Fiber Optics Transport Infrastructure of Cesnet Backbone

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Abstract: CESNET is an association of universities and Academy of science of Czech republic. It is operating a national research and education network (NREN) interconnecting all university cities in the republic. The backbone of this network is based on leased dark fiber lines. On some lines it was necessary to utilise not yet common transmission technologies for technical or economical reasons. This paper brings an overview of these solutions.

Key–Words: Dark fibre, OAM, NREN, Single fiber, NIL, DWDM, CBF

1 Introduction

CESNET is an association originated by universities and Academy of science of Czech republic in 1996. Its main goal is to operate and develop academic backbone network of Czech republic. This network started on lines with bandwidth in hundreds of kilobits per second and step by step interconnected all academic cities in republic. Contemporary generation of this network is named CESNET2 and offers bandwidth in order of gigabits per second on backbone lines.

CESNET is a member of European research organisations like GEANT and is participating in a lot of research projects.

Usually modern and progressive technologies are used on Cesnet backbone network. Currently the backbone is based on leased dark fiber lines. DWDM technology is utilised in the core of the network. Various not yet common transmission technologies are used on the edge of the network. These technologies are discussed in this paper.

2 CESNET

In the beginning of the Internet in former Czechoslovakia the national backbone network was operated by Czech University of Technology in Prague. From the beginning it was clear that all research and education institutions like universities and Academy of science will need to have access to international computer networks and that they have to participate on both funding and maintaining of common networking infrastructure which will offer data network services to all these institutions.

Since 1996 CESNET was solving project of Czech ministry of education named *TEN-34 CZ*. Goal of this project was to construct national backbone network with technical parameters corresponding to trans european research backbone named TEN-34. (34 Mbps was the nominal bandwidth used in backbone lines.) Backbone of TEN-34 CZ (how the network was named at that time) was build on ATM technology. Main nodes were equipped with ATM switches and routers and interconnection of these nodes was done via leased E3 lines. Migration of CESNET members networks to ATM backbone was finished in 1997 . At this time started discussions about possibilities for further development of network especially with respect to new transport protocols and new applications like IP multicast, IPv6, packet voice services and others.

2.1 History of Czech NREN

At the beginning of networking in former Czechoslovakia the network topology was rather poor. It was a tree structure with root in Prague. From Prague went IP line to Linz as a first international connectivity. Large cities like Brno, Ostrava, Pilsen or Hradec Kralove were connected to Prague via leased lines with typical bandwidth 128 - 512 kbps. Smaller cities were connected via leased lines to the ”second level” nodes mentioned above. Typical bandwidth of such connection was 19.2 kbps.

In the next step main lines were upgraded to 1 - 2 Mbps and mostly all university cities were connected to Prague. At the same time the topology of backbone was a little bit improved. From tree structure we have moved to some kind of ring topology. At least connectivity for largest cities was done not only to Prague but also to another suitable city of similar size. Connectivity to smaller cities was upgraded to 64 - 256 kbps.

Since 1996 when TEN-34 CZ project started The

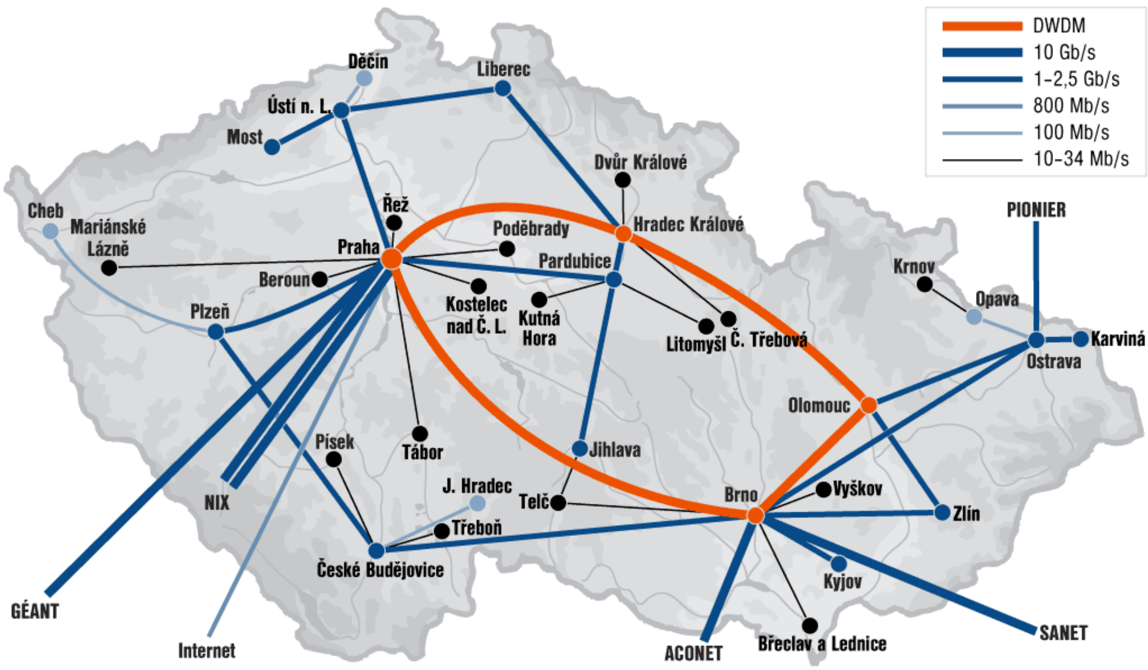

Figure 1: Physical Dark Fibre Topology of CESNET Backbone

backbone of NREN utilised ATM technology since 1996 when TEN-34 CZ project started. At that time the ATM backbone was a tree structure based on microwave E3 lines. Backup connectivity was solved on legacy technologies i.e. leased lines with bandwidth 2 Mbps.

LANE protocol in backbone network was replaced by MPLS on ATM transport layer in 2000 . The main goal of backbone network at that time was to provide reliable and stable IP connectivity to its members. Some experimental and supplemental services (e.g. IP multicast) were started that year according to Cesnet research plan. In this year was build first line based on dark fibre. It was line Prague - Brno and POS STM-16 was used on this line. The line is about 300km in length and 3 regenerators were placed along the line. ATM was step by step replaced by POS and gigabit ethernet (GE) in 2001 . It was run on a mix environment of dark fibre and leased line POS STM-16.

A next step was movement to complete dark fibre infrastructure. The reasons for this step are the following: at speed of GE and STM-16 dark fibre is more economical than leased lines and bandwidth improvement and technology migration is very easy on dark fiber lines. More over the backbone moved to NIL (Nothing In Line) technology on mostly all lines.

3 Dark Fibre in CESNET Backbone

Dark fibre provides a lot of advantages and CESNET is using this technology on all backbone lines. The schema of "L1" topology i.e. dark fibre infrastructure is on picture 1.

DWDM technology is used in the core of the network. (Orange lines on picture 1). DWDM is used to provide data channels going through several backbone nodes. The real length of data channel may be several hundreds of kilometres. Too high amplification ratio would cause distortion of the signal. For that reason we use in-line optical amplifiers on DWDM lines. Typical span length between optical amplification is about 80km. Chromatic dispersion is compensated via DCF (Dispersion compensation Fiber) at amplification nodes.

On single channel lines we use so called NIL (Nothing In Line) principle. That means optical amplifiers are located on data termination points only. By usage of fibre optical amplifiers it is no more necessary to maintain any regenerators somewhere in line. The maintenance should be done only in network nodes which are located at universities so we can avoid problems with transport of staff and material to remote locations somewhere in field.

The dark fiber utilisation becomes very popular not only in Czech republic. During past few years more NRENs in Europe start using dark fiber lines in their backbone networks. More over in many case it is reasonable to interconnect two neighbouring NRENs via dark fiber. The result is nowadays called CBF - Cross Border Fiber. One of the first CBF lines (though at the time of it's construction it was not yet called CBF) was line Brno-Bratislava which interconnects CESNET and SANET (Slovak Academic Network). Next CBF lines followed and today we utilise three CBF lines: CESNET-SANET, CESNET-ACONET and CESNET-PIONIER.

3.1 EDFA amplifiers

It is very easy to use single channel lines up to 110 km of length. Usually attenuation of such lines is below 30dB. We use unamplified gigabit ethernet with CWDM GBICs or SFPs on such lines. Power budget of CWDM pluggables is usually about 2 - 3 dBm better than power budget of traditional ZX gigabit ethernet pluggables. More difficult situation is longer lines. In such case it is necessary to use some external conversion and/or amplification equipment.

On lines above 110 km up to about 250 km we are using mostly solution with two (Booster only) or four (Booster + Preamp) EDFA amplifiers located at both ends of the line.

The situation is easy to see from picture 2.

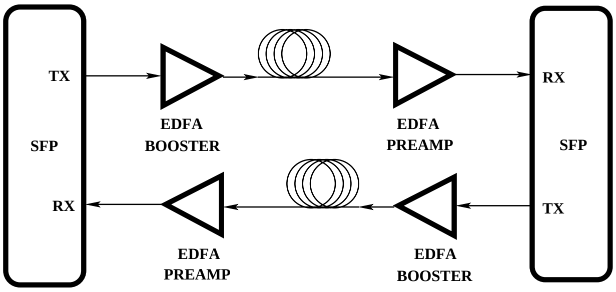

Figure 2: NIL solution for single channel lines

First real usage of this principle in CESNET backbone is run on line Prague - Pardubice. NIL is used on this line since 2001. This line is 189km in length and is equipped with EDFA (Erbium Doped Fibre Amplifier). EDFAs on this line are used as boosters i.e. are connected below transmitter on both sides of the line. The longest line equipped with this technology is line Brno - Ostrava. The length of this line is about 235 km. This line is equipped with 4 EDFAs: output of each transmitter is connected to EDFA booster. Output signal of the booster is about +22dBm. Before each receiver is connected EDFA preamplifier. This line is now used for transport of Gigabit ethernet. With similar setup it was used for POS STM-16 type of traffic.

3.2 Cost-effective solution for midsized lines

Today smart SFP modules with power budget of 36dB are available on the market. Such SFPs can be used on lines with length about 160km. However main networking equipment vendors used to limit spectrum of gigabit ethernet pluggables (GBICs or SFPs) usable in their routers and switches to a relatively small number of approved types. It prevents us from utilisation of interesting SFP modules with high power budget or SFPs with other special properties suitable for CESNET backbone network.

For utilisation of new models of SFPs which are not yet approved by our networking equipment manufacturer we propose to use small external equipment serving as a ”transponder”. The idea is easy to understand from the picture 3.

For many possible applications of this technology in CESNET network we appreciate ethernet OAM specified by IEEE 802.3ah. For this reason we have concentrated on equipment supporting this protocol. We have tested SFP-to-SFP media converter MRV model EM316-GRMAHSH. Now we are performing production testing of this equipment on line Brno-Zlin which has about 130km in length and 33dB attenuation. This converter is equipped with Optaway SFP modules SPS-73160. This SFP has power budget 36dB. We have tested a lot of other interesting SFPs, e.g. Optoway SPB-7780-1510 single fiber SFPs with 25dB power budget.

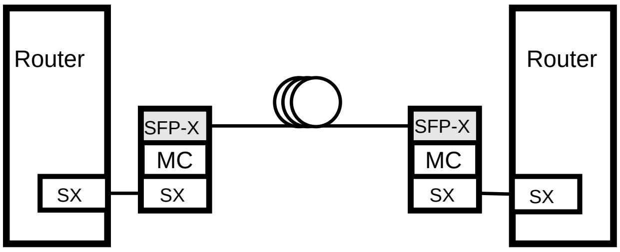

Figure 3: Usage of external ”transponder” for utilisation of special SFP modules

Another benefit of this solution (next to utilisation of special SFPs) is the possibility of Ethernet OAM utilisation.

Ethernet OAM (Operations, Administration and Maintenance) was originally introduced by EFMA (Ethernet in the First Mile Alliance) and later standardised by IEEE in 802.3ah specification. The main purpose of this protocol was to overcome some inefficiency or weakness of traditional enterprise management protocol i.e. SNMP. Although SNMP provides a very flexible management solution sometimes it is inadequate to management task. First of all it assumes operational underlying network because it relays on IP connectivity. However we need management functionality even if (and first of all if) the underlying network is not operational.

Carriers looked for management capabilities at every network layer. The ethernet traditionally doesn't offer management capabilities so the 802.3ah is mostly the only way for management of this layer. Though it was originally intended for EFM (ethernet in the First Mile) applications it is very suitable for ethernet base backbone lines.

3.3 Single fibre lines

Lines to some smaller locations like Karvina or Jindrichuv Hradec are constructed as a single fibre lines. The reason for usage of this type of lines is partially price of leased dark fibre lines and partially pure dark fibre availability in some areas.

Most of other single fiber lines are used for fast ethernet lines and are based on commercially available equipment i.e. mediaconvertors which convert signal from 100Base-T to single fiber optics. As the volume of network traffic is increasing it was necessary to upgrade several single fiber lines to gigabit speed. First such line was line Ostrava - Karvina.

Single fiber gigabit pluggables used in CESNET backbone routers would be perfect solution. Unfortunately this solution is not available due to business policy of vendor of our backbone routers. In these equipment only vendor approved GBICs and SFPs are functional. Because there are no any GBIC or SFP modules operating on single fiber lines of appropriate length (in our case 70km) we cannot utilise this solution.

We decided to use some kind of home-made WDM for this line. We have utilised the fact that optical signal receivers including that gigabit ethernet pluggables (GBIC and SFP) are wide-band. This fact allows us to use CWDM GBIC on 1550 nm on one end of the line and CWDM GBIC on 1590 nm on the other end of this line. Of course we should put an optical bandpass filter in front of each receiver to filter out transmitter of the same node. The schema of this construction is on picture 4.

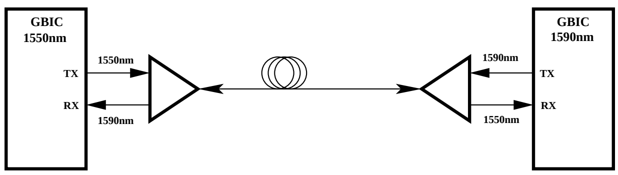

Figure 4: Schema of home made gigabit over single fibre

This approach is used for three years on the line Ostrava-Karvina. The fibre optics line between these cities is about 70km in length and it's attenuation is 23 dB. This solution allows us to utilise single fibre line with a reasonable length for about the same capital expenditures like legacy two fibre line. In the case of two fibre line we have to purchase two pieces of GBIC or SFP modules. In the case of single fibre we need the same modules plus two (one per line end) passive splitters equipped with bandpass filter.

We have very good production experiences with this solution.

4 DWDM in CESNET Backbone Network

During 2004-2005 the DWDM was implemented in the core backbone lines within the CESNET2 network. Previous technology solution of the dark fiber lines which utilizes single channel data transmission did not allow easy capacity scaling and was a limiting factor for optical channel end-to-end service (lambda service) provisioning. The objective of DWDM deployment is to integrate with the existing IP network and next to a hybrid IP/optical network controlled by GMPLS (Generalized MultiProtocol Label Switching) or a similar protocol, including the deployment of optical cross-connects for dynamic optical path switching.

The core DWDM network is based on Cisco ONS 15454 MSTP. It supports 32 traffic channels with 100 GHz spacing according to the ITU-T G.649.1 recommendation with guarantied BER for all channels. The DWDM core can transport "coloured" signal and supports transponders for all usual data traffic types.

4.1 First Stage of DWDM Deployment

The first stage of DWDM deployment was realized in 2004 when the line Prague-Brno was settled up.

Optical line Prague-Brno is the most complicated one in CESNET2 backbone network. It consists of three types of fiber optics. Local loops in Prague and Brno are legacy single mode fibers as specified by the ITU-T G.652. For the rest fiber optics cable Draka LT072 (66 SM+ 3TW+/3TW-) is used composed by fiber optic lines with either positive or negative chromatic dispersions. Sections with positive and negative dispersions are combined in an effort to achieve a line with minimal chromatic dispersion. Because the provider of this dark fiber line was not able to offer detailed documentation with complete parameters of the whole line it was necessary to measure these fiber optic lines including measuring chromatic dispersion.

Based on this measurement, the DWDM network plan was developed. It included two terminal nodes (Prague and Brno) and three OLA (Optical Line Amplifier) nodes on the path. On terminal nodes muxes and demuxes upgradable to ROADM were used. The

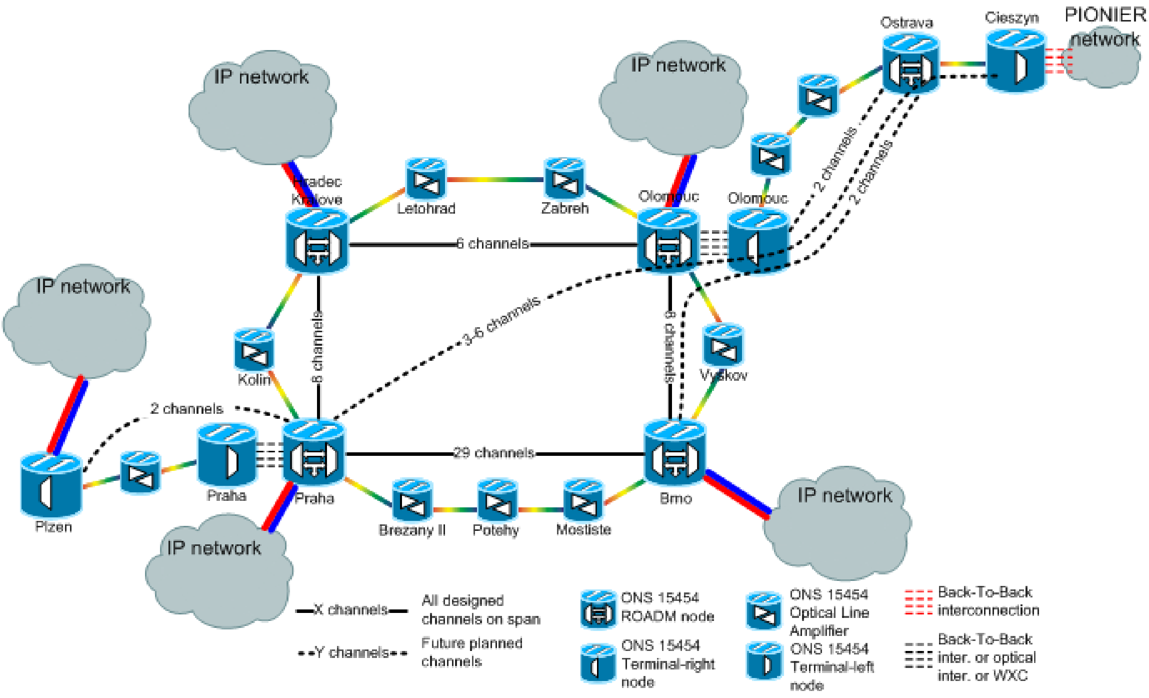

Figure 5: Core DWDM network topology

line was compensated via dispersion compensation fiber to zero chromatic dispersion.

4.2 Core DWDM Ring

In the second stage which took place in 2005 several more channels were added and both terminal nodes Prague and Brno were upgraded to full ROADM. ROADM (Reconfigurable Optical Add/Drop Multiplexer) is one of very interesting and useful properties of ONS 15454 MSTP. ROADM allows software configuration of zero up to 32 channels of pass-through or add/drop in every ROADM node. Further ROADM offers A-Z wavelength provisioning and full real-time power monitoring of each individual wavelength. These functionality allow to offer E2E (End to End) and lambda services.

Next ROADM nodes Hradec Kralove and Olomouc were added. Thereby we obtain a DWDM network of a ring topology with optical path protection capabilities.

All new fiber optic lines used in second stage were measured. Suspension cables hung on trolley lines or high-voltage lines are used on portion of these new lines. Because the lines may be influenced by mechanical stress the PMD (Polarization Mode Dispersion) was measured on most fiber optic sections. The placement of OLA nodes resulted from these measurements.

Existing DWDM network can be used (without changes in current equipment) for up to 32 channels. The whole network is calculated not to exceed the required BER = 10^{-15}. Though transponders used in the network provide a rather high dispersion tolerance, the chromatic dispersion of all lines is compensated. The resulting chromatic dispersion is near zero. The main benefit of this approach is an easy addition or reconfiguration of any number of channels up to the size of MUX/DEMUX matrix, easier scaling of DWDM network on new nodes and easier utilization of ”colored” signal. In all these cases we do not need to recalculate and check chromatic dispersion of the whole system.

4.3 International DWDM Connections

This year we expanded core DWDM network to new locations. New spans Prague-Pilsen and Olomouc-Ostrava was put into operational state. The new spans are interconnected with the main DWDM ring at the optical level to enable optical channels provisioning between any CESNET2 optical PoPs. As part of the extensions the technical solution for these interconnection has to be founded. Optical switches or WXC (Wavelength Cross-Connect) are not yet available for used DWDM equipment and utilisation of some third party devices is difficult due to incompatibility of management system. As a solution we decided to avoid ROADM functionality in corresponding DWDM muxes and to make three-way DWDM interconnection system manually on patch panel.

The DWDM span Olomouc-Ostrava is important for CESNET2 DWDM network extension to Cieszyn. There is CESENT2 and Poland Pionier network DWDM systems interconnection planned as a part of the CBF (Cross Border Fiber) project. This will start new stage of DWDM deployment.

The core DWDM network topology is depicted in figure 5

5 Single span DWDM

Demand for more bandwidth and for dedicated optical channels still grows. We need to provide multiple channels with mixed GE (gigabit ethernet) and 10GE (ten gigabit ethernet) technology even on lines originally intended as single-channel and equipped with NIL technology. For such lines we utilise simple ”single span” DWDM solution.

This solution is based on passive DWDM filters, EDFA amplifiers developed by Cesnet and FBG (fibre Bragg gratings) when necessary for dispersion compensation. The situation is easy to see from picture 6.

We have considered CWDM solution as well. The disadvantage of CWDM is EDFA amplifiers gain flatness which is insufficient outside the C-band. CWDM is possible to use on at most two channel solution. In the other case we need to replace currently used EDFAs by some more sophisticated optical line amplifiers which will work in both C and L bands.

The single span DWDM solution is used on several lines including CBF lines Brno - Bratislava and Brno - Wien. On line Brno - Bratislava which interconnects Cesnet and Sanet we use 4-channel DWDM system. On line Brno - Wien which interconnects Cesnet and Aconet we use 8-channel system. In both cases currently only one 10GE line is used. Chromatic dispersion is compensated with FBG. This technology is both more cost-effective and brings less insertion loss than legacy dispersion compensation fiber.

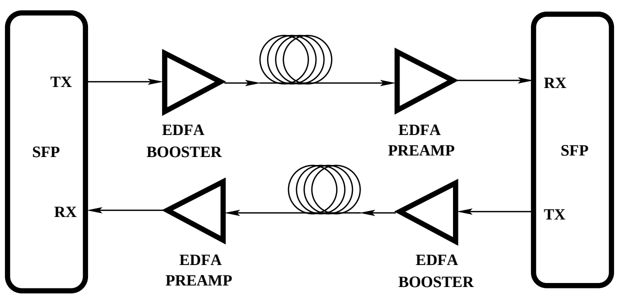

Figure 6: Passive DWDM network

6 Conclusion

The CESNET2 optical network layer development based on DWDM technology with the ROADM is the key requirement for new services introduction. It enables the support of on-demand E2E services on L1 and L2 network layers between the optical PoPs. It also provides an easy capacity scaling of the dark fiber optical lines and optical channel provisioning. The objective of the DWDM deployment is an integration with existing IP network and a step forward to a hybrid IP/optical network controlled by GMPLS or similar protocol including deployment of optical cross-connects for dynamic optical path switching. Cesnet utilises dark fiber on all backbone lines. Except core DWDM system which is constructed as compact network entity NIL technology is used on all lines up to 250km length. The number of lines equipped with DWDM muxes is still increasing and new optical technology is used in the network.

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