

Fibres and advanced optical devices for a new networking strategy

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Fibre is strategic asset

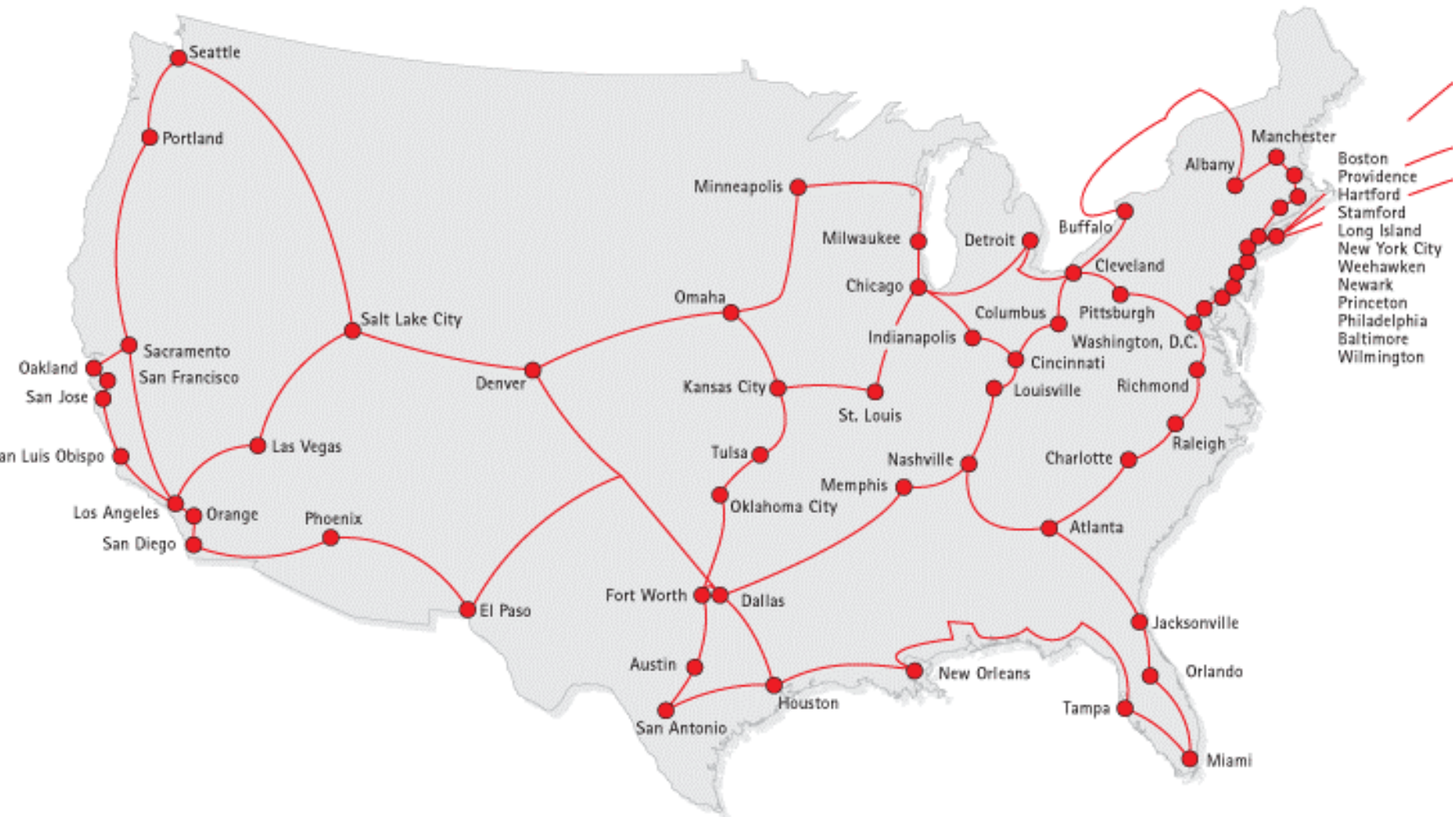
- Fibre infrastructure considered strategic asset for research and education networking
 - In some countries, states or regions in Canada, Europe and USA since 2000
 - In USA (national scale) since 2003
 - in EU since (GN2?)
- Some information publicly available about prepared fibre application for R&E networks in USA follows:

Fiberco as fibre source

Fiberco is a limited liability corporation (LLC), established in USA in May 2003 for fibre holding:

- Initial assets include over 2,600 miles of dark fibre, investment is up to \$10M over 5 years. Fiberco is able to use „buy or bought“ strategy for national fibre footprint development and for first mile procurement.
- Potential for the facility to serve as transport platform for 3rd generation Abilene IP backbone (2005-2006 time frame)
- Support of regional fiber optical networking initiatives dedicated to research and higher education, with the benefit of a national-scale contract and aggregate price levels
- U.S. research university collective maintains access to a strategic fibre acquisition capability on the national scale for future initiatives

Current Fiberco capability to provision fiber



Fiberco use Level3 fibre lines

Level3 built fiber is on the 6x100 model

- ~100km between huts (amps)
- Ever 6th hut has regen, retiming & reshaping

Gateways and all huts have provision for co-lo, at least 30/60 amps (hut/gateway) of power & 1 rack

Can also access at splice points

The Fiberco <> L3 fiber is inter-city, LEAF

L3's metro fiber is also possible

Cooperative approach to metro, laterals, access & x-connects

Regional optical networks in USA

- California (CENIC Optical Networking Initiative)
- Connecticut (Connecticut Education Network)
- Florida (Florida LambdaRail)
- Indiana (I-LIGHT)
- Illinois (I-WIRE)
- Maryland, D.C. & northern Virginia (MAX)
- Michigan
- New York + New England states (NEREN)
- North Carolina (NCNI)
- Ohio (Third Frontier Network)
- Oregon
- SURA Crossroads (southeastern region)
- Texas (Star of Texas)

U.S. optical network projects

(differentiation seen by Fiberco)

	<i>Distance scale (km)</i>	<i>Examples</i>	<i>Equipment</i>
Metro	< 60	UW(SEA), USC/ISI(LA)	Dark fiber & end terminals
State/ Regional	< 500	I-WIRE (IL), I-LIGHT (IN), CENIC ONI	Add OO amplifiers
Extended Regional/ National	> 500	TeraGrid NG Abilene, Light Rail	Add OEO regenerators & O&M \$'s

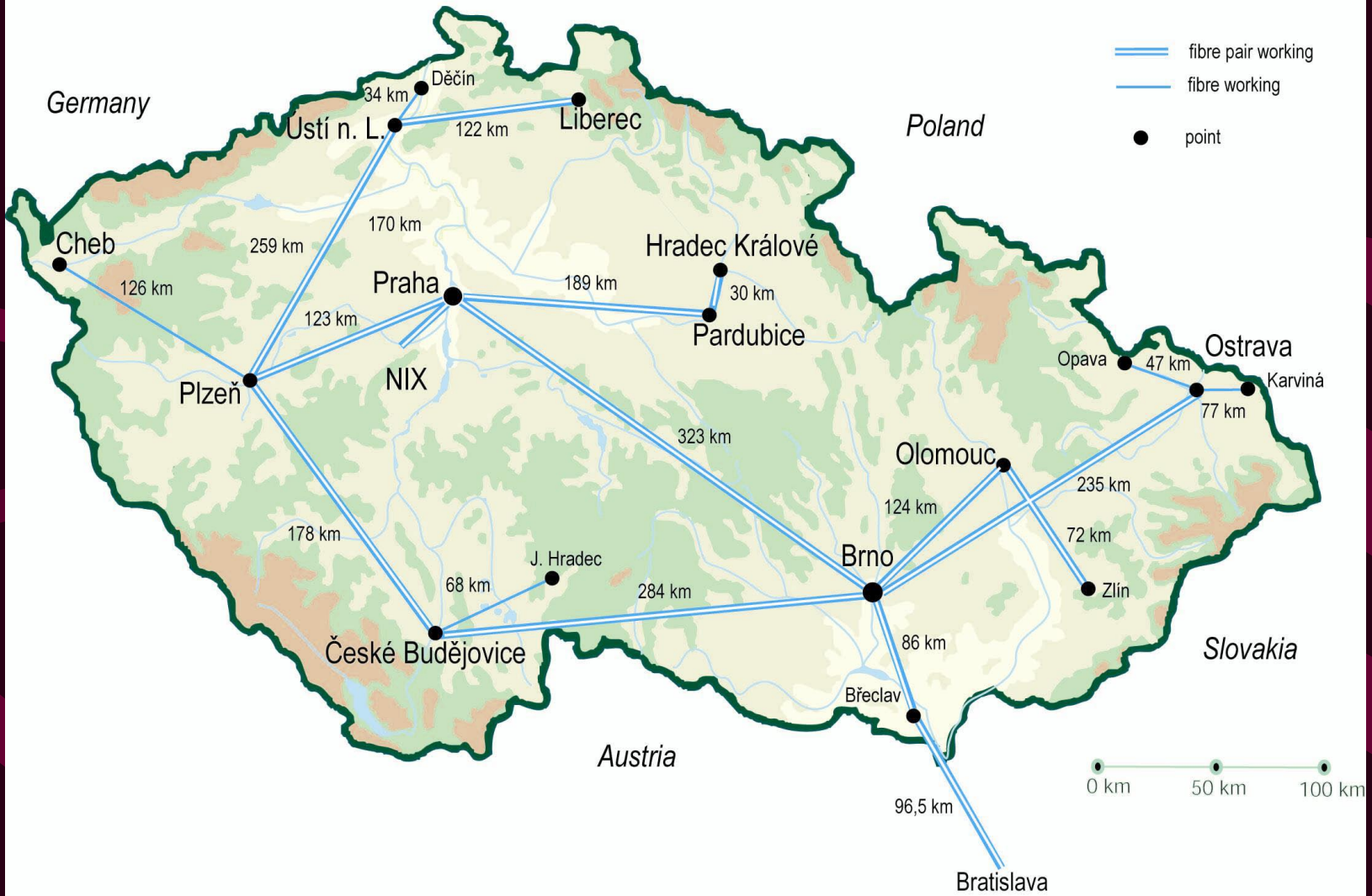
Fibres in CESNET - strategic results

- National fibre footprint realized or contracted (for 1 – 5 year)
 - 17 lines, overall length 2 513 km
- 2 fibre providers offer on-demand fibre cable laying for first mile (delivery before 6 month, price about 30 000 Euro/km for 12 strand cable)
- 1 fibre provider offers also single fibre leasing (price is 60% of fibre pair leasing)
- For traffic statistics (actual and past) please see:
<http://www.cesnet.cz/provoz/zatizeni/>

Fibres in CESNET - update

- Tender for new lines and shorter fiber lines between PoPs (delivery before 31.12.2003):
 - 19 lines, overall length 2 650 km
- 8 participants in last fibre leasing tender (5 fibre providers + 3 carriers)
- If tender do not allow lambdas, carriers offer fibre leasing (some of them in first time in their history!)
- Results allow to change from longer fibre to shorter (e.g. by 35%) and to eliminate expensive lambdas in CESNET2 network

Fibres of CESNET2 (September 2003)



Customer Empowered Fibre (CEF) networks – general view

- CEF networks are emerging technology, that gradually changes network topology, architecture and services from bottom of hierarchy to top
- Very important advantage is wide independence on carriers
- Getting fibre means controlling the network

Lightpath for grid end users

- Some sections of lightpath to grid end users will be implemented on user owned/leased dark fibres in:
 - University networks (LAN) - usually
 - First mile – often
 - Metropolitan networks – often
 - NRENs – often in some regions (Czech, Ireland, Netherlands, Ontario, Poland, Serbia, Slovak, Swiss, US regional networks,)
 - Transcontinental networks – is prepared – some regions (Central Europe,)
 - Worldwide, transatlantics – in the future
- Remaining sections will be implemented by lambdas delivered by carriers
- **Decision is not dependent on price and availability only, strategic importance of getting fibres has been recognised**

Buying lambdas is mostly too expensive

- Preferred method should be leasing or buying/laying fibre
- Reasonable exceptions are impossibility of fibre acquisition (in short time) or price advantage of buying lambdas (rarely for distances under about 500 km)
- Prices should be compared also for future upgrade of the transmission rate
- Price comparison example follows:

2.5 Gbps case study in Central Europe: buying lambdas vs. implementation

1 x 2,5G	Leased 1 x 2,5G (EURO/Month)	Leased fibre with own equipment (EURO/Month)
about 150km (e.g. Ústí n.L. - Liberec)	7 000	5 000 *
about 300km (e.g. Praha - Brno)	8 000	6 000 **
*	2 x booster 18dBm	
**	2 x booster 27dBm + 2 x preamplifier + 2 x DCF	

4 x 2,5G	Leased 4 x 2,5G (EURO/Month)	Leased fibre with own equipment (EURO/Month)
about 150km (e.g. Ústí n.L. - Liberec)	14 000	9 000 *
about 300km (e.g. Praha - Brno)	23 000	13 000 **
*	2 x booster 24dBm, DWDM 2,5G	
**	2 x (booster +In-line + preamplifier), 6 x DCF, DWDM 2,5G	

10 Gbps case study in Central Europe: buying lambdas vs. implementation

1 x 10G	Leased 1 x 10G (EURO/Month)	Leased fibre with own equipment (EURO/Month)
about 150km (e.g. Ústí n.L. - Liberec)	14 000	5 000 *
about 300km (e.g. Praha - Brno)	16 000	8 000 **
*	2 x booster 21dBm, 2 x DCF	
**	2 x (booster 21dBm + in-line + preamplifier) + 6 x DCF	

4 x 10G	Leased 4 x 10G (EURO/Month)	Leased fibre with own equipment (EURO/Month)
about 150km (e.g. Ústí n.L. - Liberec)	29 000	14 000 *
about 300km (e.g. Praha - Brno)	47 000	17 000 **
*	2 x booster 24dBm, 2 x DCF, DWDM 10G	
**	2 x (booster +In-line + preamplifier), 6 x DCF, DWDM 10G	

Comments to case study

- CEF network advantages are increasing for higher transmission rate and for more lambdas
- Multivendor equipment brings economical advantages (buy best equipment in each category if interoperability is verified)
- Cisco and Keopsys equipment available in April 2003 is used
- 4 year depreciation of equipment is calculated, taxes and academic discounts included, equipment service fees included
- Calculated expences of lambda leasing and fibre leasing (0.4 - 0.5 Euro/m/year) are based on offers for year 2003
- Raman amplifiers instead of in-line EDFA should be used, if NIL is preferred

Customer Empowered Optical (CEO) networks – one interesting possibility

- CEO network is based on fibres and free space optics
- Multiple first mile problem: one line should be cheap, clustering of lines are possible
- Free space optic line:
 - For example 10 Mbps, <1 km, <1500 Euro
 - Used by some of Prague students for home connection
 - As DIY <300 Euro (mastered by 15-year child)
- Availability limited by weather conditions (mainly fogs) – but proved as acceptable e.g. for home use
- 100 Mbps version prepared with backup by 802.11ag microwave devices

Equipment for CEF networks

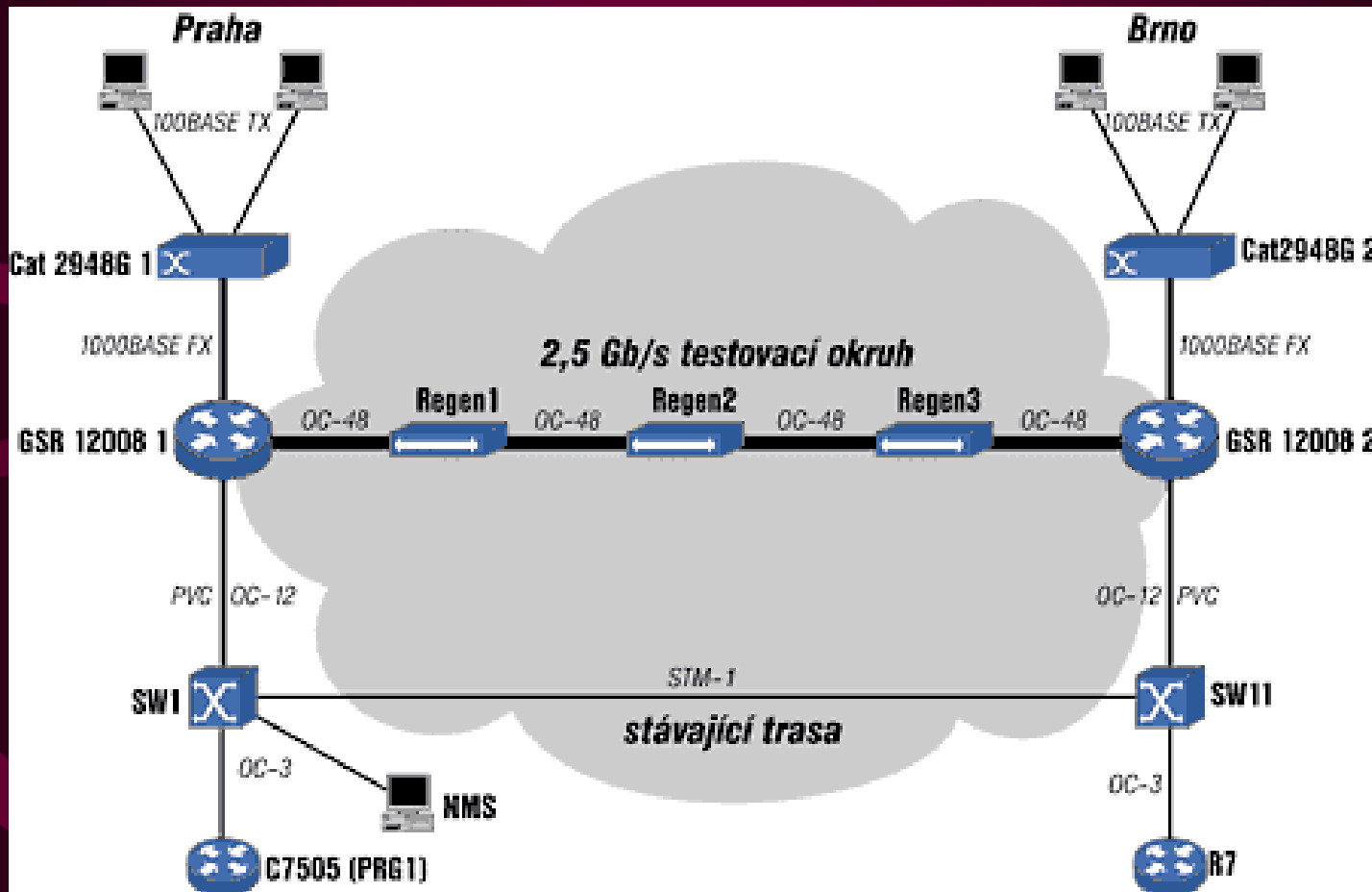
- Equipment needed for R&E networks **differs** in some points from equipment for carriers or commercial ISP providers
- Not for profit/for profit deployment (different timing), etc.
- Future solution?
 - R&D activities shared with NRENs and producers
 - Application of programmable HW
 - Using of PC hardware development for long distance transmission (for example GE and 10GE), etc.

First leased dark fibre for CESNET

- 1999: Convinced one (fuel distribution) company to lease dark fiber between Praha – Brno (323 km) for pilot project.
- 2.5 Gb/s line implemented with 3 in-line regenerators (Cisco ONS 15104)
- Span is about 80 – 90 km
- Line is operating since February 2000
- **Actual traffic statistics:**

http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Praha-Brno.10min.current.html

Original configuration



Praha-Pardubice

(Long distance GE line since May 17, 2002)

- 189 km leased fibre G.652, attenuation 44.65dB, without in-line equipment
- **Actual traffic statistics:**
http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Praha-_Pardubice.10min.current.html
- **Line cards:** GE for GSR with GBIC-ZX
- **Optical amplifier:** Keopsys KPS-BT-C-21-Bo-FA 21dBm booster, C-band single channel
- **Optical attenuator:** 5dB (for optical amplifier input)

Brno - Ostrava

(Long distance GE line since June 1, 2003)

- **235 km leased fibre pair G.652, attenuation 50,55dB, without in-line equipment**
- **Actual traffic statistics:**
http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Brno-_Ostrava.10min.current.html
- **Line cards: GE for GSR with CWDM GBIC**
- **Optical amplifier: Keopsys KPS-BT2-C-27-Bo-FA 27dBm booster, C-band single channel**
- **Optical preamplifier: Keopsys KPS-BT2-C-10-LN-SA (for upgrade to 2.5 G POS)**

Comments to line Brno - Ostrava

- The longest known line NIL operational (235 km)
- Two other configurations where tested:
 - For GE transmission is not preamplifier necessary (only booster)
 - For 2,5G POS transmission with booster and preamplifier is possible

Plzeň – České Budějovice

(Long distance 2,5G line since July 25, 2003)

- 178 km leased fibre pair G.652, attenuation 40,78dB, without in-line equipment
- **Actual traffic statistics:**
http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Ceske_Budejovice-_Plzen.10min.current.html
- **Line cards:** OC48E/POS-1550-SC for GSR
- **Optical amplifier:** Keopsys **KPS-BT2-C-24-Bo-SA** booster, C-band High Power Fiber Amplifier

Brno – České Budějovice

(Long distance 2,5G line since **September 15, 2003**)

- **284 km leased fibre pair G.652, attenuation 70dB**
- **In-line amplification in Jihlava (147km, 137km)**
- **Actual traffic statistics:**
http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Ceske_Budejovice-_Brno.10min.current.html
- **Line cards: OC48E/POS-1550-SC for GSR**
- **Optical amplifier: Keopsys KPS-BT2-C-27-Bo-SA booster, C-band High Power Fiber Amplifier**
- **Optical preamplifier: Keopsys KPS-BT2-C-10-LN-SA (for upgrade to 2.5 G POS)**
- **Prepared for testing of NIL solution with Raman amplifiers**

10 GE NIL over long distance

- 40 km is maximum in 10 GE standard, 80 km is possible with Cisco equipment today
- Results presented by CESNET in Zagreb TNC 2003 (Radil, Bohac, Karasek):
 - reach is at least 150 km with commercially available devices
 - see:
file:///C:/Documents%20and%20Settings/Administrator/Local%20Settings/Temporary%20Internet%20Files/Content.IE5/7HBD3XL0/256,1,Optically Amplified Multigabit Links in CESNET2 network
- Publication of new better results is prepared



Optically Amplified Multigigabit Links in CESNET2 network

Practical results – 10 GE

- ◆ Booster only, no DCF
- ◆ 100 km
- ◆ Booster, preamplifier with DCF and OF
- ◆ 150 km
- ◆ Raman pump
- ◆ 200 km – LINK OK, link protocol NOT

May 19-22, 2003

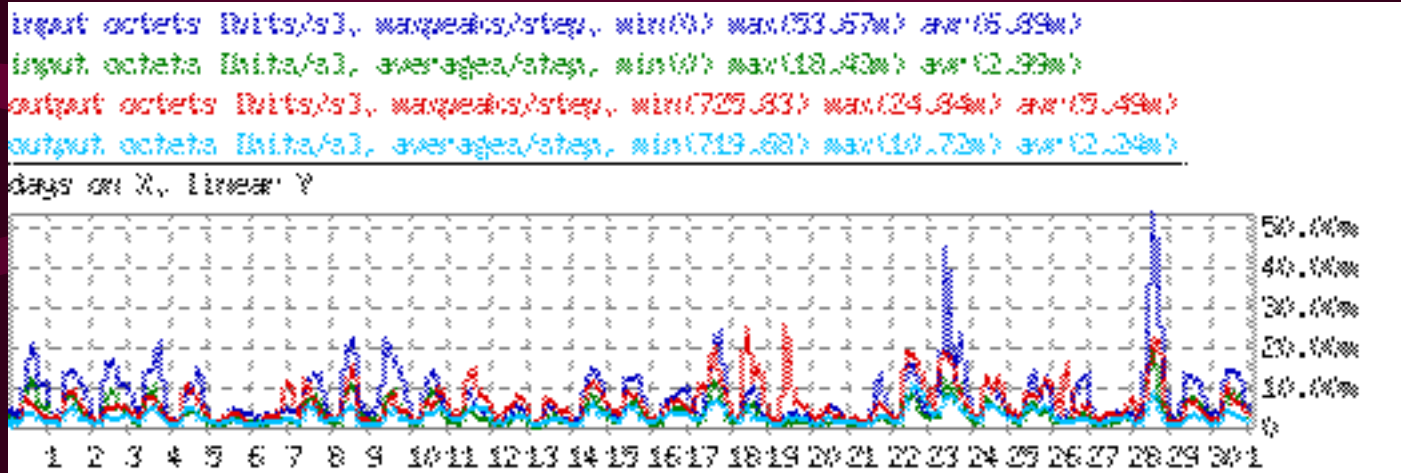
TERENA Networking Conference
Zagreb, Croatia

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Cheaper than fibre pair: single fibre with bidirectional transmission

- Single fibre NIL intercity line Ostrava – Opava (47 km) since 26 March 2003 (FE, upgrade to GE possible)
- One of first single fiber NIL intercity line in NRENs
- Converters MRV EM316 WFC/S4 & MRV EM316 WFT/S4
- 16 month converters payoff (since 16 month is single fibre with converters cheaper than fibre pair without converters)
- Payoff for GE converters is about 24 month
- Actual traffic statistics:
http://www.ten.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Opava-_Ostrava.10min.current.html/

Bi-directional FE transmission on NIL single fibre Ostrava-Opava in April 2003



Plzeň - Cheb

(FE line since July 16, 2003)

- 126 km leased one fibre G.652, attenuation 35,65dB without in-line equipment
- Probably the longest single fibre line without in-line equipment, operational in R&E networks
- Actual traffic statistics:
http://www.cesnet.cz/provoz/zatizeni/ten155_mapa_static_output/Line_usage_Plzen-_Cheb.10min.current.html
- Line cards: with FE ports
- Optical converters: MRV EM 316WFC/S5 & EM 316WFT/S5, 100BaseTx, SM, 1560nm, 40-125km, RJ45/DSC

Single fibre lines

Line	km	Since	HW		Attenuation (dB)
			MRV	100BaseTx, SM,1560nm	
Ostrava - Opava	47	26.3.03	EM 316WFC/S4 & WFT/S4, 40-100km,RJ45/DSC		18,22
Ostrava - Karviná	77	24.7.03	EM 316WFC/S4 & WFT/S4, 40-100km,RJ45/DSC		20,27
Plzeň - Cheb	126	16.7.03	EM 316WFC/S5 & WFT/S5, 40-125km,RJ45/DSC		35,65
Ústí n. L. - Děčín	34	1.7.03	EM 316WFC/S3 & WFT/S3, 20-50km,RJ45/DSC		8,6

Actual and past traffic statistics:

<http://www.cesnet.cz/provoz/zatizeni/>

Single fibre with converters is cheaper than fibre pair

Dark fibre line	Fibre length (km)	Leased single fibre (EURO/month)	Pair of convertors for FE (EURO)	Leased pair of fibres (EURO/month)	Convertors for FE payoff (month)	Comment
Cesnet-National Library	4,4	852	5 088	1 419	9,0	City price
Ostrava-Opava	47	1 202	10 084	1 850	15,6	Intercity price
Plzeň-Cheb	128,4	3 285	11 885	5 053	6,7	Intercity price

National Library 4,4 km (city line) since October 2002

Opava-Ostrava 47 km (intercity line) since March 2003

Plzeň – Cheb 128 km (intercity line) since June 2003

Connect Near over Border (NoB approach)

Shorter fibre lines means cheaper lines (KIS now means Keep It Short)

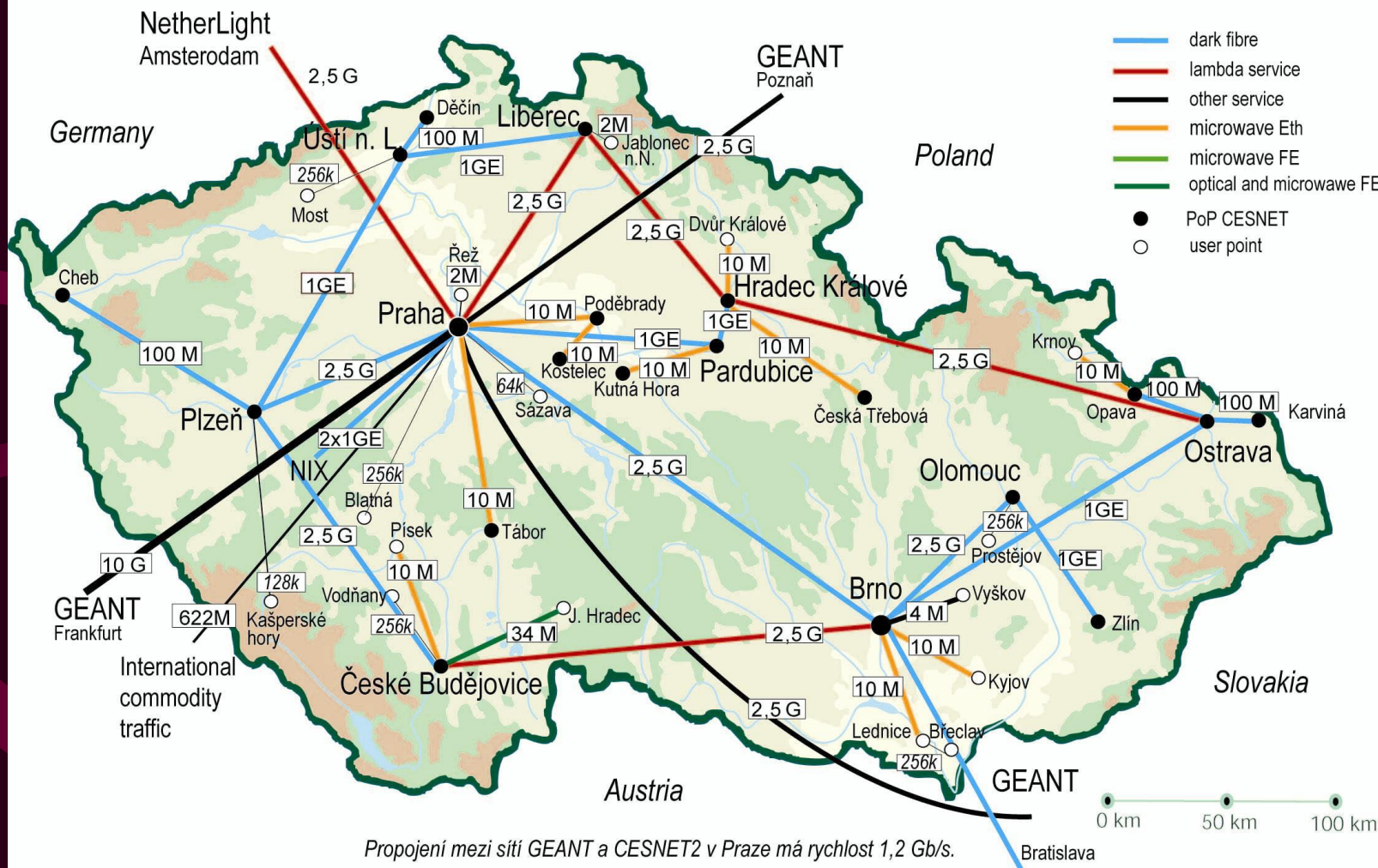
Fibres for connecting NREN centers	km	Euro per month	Fibres for connecting NRENs PoPs near border (alternative)	km	Euro per month
Ostrava - Poznan	970	40 400	Ostrava - Bielsko Biala	150	6 300
Ostrava - Frankfurt	690	28 800	Plzeň - Munich	330	13 800
			Plzeň - Norimberk	227	9 500
Ostrava - Wien	520	21 700	Brno - Wien	250	10 400
			Č. Budějovice - Linz	200	8 300
Ostrava - Bratislava	432	18 000	Brno - Bratislava	182	7 600
Ostrava - Berlin	530	22 100	Ústí n.L.-Dresden	230	9 600
	3 142	131 000		1 569	65 500

This table illustrates possibilities, i.e. fibres are actually available.

Line Brno-Bratislava between CESNET and SANET is operating.

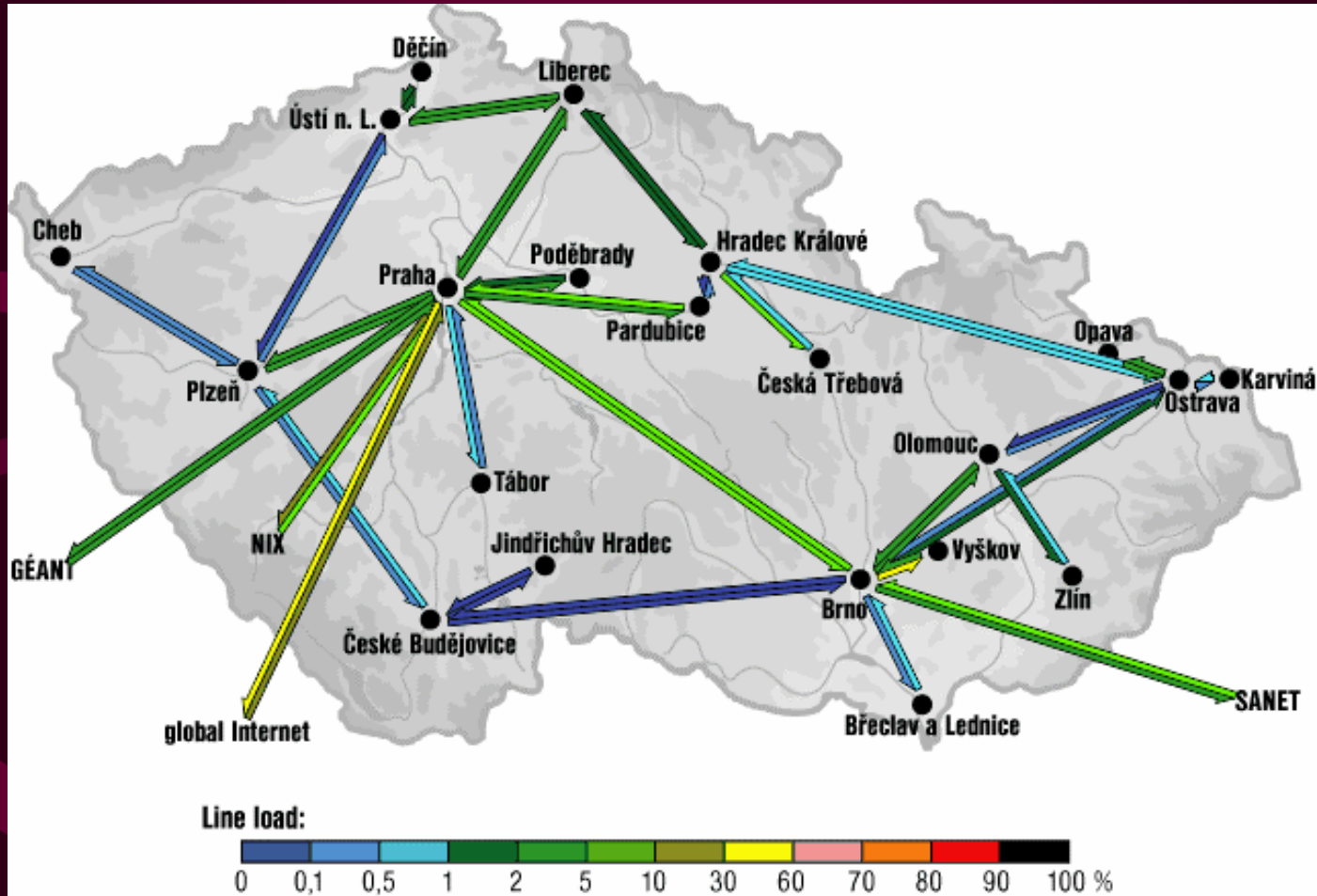
Dark fibre to Bratislava since April 2003

CESNET2 Topology (September 2003)



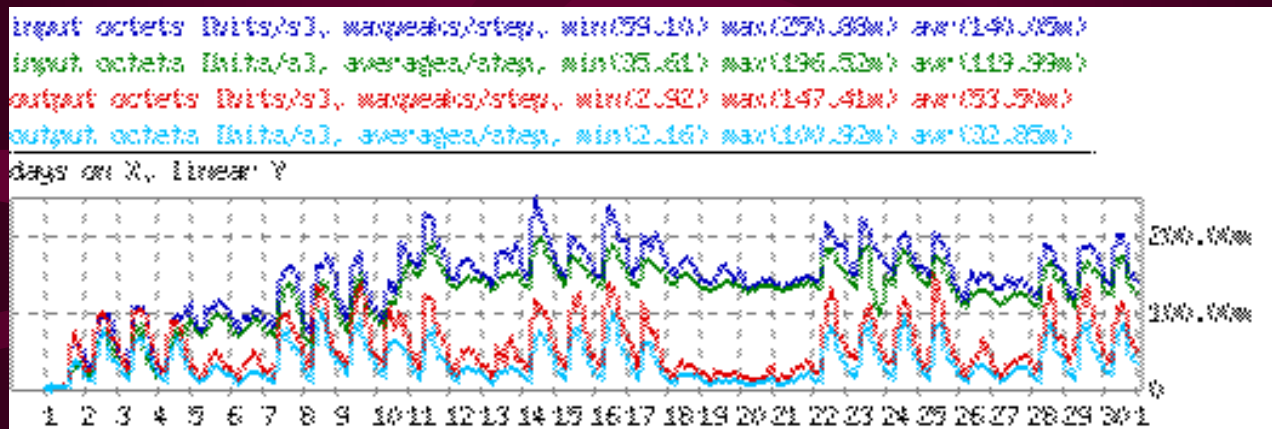
Dark fibre over border

Brno-Bratislava 182 km since 2 April 2003



International dark fibre connection CESNET-SANET April 2003

Line usage Brno->SANET, month view, end time 2003/05/01 00:59



Please see actual and past statistics in click-able map:

<http://www.cesnet.cz/provoz/zatizeni/>

and compare it with CESNET-GEANT traffic statistics: NoB is very cost effective and useful approach

What will be the right steps (or projects) for:

- Deployment of our results in others NRENs, if they are interested
- Development of (kit of) tested or operational solutions for NREN designers
- Information exchange between NREN concerning transmission systems for dark fibres (conference for active participants)
- Support NRENs going to CEF network



Acknowledgements

- Colleagues from CESNET for cooperation in CESNET2 development
- Colleagues from SANET for cooperation in NoB connection
- Colleagues from HEANET, PSNC, SANET, SURFNET and SWISS for valuable information concerning fibre application
- Comment: presented ideas and opinions are result of our ongoing R&D activities and are open to improvement