks (NREN) of individual European countries via high-speed links. Year 2004 was no exception. The Association's involvement in these activities became much more intense because of the forthcoming completion of the *GÉANT* project and especially because of the preparation of a new international project, *GN2*.

14.1 GÉANT Project

The objective of the *GÉANT* project, supported by the European Commission within the 5th EU Framework Programme, was to design, develop and operate a Europe-wide infrastructure among individual NRENs during 2000–2004 which would meet at least the following requirements:

- enable users to transfer large data volumes in short times
- create an environment for advanced networking applications, such as computational grids
- ensure interconnection with similarly oriented networks within the global scope

The result of the four-year effort of a consortium comprising 27 NREN operators led by the DANTE Ltd. acting as a project coordinator, is the *GÉANT* network. The topology of this network as of October 2004, when the *GÉANT* was completed, is illustrated in the Figure 14.1.

The *GÉANT* network is currently interconnecting 34 European countries. The core of the network (one of its nodes is located within the premises of the CESNET Association in Prague) comprises circuits with a capacity of 10 Gbps. Nodes outside this network core are usually interconnected using circuits with a capacity of 2.5 Gbps. The *GÉANT* network is also interconnected with North-American networks (*Abilene*, *ESnet*, and *CANARIE*) and the Japanese NREN (*SINET*). Within joint projects, additional connections to *GÉANT* have been established to the Latin America (the *ALICE* project) and to the Southern Mediterranean area (*EUMEDCONNECT* project).

The active participation of the CESNET Association in the *GÉANT* network topology planning allowed the Czech Republic to connect directly to the network core. Even better, the node is located directly in premises of the CESNET Association in Prague; this considerably increases the reliability of our connection to the *GÉANT* network and lowers the costs of this connection. CESNET experts have been actively participating in several research tasks within the *TF-NGN*

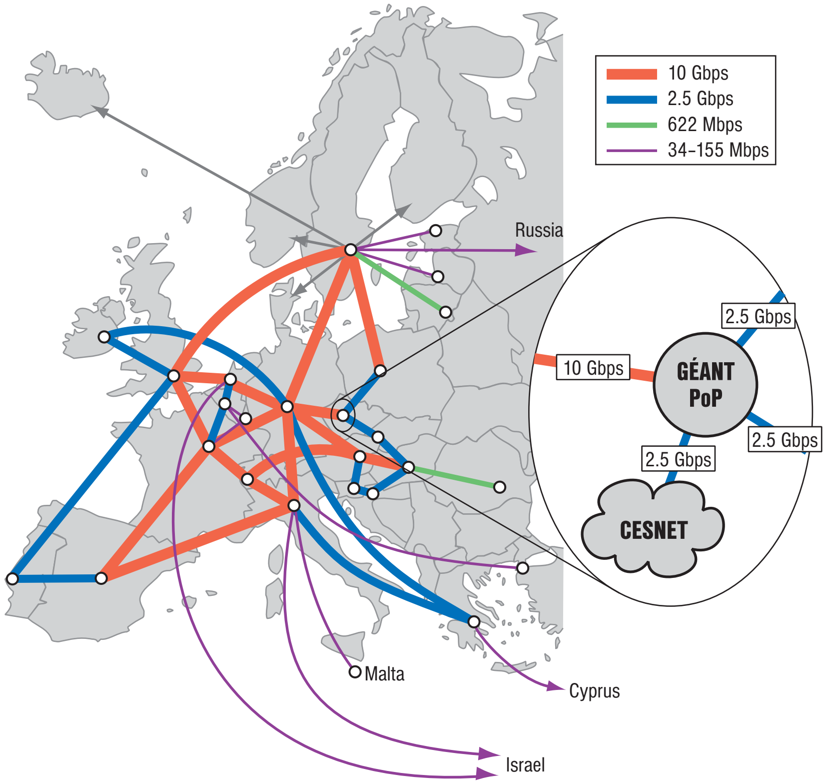

Figure 14.1: *GÉANT* Network Topology, October 2004

workgroups (Task Force – Next Generation Network) where they can exercise their experience – mainly from the area of developing tools for large networks monitoring and traffic analysis, developing tools for monitoring network performance characteristics and implemenenting the IPv6 and multicast.

More detailed information is available on the project website[1].

14.2 The GN2 Project

Continuity of developing the European research and education infrastructure is ensured through the implementation of a new four-year project within the 6th EU Framework Programme named the *Multi-Gigabit European Academic Network* which may be better known among the public by its acronym, *GN2*. The project was officially launched on September 1, 2004 with the objective of constructing an advanced, high-performance infrastructure (*GÉANT2*), allowing users to access their resources (in terms of information resources, computing capacities, etc.) in real-time from anywhere within the so-called European Re-

[1] *http://www.geant.net/*

search Area (ERA). Great emphasis is put on supporting services which ensure guaranteed connectivity among terminal devices (End to End Performance), resolving mobility-related issues as well as overcoming the "Digital Divide" (the disparity between developments in different countries and regions).

32 organizations dealing with the issues of research and educational high speed networks are involved in the project. The leadership of this also belongs to the DANTE Ltd. The total planned project budget amounts to approx. 180 million Euro, while a contribution from the EU amounting to 93 million Euro is planned.

The topic of high-speed data communication in the research and education environment is conceived very comprehensively within this project. Next to activities related to the development and operation of a given infrastructure, or research in the area of information and communication technologies, great attention is paid to the end-user support and support of developments within particular NRENs. The aim of these activities, encompassing not only technical but also organizational and economical aspects of implementing the state-of-the-art information and communication technologies, is mainly to wipe away existing differences between the technical levels of individual NRENs, thus preparing to build a homogeneous environment for scientific information exchange.

From the network topology and parameters perspective, the *GÉANT2* network will be a follow-up to the existing *GÉANT* network topology, with network core line capacities of 40 Gbps. This network, the operation of which will start during 2005, will support not only basic IP connectivity (via both the IPv4 and IPv6 protocols) including multicast support but also creation of temporary single-purpose infrastructures (grids) or point-to-point connections, based either on VPNs or on providing reserved wavelengths (lambda services).

Unlike the *GÉANT* project, the *GN2* involves also many research activities. These are of a great importance since the overall success of the project depends on results achieved, as the project ambitions are high. The activities are as follows:

14.2.1 JRA1 – Performance Measurement and Control

The goal of this activity is to design and implement an inter-domain performance monitoring system. This system will conduct regular and on-demand measurements of performance characteristics, such as available bandwidth, delay, or packet loss rate for the GÉANT2 network and connected NRENs. The system will be implemented as an extensible set of communicating services (e.g., measurement point service, archive service) using a combination of active monitoring, passive monitoring and processing information obtained from network infrastructure.

CESNET is responsible for specifying requirements for this monitoring system and for passive monitoring. In cooperation with other partners we analysed a set of questionnaires to obtain information about the current state of monitoring in NRENs and about monitoring requirements of NRENs, research projects and users. For passive monitoring, we started work on integrating the SCAMPI passive monitoring platform with the emerging JRA1 infrastructure.

14.2.2 JRA2 – Security

The JRA2 activity deals both with security policies and network monitoring tools. Its activities are closely related to the TERENA CSIRT task force.

In the policy area, the main goal is to deepen the cooperation among the GN2 partners in all areas of network security and to coordinate their actions during security incidents and attacks. In particular, this activity is expected to deliver a consistent security policy for the *GÉANT2* core in cooperation with DANTE. However, the activity will by no means limit its focus to backbone networks. It aims to mediate exchange of experiences in fighting all types of security threats, even if they are more of concern to campus and department networks.

CESNET involvement in the international security policy community was so far only marginal. This status was felt inacceptable though, and so a specialised CESNET CSIRT team was established in 2004. This team already started the process of becoming a "listed" member of TF-CSIRT. We expect the group to join GN2/JRA2 activities in 2005.

On the side of network security monitoring tool, JRA2 will identify, test and further develop a set of various monitoring tools. For the most part, this toolset will consist of open source software programs, some of them developed previously by the *GN2* partners. CESNET will contribute to the toolset by developing hardware-accelerated network monitoring devices. The short-term target is an autonomous probe generating NetFlow version 9 records (see Section 4.6 for details). Later, the hardware development will continue with a more general packet payload scanner that will be able to recognise incoming worms, viruses etc. by their "signatures" (unique sequences of bytes). Both the NetFlow probe and payload scanner will be based on the existing COMBO family of cards and will fully utilise the flexibility of the FPGA technology, namely, the ability to reload the firmware on the fly.

14.2.3 JRA3 – New Services Development

The aim of this activity is to prepare conditions for providing dedicated switched connections, especially so-called lambda services. Technologies for automated establishment and control of optical connections based on user requests will be sought, designed and tested. Within this activity, we will take part mainly in defining requirements and selecting suitable technologies for the type of services mentioned above.

14.2.4 JRA4 – Service and Technology Testing

This activity focuses on designing and implementing a testing infrastructure for new transmission technologies and network applications. The testing infrastructure will be formed by combining national testing infrastructures comprising dark fibres that will be fitted with necessary equipment, depending on the experiment type. CESNET experts participate in designing a suitable testing infrastructure topology and in selecting experiments within the area of optical transfer technologies.

14.2.5 JRA5 – Mobility and Roaming

The goal of this activity is to provide users with transparent and simple access to network resources from anywhere. This task requires the roaming issues to be resolved, including the development of unified authentication and authorization infrastructure. Representatives of the CESNET Association contribute to this activity by dealing with the roaming issues within the *eduRoam* initiative, taking part also in the definition of policies for the shared authentication and authorization infrastructure.

14.2.6 Other CESNET involvement

In addition to the research activities mentioned above, the CESNET Association is involved also in the **SA3** activity. This “Service Activity” is concerned with the End-to-End Quality of Service to enable end users to exchange data with guaranteed transfer parameters through the *GÉANT2* network. The first task of the CESNET Association within this activity is to design and establish a distributed *PERT (Performance Enhancement Response Team)* that will handle user problems related to network performance characteristics. The second task is to implement a monitoring system for the *GÉANT2* network.

The Europe-wide prestige of CESNET in the framework of R&D activites related to NREN development and operation has been confirmed by electing the managing director of CESNET, Jan Gruntorád, to the five-member executive committee managing the work on the *GN2*. Achievements of the CESNET Association in the optical network development field have been rewarded also by electing Stanislav Šíma into a closed group of experts responsible for the *GÉANT2* network topology design and for selecting suitable optical lines and transfer technologies.

More detailed information is available on the official project website[2].

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[2] *http://www.geant2.net/*

15 EGEE Project

The EU 6th Framework Program project EGEE (Enabling Grids for E-sciencE) is one of the largest international projects funded by the European Union, both in the number of involved partners and in the EU financial contribution. The two-year project led by CERN started on April 1, 2004 and includes 70 partners not only from almost all European countries but also from Russia and USA, although the U. S. institutions do not receive direct financial contribution from the EU. Nowadays, some Asian partners from Korea and Japan also expressed interest in collaborating with the EGEE project.

The EU contribution of some 35 million Euro is used to build a pan European Grid that will be prepared to interoperate with similar non-European Grids. The EGEE Grid is based on a network of interconnected data warehouses and computers, mostly clusters with Intel IA-32 and IA-64 architecture based processors or compatible architectures made by AMD. The project budget does not include direct investment; on the contrary, the equipment should be contributed by interconnected countries and project partners. The project contribution is the middleware, i.e., the programs used to interconnect individual computers and data warehouses to hide the complexity of the underlying fabric and to present the Grid environment in a form as unified as possible. This middleware will be used to connect individual computers and already existing thematic, regional or national Grids into one unified pan European Grid infrastructure.

To simplify the management of such a large project, whole Europe is divided into several so-called *Federations* based on the regional affiliation. The Czech republic is a member of the Central European Federation whose other members are Austria, Hungary, Poland, Slovakia and Slovenia. CESNET is the only institution from the Czech Republic directly participating in the EGEE project but in fact, CESNET coordinates researchers from several other institutions, most notably the Masaryk University in Brno, Institute of Physics of the Academy of Sciences, West Bohemia University in Pilsen, and Charles University in Prague. The extent of CESNET involvement, as well as the financial contribution, makes CESNET the largest EGEE partner from the whole Central European Federation.

The regional division of partners is complemented by the division of the technical content of the project. There are four groups of activities:

- Joint Research Activities (JRA)
- Networking Activities (NA)
- Specific Service Activities (SA)
- Networking (Coordination) Activities (NA)

The Joint research activities cover the following areas:

- JRA1 – middleware development, re-engineering and integration
- JRA2 – quality assurance

- JRA3 – security
- JRA4 – advanced network services

CESNET is involved in the middleware development and re-engineering activities of the JRA1. This is the largest research activity of the EGEE project and its results will deeply influence the success of the whole project. The JRA1 work builds on the results of the preceding DataGrid (where CESNET also participated) EU 5FP project; its goal is to create a uniform environment for resource management and scheduling and for the access to the data storage and to data stored there. The complete middleware will be available under the brand name *gLite*.

The JRA1 activities are led by CERN with participation from institutions from the Great Britain, France, and Italy. The Czech Republic is the only other country also involved in these research activities – this success is the result of previous CESNET work within the EU DataGrid project. CESNET is responsible for the development of the Logging and Bookkeeping service. This service is responsible for monitoring the job flow through the individual middleware and other Grid fabric components. It collects events triggered by jobs passing through these components and reconstructs the state of jobs (submitted, queued, waiting, running, etc.) from these events. The Logging and Bookkeeping service was designed as a specialized Grid monitoring service, with proprietary interfaces for event logging and also for access to the database that stores both the events and job states. It is being re-engineered to provide standard grid service interfaces which will allow its more extensive use as part of a general Grid monitoring infrastructure.

The CESNET research team also designed and is currently developing the Job Provenance - a long-term storage of job related information. While the Logging and Bookkeeping service keeps track of active jobs only (the information is purged from the bookkeeping database when the job is finished or aborted), the Job Provenance will keep the information as long as necessary. The information stored in the Job Provenance could be used for statistical purposes (we collaborate with the JRA2 activity which uses the bookkeeping information to evaluate the EGEE Grid use efficiency) but also to re-run jobs (e.g., when a new algorithm is developed and the same data must be re-examined). While the Job Provenance is a new, EGEE related concept, it has been included already as a part of the first version of the gLite middleware (it is a part of the so-called Release Candidate 1).

As already mentioned above, CESNET collaborates with the JRA2 on providing input information for Grid metrics evaluation. While not directly involved in the JRA3 activities, a member of the CESNET team serves as an official liaison between the JRA1 and JRA3 groups. CESNET is not directly involved in the JRA4 activities, however, participating in the GÉANT2 project, the CESNET also contributes to the networking related work of the EGEE project.

A stable and reliable production Grid is the main goal of the EGEE project. This Grid should interconnect over 100 sites with more than 50 thousand processors and at least 1 PB of disk capacity, all available in the year 2006. It is the responsibility of the SA1 – the Grid management and operation activity – to deploy the middleware and manage the resulting Grid. Almost all EGEE partners are to some extent involved in this activity, and CESNET is no exception. We are a part of the Central European Regional Operating Centre (ROC); CESNET provides a backup for most of the services running in the ROC headquarters in Poland. The Institute of Physics (Academy of Sciences) closely cooperates with CESNET on the ROC management in the Czech Republic, and nowadays some 300 processors represent the Czech Republic contribution to the EGEE project – this is almost 50 % of all the current Central European capacity. In November 2004, CESNET took a leading role to develop and deploy a Central European Virtual Organization (VOCE) which will provide production access to the CE resources to end users not (yet) participating in any of the application oriented virtual organizations (like High energy physics, computational chemistry, bioinformatics, etc.) already established within the EGEE.

The SA2 activity – deployment of specific network services – is responsible for interconnecting the EGEE project with the GÉANT2 EU project. As with JRA4, CESNET is involved indirectly, through its participation in the GÉANT2 project.

CESNET is also participating in two of the five networking (coordination) activities: the NA3 (Training) and NA4 (Application Identification and Support). CESNET has organized two user training events already – the introductory seminar in late October and an end user training workshop in early December. We also intensively support high energy physics applications, especially through participation in the so-called Experiment Data Challenges where hundred thousands jobs are submitted and run on the already available Grid infrastructure both to get some scientific results and also to stress test the infrastructure itself. The combined CESNET and Institute of Physics contribution has been usually the largest from the whole Central European region. We also collaborate with other application groups, helping them to move their applications into the EGEE Grid environment. The most active collaboration exists with teams involved in computational chemistry.

The remaining three networking activities are the Project management (NA1), Dissemination (NA2), and International Cooperation (NA5). CESNET is not directly involved in any of these activities, although a CESNET representative is a member of Collaboration Board (a body consisting of one representative from each EGEE partner).

More information about the project can be found at its web pages[1]. Specific information about the CESNET participation with the EGEE project can be found at the following URL: *egee.cesnet.cz*[2].

[1] *http://www.eu-egee.org/*
[2] *http://egee.cesnet.cz/*

16 SCAMPI project

16.1 SCAMPI project

The SCAMPI project (IST-2001-32404) continued in 2004. CESNET is a principal contractor of the project which was originally scheduled until September 2004. However, it was decided to prolong the project until March 2005.

The main goal of the SCAMPI project is to design and develop an architecture for passive monitoring of high-speed networks up to 10 Gbps. The highest layer of the architecture contains the applications (e.g. QoS monitoring, SLS/SLA audit, DoS detection, accounting). The middle layer is a MAPI (Monitoring API), an universal interface between the applications and the hardware platform. MAPI supports three kinds of hardware: commodity NICs, DAG family cards and a specialized adapter which was developed as a task of the SCAMPI project.

16.1.1 SCAMPI progress in 2004

The review report (Amsterdam, May 2004) stated that the project continued successfully and fulfilled its goals. All deliverables were accepted and reviewers found the SCAMPI adapter and the MAPI technologically advanced and having potential for commercial utilization. We were asked to elaborate a study discussing ways of commercial production.

Project participants from CESNET and Masaryk University worked mainly on hardware and VHDL design of the adapter, drivers, libraries and the MAPI implementation. Development and testing of Phase 1 of the adapter was finished successfully and Phase 2 design was done by the end of 2004. The precise timestamp card COMBO-PTM including software is ready for use. Details about hardware and VHDL design can be found also in the *Programmable hardware* chapter.

We made experiments and measurement of the adapter Phase 1 version. We verified the general functionality and the ability to filter packets. COMBO-PTM card tests confirmed that the real accuracy of clock synchronization is even better than projected, i.e., the time difference between the card clock and GPS is not worse than 1 microsecond.

16.1.2 Events in year 2004

Five meetings of SCAMPI partners and a second SCAMPI workshop (Amsterdam, April 2005) took place in 2004. Five deliverables were written:

- D2.3 – Enhanced SCAMPI Implementation and Applications
- D3.3 – Risk and Security Analysis

- D3.4 – Description of Experiment Results, 1st version
- D4.3 – 2nd SCAMPI Workshop
- D4.4 – Exploitation and Use Plan (Preliminary version)

Apart from the SCAMPI workshop, we had other presentations to introduce the SCAMPI project and the SCAMPI monitoring adapter. It includes papers on the *TNC-2004* TERENA conference (Rhodos, June 2004), *IPS-2004* workshop (Budapest, March 2004), *TPM-2004* workshop (Geneva, March 2004), and *Sledování sítě a jejího provozu (Network and traffic monitoring)* seminary (Prague, November 2004).

16.1.3 Plans for 2005

2005 will be the last year of the SCAMPI project. Our goal is to prepare a final review (Brno, January 2005) and to finish last deliverables in order to demonstrate advantages of the programmable monitoring adapter. We have to finish the Phase 2 tests and write a final version of the D3.4 deliverable *Description of Experiment Results*.

16.2 LOBSTER project

The LOBSTER project is a successor of the SCAMPI project. The result of SCAMPI is a complete passive monitoring architecture with hardware acceleration. The goal of LOBSTER is to install a European large-scale monitoring infrastructure based on SCAMPI. The project concentrates especially on security monitoring – early detection of intrusion and denial of service attacks. Such attacks can only be detected by passive monitoring, i.e., observing existing traffic, as oposed to active monitoring, which uses injected test packets. However, because passive monitoring observes user data, it is often possible only when this data is anonymized properly.

LOBSTER started in October 2004 and is scheduled until December 2006. The concorcium consists of 9 academic and industry partners from 5 European countries, together with the Endace company from New Zealand. There were two project meetings in October 2004 and January 2005. Currently we are working on gathering user requirements and on investigating design variants of low-level part of anonymization implemented in firmware of the SCAMPI monitoring adapter.

17 6NET

The nternational project 6NET[1] is a part of the 5th EU Framework Programme. Its main goal is the development and popularisation of the IP version 6 protocol. The project was scheduled to end in 2004 but it was extended till June 2005. By the end of 2004, the core network infrastructure of the project was dismantled; during 2005, project activities should focus on result publication and dissemination. The remaining development work that still requires the network – mainly in the area of IPv6 multicast – will utilise the Géant2 network which already offers production IPv6 multicast service.

In 2004, CESNET was involved mainly in the continuing development of the *Liberouter* (PC-based IPv6 router with hardware acceleration, see section 4.3). In cooperation with the CzechLight project, we deployed a Liberouter prototype equipped with the COMBO6 card and COMBO-4SFP interface card (Gigabit Ethernet). Since March 2004, this router has been connected to the 6NET core router (Cisco GSR) through the Praha–Amsterdam optical lambda circuit. This premiere semiproduction deployment of Liberouter ran the NetBSD operating system and the BIRD[2] routing daemon which was successfully ported to NetBSD for this purpose. After correcting several bugs in the COMBO6 driver, the router operated from May 2004 till the end of that year without any major problem. Of course, this was a relatively gentle test since the traffic volume on that line was very low.

CESNET also continued IPv6 dissemination activities. On June 1 we repeated the successful seminar "IPv6 – development and implementation". We also contributed to the 6NET deliverable [d223] and published an overview article on Liberouter in the *6NET Newsletter*.

[1] *http://www.6net.org/*

[2] *http://bird.network.cz/*

Part III

Conclusion and Annexes

18 Conclusion

The next generation of research and education backbone networks (GÉANT2, National LambdaRail, Abilene2 as well as individual NRENs) will have to provide especially higher transmission bandwidths and complement the classical IP service with lambda services. At present, the capacity of $n \times 10$ Gbps backbone lines is a short-term goal; for longer-term prospect (2–4 years), higher transmission speeds ($n \times 40$ Gbps and more) should be expected. These speeds and services will be of an end-to-end character so that the end users will not have to deal with features and differences of backbone, metropolitan and institutional networks and services. The reasons are in particular:

- requirement for creating research cooperation environments (Grids and other new classes of applications and middleware services)
- possibility of rendering multigigabit connections including the first mile for those research and education workplaces which can take advantage of them
- possibility of making unique or very expensive research equipment accessible for remote users in real time
- users' lasting interest in videoconferences and other applications (media streaming, eLearning support)
- the organic growth of IP user traffic enabled by continuous institutional and metropolitan network upgrades

At the same time, the technical foundation on which the research networks are being built is changing. The changeover to CEF networks became a widely accepted strategy because it allows providing better services for research and education. The price reasons for this changeover are gradually turning out as important but not of the highest priority (in some cases, this transfer is not cheaper but new opportunities for research support are created). This situation is difficult for management and staff of some NRENs because they did not expect it. Moreover, some of the telecommunication operators and network equipment producers intensively and often successfully resist it, especially when their position is dominant. However, other operators begin to offer the support and projecting of CEF network deployment and maintenance, in addition to "telecommunication services with high added value", and they offer also modules and equipment for multivendor networks in addition to closed company solutions.

Judging from the development in this field, the research goals given in the research plan have been defined correctly and changing them in 2005 is not necessary. Obviously, one can not suppose for sure that all goals for the seven-year period have been defined perfectly; therefore, defining more accurate goals or only the ways of reaching them may be needed in later phases (e.g., after some four years).

More importantly, the basic results and realisation plans of the research project should be consulted often both with international and our national experts and customers, and various opinions, suggestions and comments should be analysed and evaluated. For this purpose, the CESNET Association traditionally holds specialised seminars and presents the results at international conferences. This will continue in future.

All in all, we held the following seminars in 2004:

In February, we held a seminar called *CESNET2 – the National Research Network* for current and potential participants in our NREN. Its aim was to inform about the present state of the network, its features and applicability.

The international workshop *Customer Empowered Fibre Networks*, held in May, brought a wide response. It was intended mainly for foreign participants; its main purpose was exchange of experience with CEF network building in various countries.

Based on the response to the *IPv6 seminar* held in autumn 2003 for the professional public, the Association prepared another seminar on this topic in June, this time for the CESNET members. The participants were informed about the actual state of IPv6 protocol and the experience with its practical deployment.

In June, we held a professional seminar called *Technical, Commercial and Legal Solutions in the Sphere of Identification Cards and PKI*, with the participation of the Czech Ministry of Informatics. Nine Czech firms presented their samples of technologies using R/W cards with encryption and using the PKI. The seminar closed the first stage of intensive discussion between the representatives of universities and the Academy of Sciences of the Czech Republic. This discussion concerned:

- unification of ID cards used by university students and employees
- purposeful standardising of data in the ID card system
- PKI technology integration.

In October, an introductory seminar of the *EGEE (Enabling Grids for E-SciencE)* project was held. Its main topic was the pan-European grid infrastructure which is being built within the EGEE project. The participants were informed about the applications which this environment is meant for, and about possible environment adaptation for further applications. Basic operation in the grid environment was also presented to the professional public during the seminar.

In December, this seminar was followed up with a *seminar for advanced users of grid infrastructure* being built within the EGEE project framework. Its main motivation was to enable the applicants to see the way of working in the EGEE Grid environment in detail.

The Network and Its Traffic Monitoring was the topic of the last seminar. The results of the work and the experience of the Association in the following areas were presented:

- monitoring and analysis of traffic based on flow measurement
- measuring high-speed networks and their properties
- communication performance characteristics in the perspective of end terminals.

A List of Connected CESNET Members

institution	*connection [Mbps]*
Academy of Arts, Architecture and Design in Prague	100
Academy of Fine Arts in Prague	10
Academy of Performing Arts in Prague	100
Academy of Sciences of the Czech Republic	1000
Brno University of Technology	1000
Charles University in Prague	1000
Czech University of Agriculture in Prague	1000
Czech Technical University in Prague	1000
Institute of Chemical Technology in Prague	1000
Janáček Academy of Musical and Dramatic Arts in Brno	1000
Masaryk University in Brno	1000
Mendel University of Agriculture and Forestry in Brno	1000
Palacký University in Olomouc	1000
Silesian University in Opava	100
Technical University in Liberec	1000
Technical University of Ostrava	1000
Tomáš Baťa University in Zlín	1000
University of Defence in Brno	1000
University of Economics in Prague	1000
University of Jan Evangelista Purkyně in Ústí nad Labem	1000
University of Hradec Králové	1000
University of Ostrava	1000
University of Pardubice	1000
University of South Bohemia in České Budějovice	1000
University of Veterinary and Pharm. Sciences in Brno	1000
University of West Bohemia in Plzeň	1000

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C Own Publishing Activities

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