Towards Terabit per Second Optical Networking

Photonic Services

International Workshop on Trends in Optical technologies,

CPqD, Campinas, SP, Brazil 2012 May 9-10th

Josef Vojtěch, CESNET

Photonic Services

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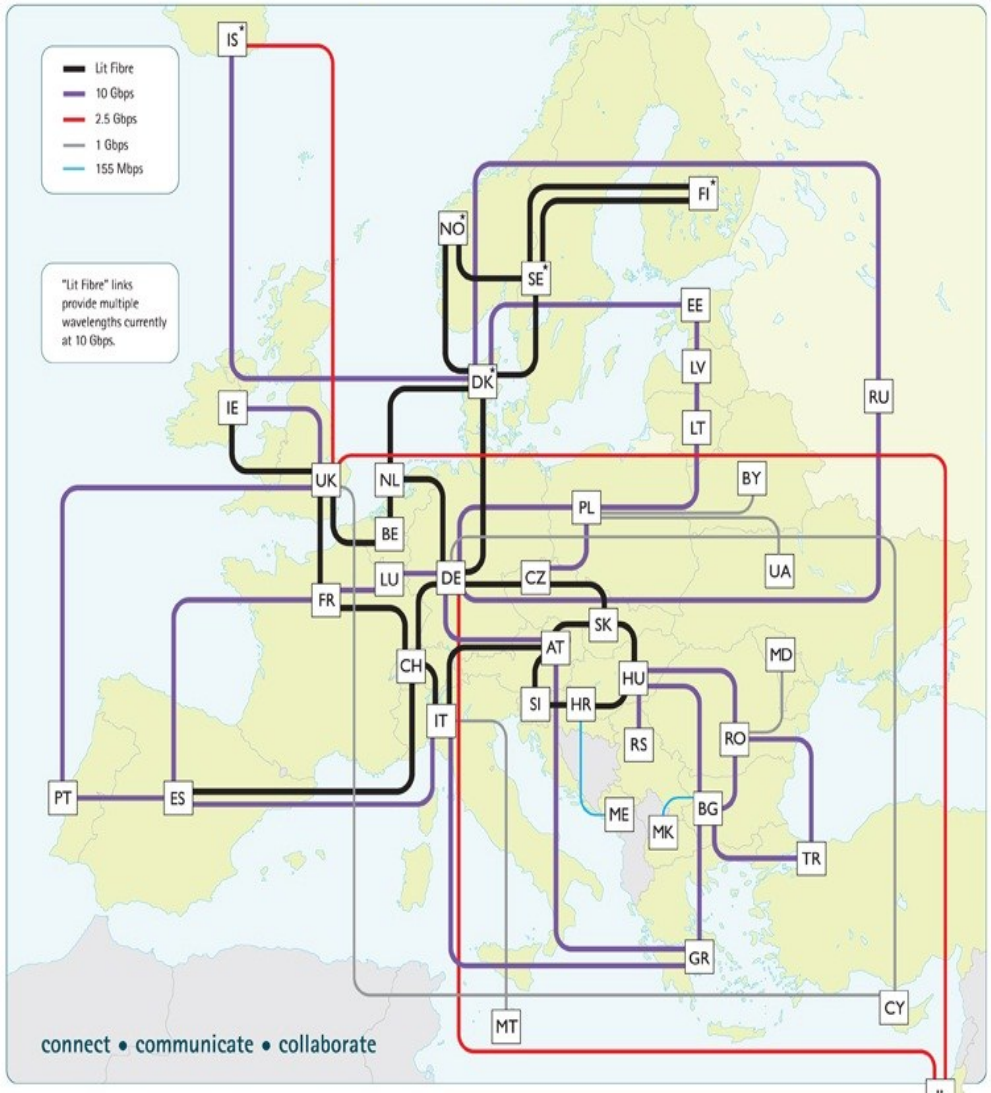
  - GÉANT - GN3 (www.geant.net)
  - Large infrastructure CESNET (www.ces.net)

Photonic Services
Outline

- Quick overview of the GÉANT project
- Overview of photonic services, advantages and disadvantages
- General applications
- Demonstrations and experiments
  - Conducted
  - Planned
- Photonic Services within context of GN3 project
- Cooperation in Photonic Services

Photonic Services
The GÉANT Network



Backbone topology as at March 2012. GÉANT is operated by DANTE on behalf of Europe's NRENs.

- 7th generation of the pan-European Research and Education Network infrastructure – continuation of a success story
- Connects 40 European countries through 32 NREN Project Partners & 4 NREN Associates
- 40 million users, 8000 institutions
- 50,000km of infrastructure and 12,000km of lit fibre
- Outstanding service availability

Photonic Services
GÉANT NRENs: Partners & Associates

GÉANT Partners

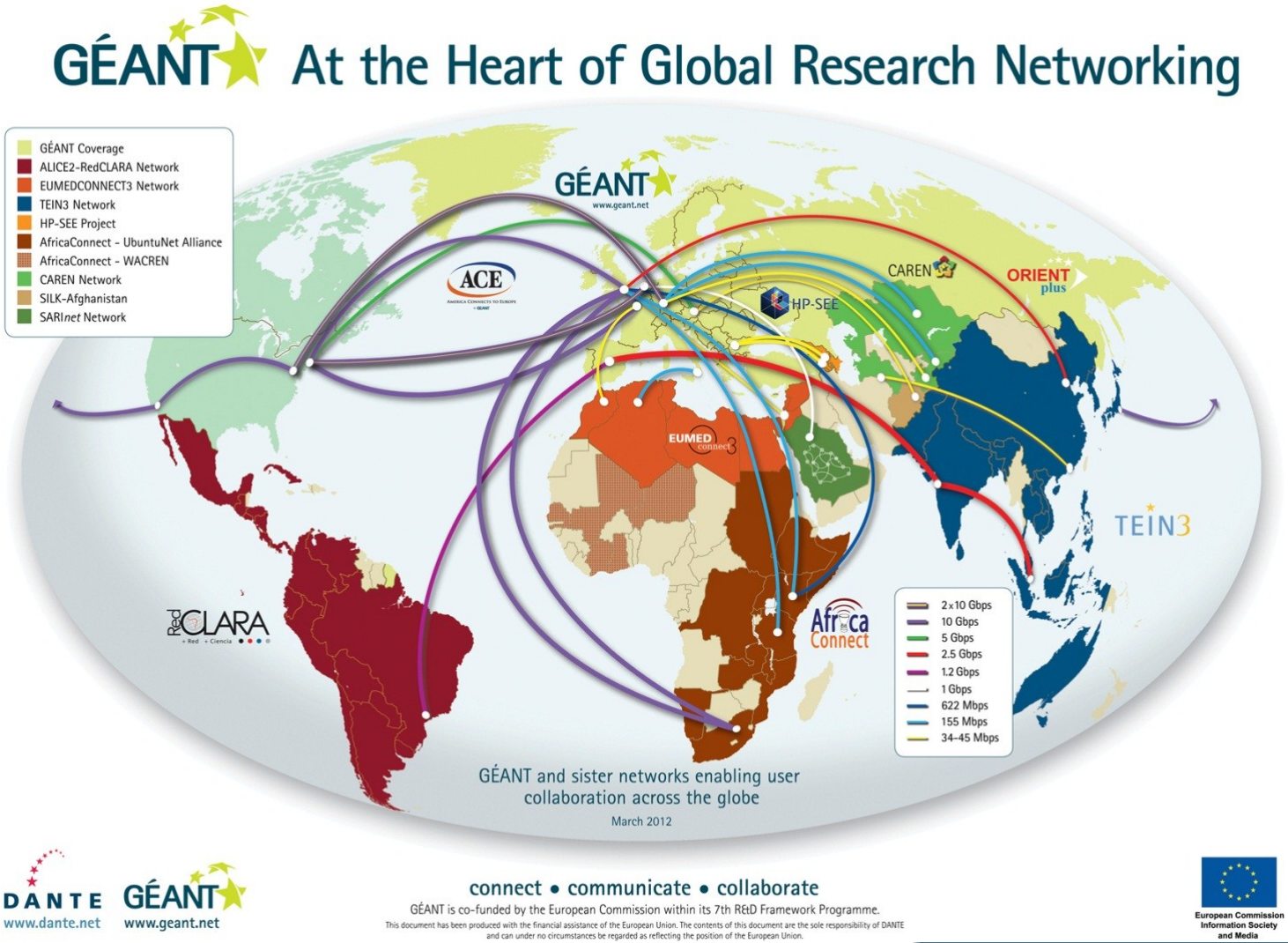
• ACOnet	Austria
• Belnet	Belgium
• BREN	Bulgaria
• CARNet	Croatia
• CYNET	Cyprus
• CESNET	Czech Republic
• EENet	Estonia
• RENATER	France
• DFN	Germany
• GRNET	Greece
• NIIF	Hungary
• HEAnet	Ireland
• IUCC	Israel
• GARR	Italy
• SigmaNet	Latvia
• LITNET	Lithuania
• RESTENA	Luxembourg
• MARNet	Macedonia
• University of Malta	Malta
• MREN	Montenegro
• SURFnet	Netherlands
• NORDUnet	Nordic region (Denmark, Finland, Iceland, Norway, Sweden
• PSNC	Poland
• FCCN	Portugal
• RoEduNet	Romania
• AMRES	Serbia
• SANET	Slovakia
• ARNES	Slovenia
• RedIRIS	Spain
• SWITCH	Switzerland
• ULAKBIM	Turkey
• JANET	United Kingdom

Associate NRENs

• BASNET	Belarus
• JSCC	Russia
• RENAM	Moldova
• URAN	Ukraine

http://www.geant.net/About_GEANT/Partners/pages/home.aspx

Photonic Services
GÉANT: At the heart of the Global R&E Village



DANTE www.dante.net GÉANT www.geant.net

connect • communicate • collaborate

GÉANT is co-funded by the European Commission within its 7th RtD Framework Programme.
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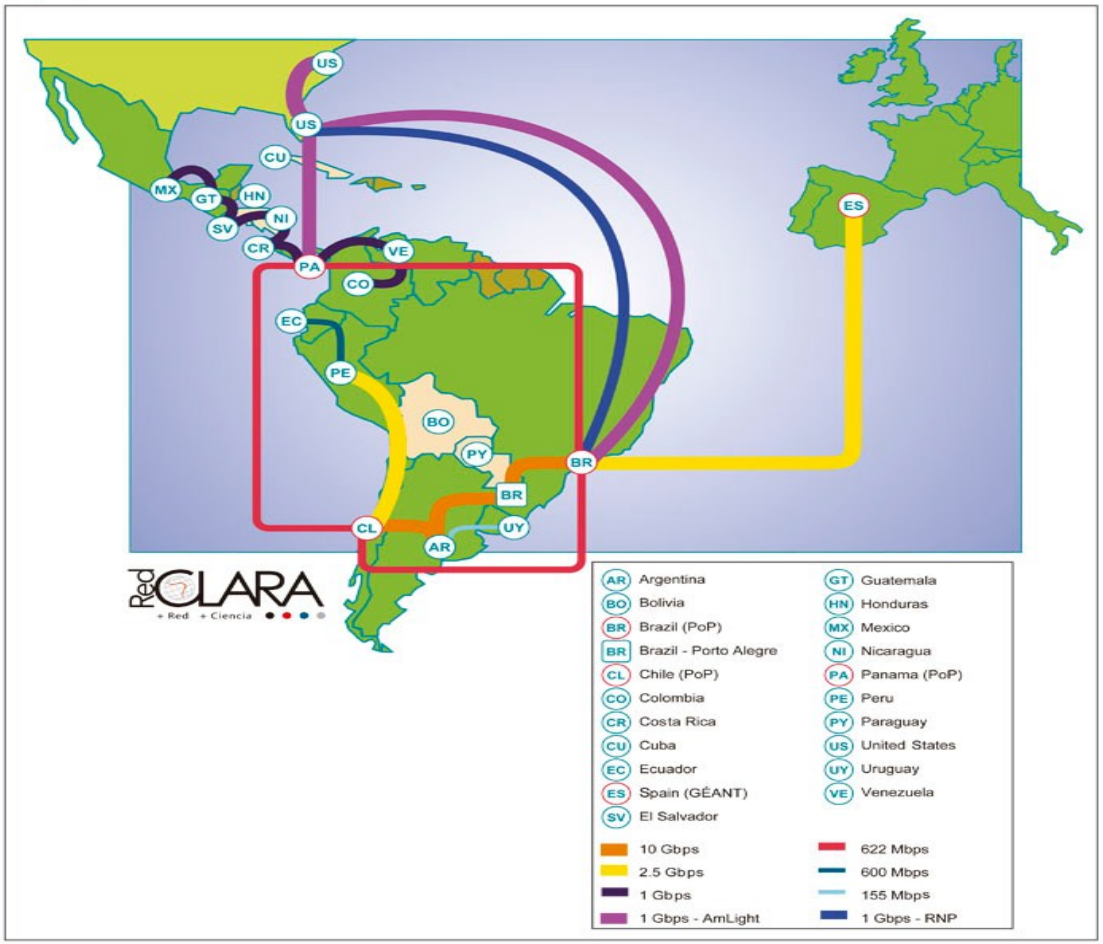
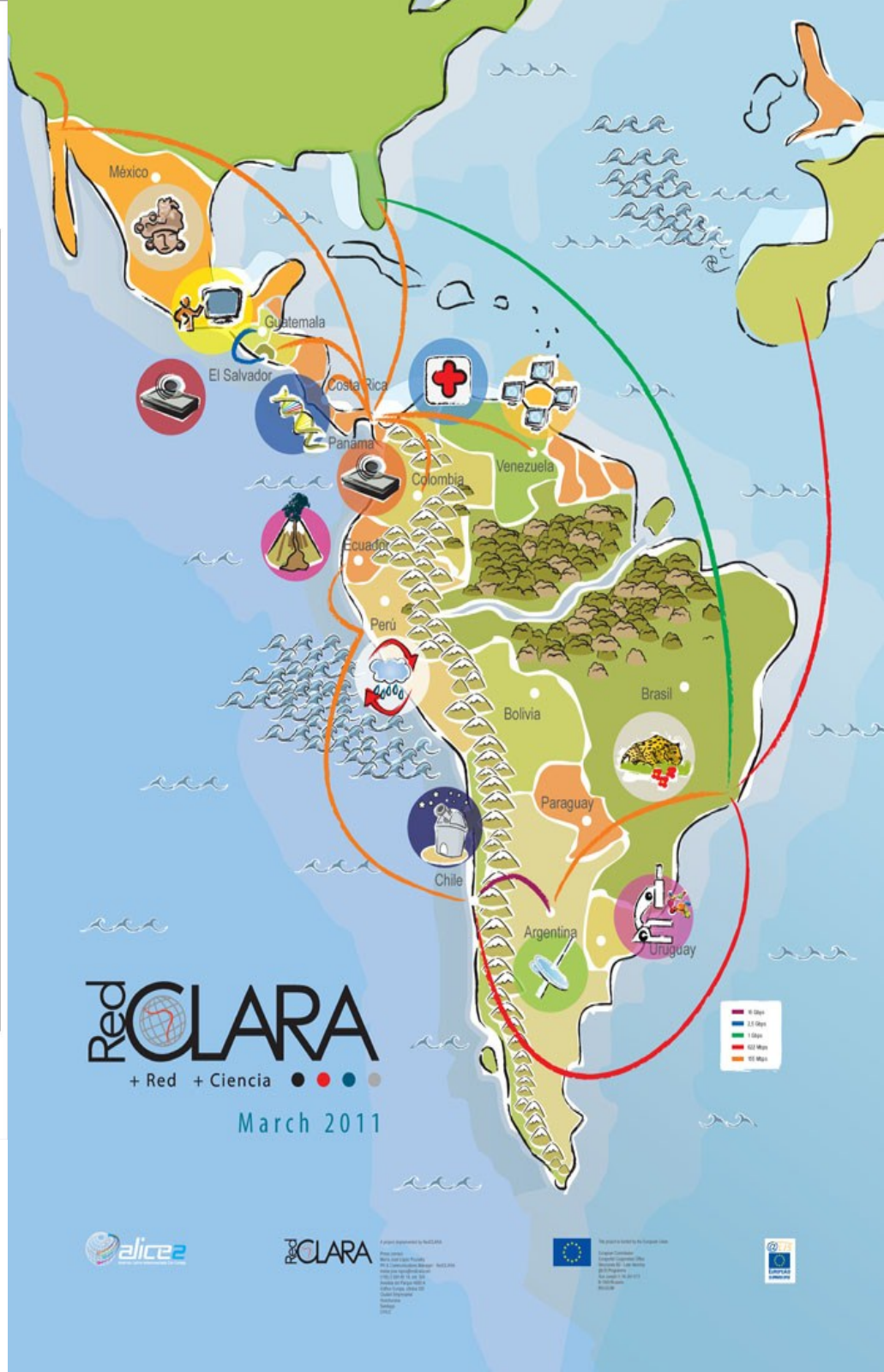
European Commission Information Society and Media

http://global.geant.net/

Innovation through participation





- Created 2004
- Connects 13 countries, almost 800 universities

Photonic Services
GÉANT: The Best-connected R&E Network

59 NRENs outside Europe connected to GÉANT

Americas

- CANARIE — Canada
- CEDIA — Ecuador
- CoNARE — Costa Rica
- CUDI — Mexico
- ESNet — USA
- INNOVA|RED — Argentina
- Internet2 — USA
- NISN (NASA) — USA
- NLR — USA
- RAAP — Peru
- RAGIE — Guatemala
- RAICES — El Salvador
- RAU2 — Uruguay
- REACCIUN2 — Venezuela
- RedCyT — Panama
- RENATA — Colombia
- REUNA — Chile
- RNP — Brazil
- USLHCNet — USA

Middle East & Africa

- ANKABUT — United Arab Emirates
- ARN — Algeria
- PalNREN — Palestinian Territories
- KENET — Kenya
- MARWAN — Morocco
- Qatar Foundation — Qatar
- SARInet — Saudi Arabia
- TENET — South Africa
- TERNET — Tanzania

Asia & Oceania

- AARNet — Australia
- AfRENA — Afghanistan
- AM NREN — Armenia
- ASGC — Taiwan
- AzRENA — Azerbaijan
- BdREN — Bangladesh
- CamREN — Cambodia
- CERNET — China
- CSTNET — China
- INHERENT/ITB — Indonesia

Asia & Oceania (cont.)

- JGN2plus/NICT — Japan
- HARNET — Hong Kong
- KazRENA — Kazakhstan
- KOREN/NIA — Korea
- KRENA-AKNET — Kyrgyzstan
- KREONET2 — Korea
- LEARN — Sri Lanka
- MAFFIN — Japan
- MYREN — Malaysia
- NKN — India
- NREN — Nepal
- PERN2 — Pakistan
- PREGINET — Philippines
- SINET3/NII — Japan
- SingAREN — Singapore
- TANET/NCTU — Taiwan
- TARENA — Tajikistan
- ThaiREN/ThaiSARN — Thailand
- ThaiREN/UniNet — Thailand
- TuRENA — Turkmenistan
- VINAREN — Vietnam

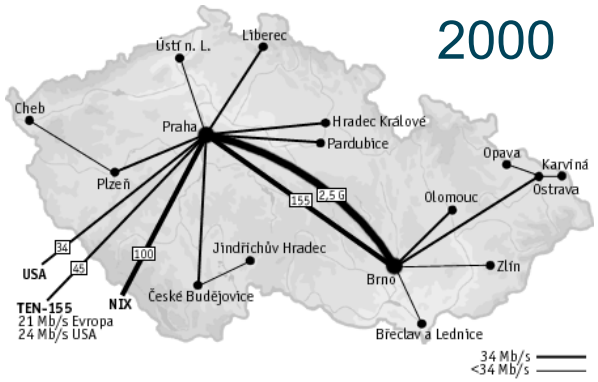
Photonic Services
GÉANT project

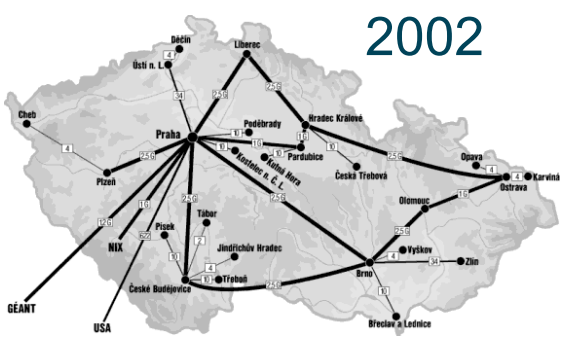
- Networking Activities (NAs) deal with the general management of the project, publicity and dissemination of results.
- Joint Research Activities (JRAs) deal with the critical analysis of future networking technologies and research into new services.
- Service Activities (SAs) of the project develop and deliver services

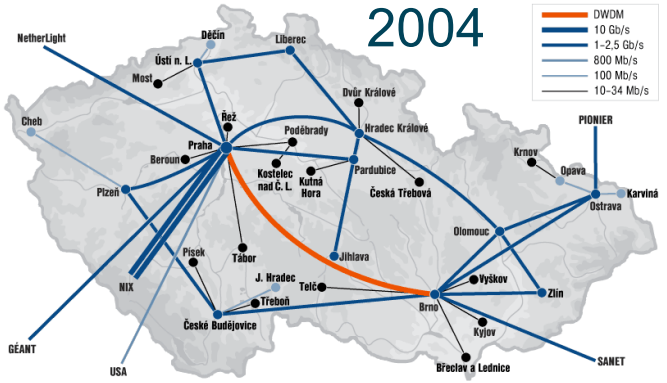
Photonic Services
CESNET

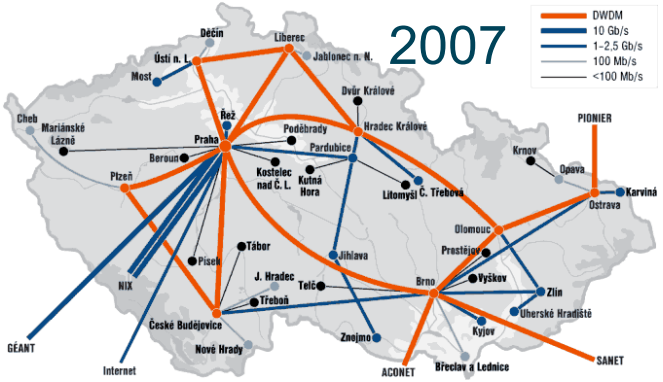
- Established 1996 as non-profit organisation, association of legal entities.
- Public universities (26) and Academy of sciences
- It operates:
  - National research and educational network – CESNET2
  - Experimental facility – CzechLight

Photonic Services
CESNET development



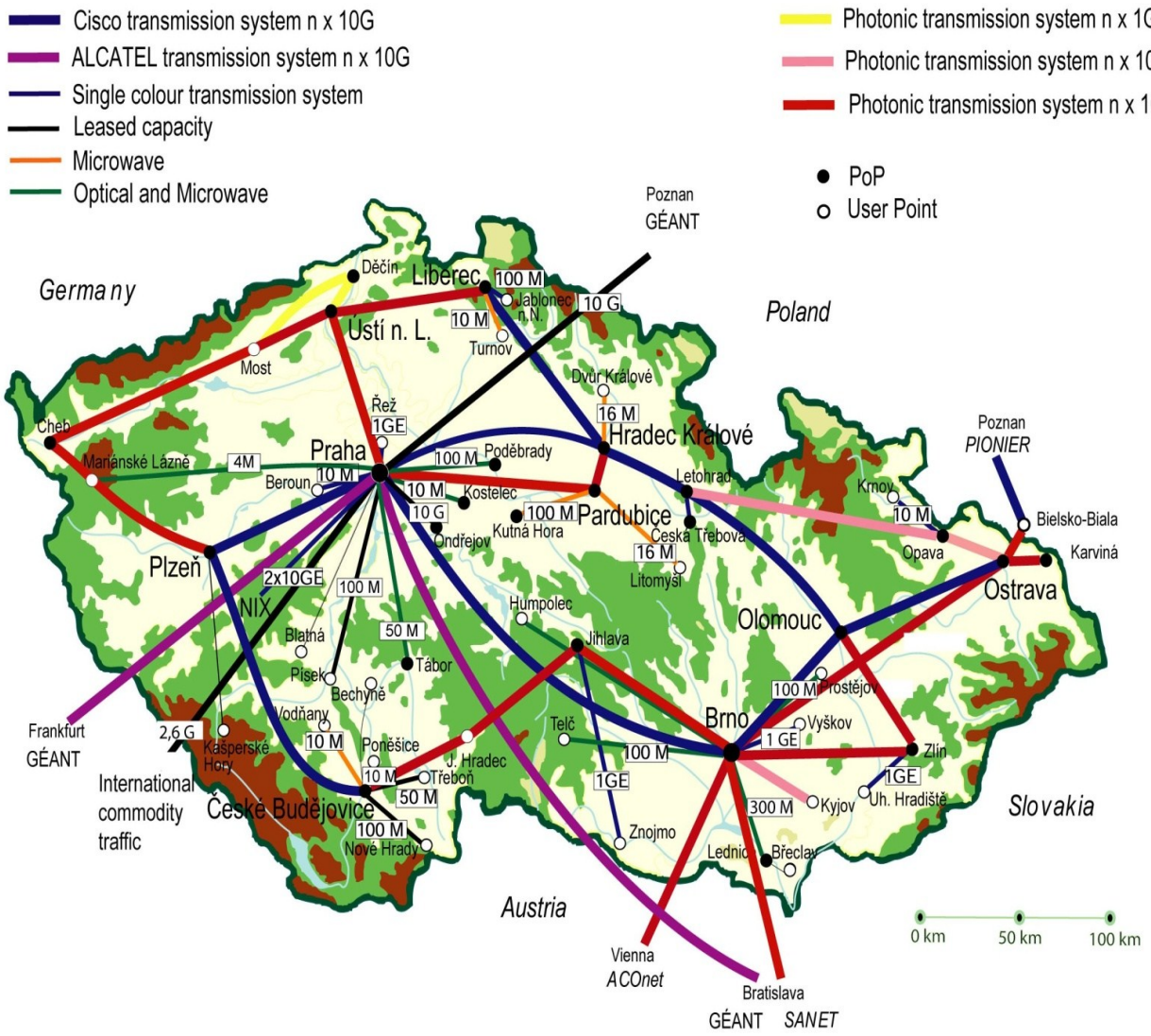






- Dark Fibers (DF), since 1999
- Nothing in Line approach (NIL), since 2002
- Single fibre bidirectional transmission, since 2002
- Cross Border Fibres (CBF), since 2003
- Open transmission system, since 2004

Photonic Services
NRENs as testbed for real-time applications



- DWDM:
- Cisco - 1410km
- Open DWDM - 2660km, incl. 905km single fibre
- 100Gbps trials reach:
- 1063km, 276 dB
- 655km, incl. 368km single fibre, DCF+FBG

* all-optical lambdas are available in CESNET2 and CBFs

Photonic Services
Real-time

- **Real time has nothing to do with speed, but with timeliness constraints**
- For the **interaction with external processes** (processes running outside network) real time network services are needed if timing of interaction limits quality or even the acceptability of network application.
- Real-time network service should respond to an event within a predetermined time (i.e. there are "real time constraints" - operational deadlines from event to system response). The timeliness constraints or deadlines are generally a reflection of the physical process being monitored or controlled.

Photonic Services
Real-time applications

- Soft real time applications – penalty for not meeting constraints is mild (e.g. interactive HD videoconferencing)
- Hard real time applications – penalty for not meeting constraints is unacceptable (e.g. remote control of vehicle or instrument)

- Contemporary network services are usually non-real-time services, i.e. no timeliness constraints are defined. If we need services with a guaranty of real-time bounds, the "best effort" principle is not acceptable.
- All-optical e2e lambdas can be an enabler for fixed latency of transmission and for reproducibility of experiments.

Photonic Services
Overview

- Photonic Service
- End-to-end connection between two or more places in network
- Described by Photonic-path and allocated bandwidth
  - Photonic-path is a physical route that light travels from the one end point to the other or to multiple other end points respectively
  - Allocated bandwidth is a part of system spectrum that is reserved for user of Photonic Service all along the Photonic-path.
  - Minimal impact of network (no processing) on transmitted data
  - Path all-optical , no OEO except special cases.

Photonic Services
Overview

- Advantages
  - Transparency to modulation formats
  - Low transmission latency as the shortest photonic path is formed
  - Constant latency (i.e. negligible jitter), because non or only specially tailored electrical processing is present
  - Stable service availability (due allocated bandwidth) with some exception for protection switching
  - Future-proof design thanks to grid-less bandwidth allocation

Photonic Services
Overview

- Disadvantages
  - Service reach in general is limited due to missing universal all-optical regeneration, but it can be extended by specialized OOO and/or OEO regenerators suitable just for limited number of applications. Potential waste of bandwidth.
  - All-optical nodes should be grid-less and direction-less.
  - In multi-domain scenario - absence of global management and operation system or communication between separate management systems.
  - Multi-vendor network interoperability with AWs, although first tests were already successful, e.g. concurrent 100G and precise time transmission and ITU-T also has produced recommendation G.698.2 - “Black link”.

Photonic Services
General Applications

- ***Interactive human collaboration***
  - Latency jitter limit: 10-50 ms (adaptive play-out delay buffer)
  - End-to-end latency: 100-200 ms
  - Penalty: mild (user disappointment).
- ***High definition video and Cave-to-cave***
  - Latency jitter limit: 20 ms (buffer dependent)
  - End-to-end latency: 150 ms
  - Penalty: mild (user disappointment).

Photonic Services
General Applications

- ***Remote instrument control***
  - Latency jitter limit: 20 ms
  - End-to-end latency: 100 ms
  - Penalty: depends on application (can be severe in case of tele-surgery)
- ***Remote control of vehicles***
  - Latency jitter limit: 50 ms
  - End-to-end latency: TBD
  - Penalty: not acceptable (vehicle crash).

Photonic Services
General Applications

- ***Comparison of atomic clocks***
  - Latency jitter limit: 50 ps (short time, typ. over 1000 s) and 1 ns (long time fluctuation, typ. over days)
  - End-to-end latency: should be minimized to the optical signal propagation delay
  - Penalty: mild (experiment failure) - principal (service impossible)
- ***Ultra-stable frequency transfer***
  - Latency jitter limit*: NA
  - End-to-end latency: should be minimized to the optical signal propagation delay
  - Penalty: mild (experiment failure) - principal (service impossible)

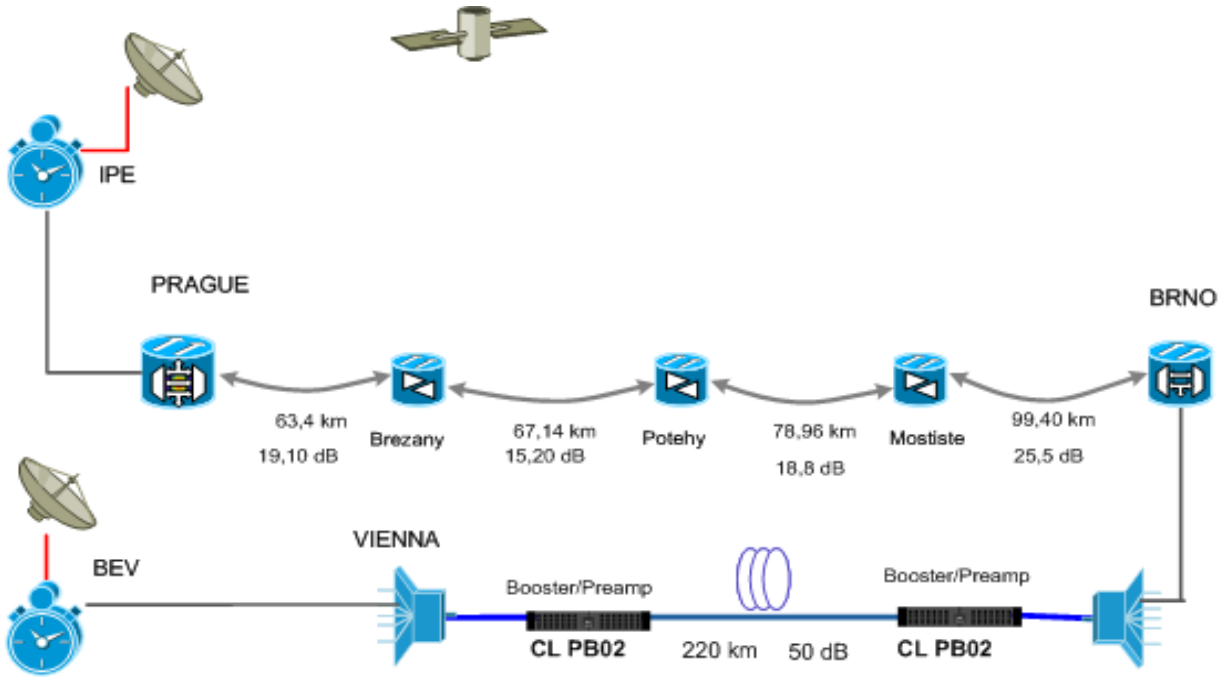
*The term *jitter* is not appropriate here. The phenomenon is rather expressed as a stability that should correspond to the stability of primary frequency standard, e.g. 10^{-17} in ultimate case of optical clocks.

Photonic Services
Demonstrations

- **Comparison of atomic clock scales on live network : CESNET+ACONET**
- Transmission of time marks (pulses modulated on optical carrier)
- Started by loop tests and GPS assisted transmission over standard DWDM systems, 2010
- Comparison of time scales between Czech and Austrian national time and frequency laboratories in Prague and Vienna (IPE-BEV) over operational DWDM since Aug 2011

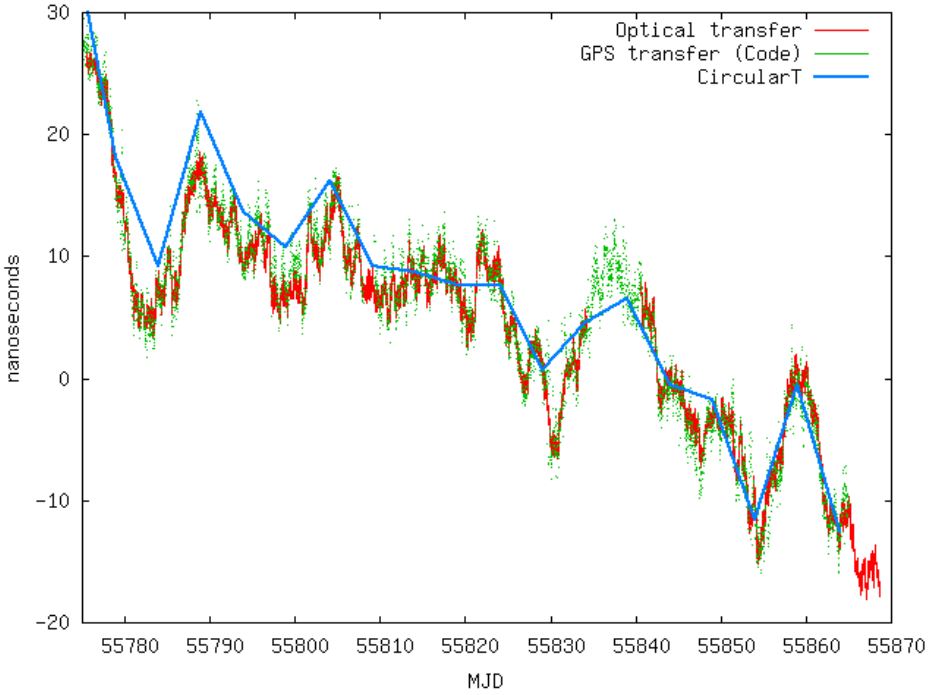
Photonic Services
Demonstrations

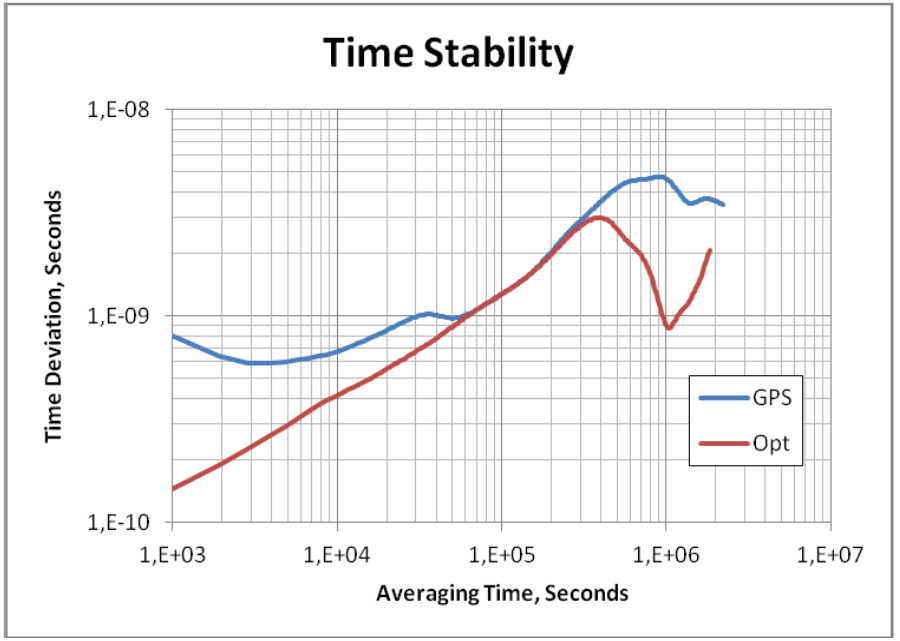
- Comparison of atomic clock scales cont.
- Photonic path – dedicated lambda over operational DWDM network:
  - Mixture of fibre types (G.652/655)
  - Mixture of transmission systems Cisco/Open DWDM Czechlight
  - Mixture of CD compensation types (DCF, FBG)
  - One way distance 550km, including 220km NIL, 137 dB



Photonic Services
Demonstrations

- Comparison of atomic clock scales cont.





Time difference UTC(TP) − UTC(BEV) measured using optical link (red), via GPS (gr) and from BIPM Circular-T (bl)

CircularT = published offsets between sources of UTC

Time stability of the optical (red) and GPS (blue) time transfer:

Tdev 130 ps vs. 800 ps for 1000s averaging

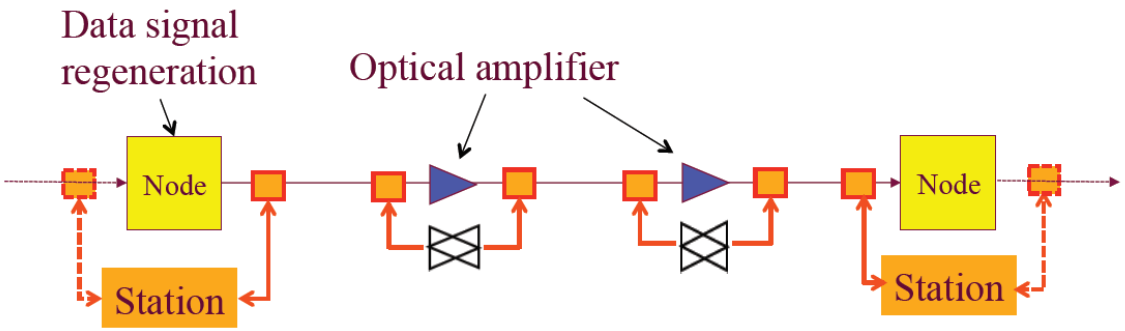
More stable till 50000 s avaraging

Photonic Services
Demonstrations

- **High definition video (e.g. 3D Full HD, 2K, 4K) broadcast: CESNET**
- Remote demonstration of a kidney surgery by robotic instrument (da Vinci robot) from the Masaryk Hospital in Ústí nad Labem, stereo 3D Full HD
  - About 2.5 Gbps stream
  - Specialized video processing device latency – up to 1ms
  - To Prague,CZ (130 km by fibre), transmission latency <1ms
  - To Brno,CZ (550 km by fibre), transmission latency < 3ms
  - To Tsukuba,JP IP service, transmission latency about 150ms
  - see http://www.ces.net/doc/press/2010/pr100618.html

Photonic Services
Demonstrations

- **Ultra-stable frequency transfers on live network: RENATER**
- Transmission of ultra-stable CW optical frequency itself (in region 1550nm)
- Needs same path for both directions noise correction and propagation delay fluctuation compensation
- Datacom bidirectional devices must be bypassed (e.g. EDFAs)



Source: G. Santarelli at al"Transmitting ultra-stable optical signals over public telecommunication networks"

Bypass : bidirectional amplifiers + OADM (+ AOM?)

Station : every 400 km -600km

OADM

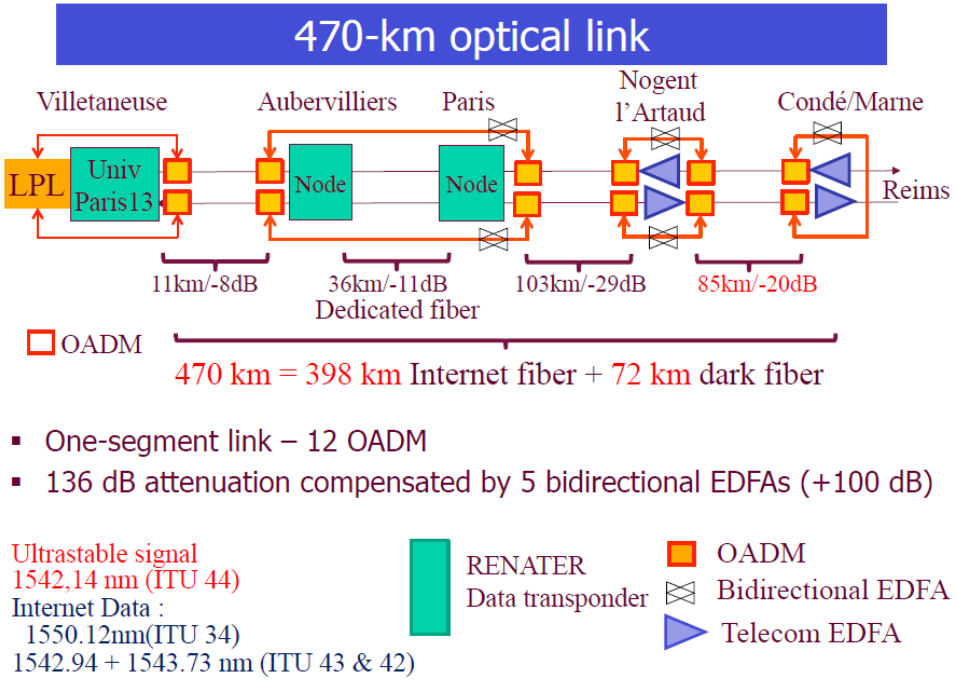
Bidir EDFA

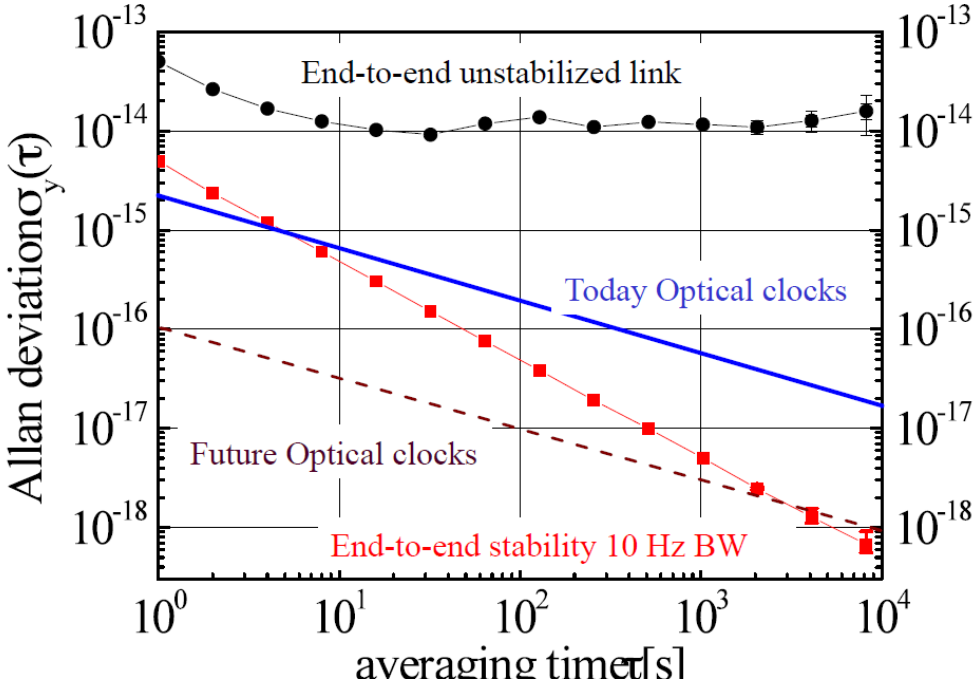
Photonic Services
Demonstrations

- **Ultra-stable frequency transfers on live network: RENATER + LNE-SYRTE (Système de Référence Temps Espace) + LPL (Laboratoire de Physique des Lasers)**
- 2009 - 90km DF loop test only
- 2010 - LPL-Nogent l'Artaud-LPL
  - 300km loop (228km over DWDM system), 100dB attenuation, 4 bidirectional EDFAs
- 2011 - LPL-Condé/Reims-LPL
  - 470km loop (398km over DWDM system), 136dB attenuation, 5 bidirectional EDFAs
  - 540km loop (470km over DWDM system), 6 bidirectional EDFAs

Photonic Services
Demonstrations

- **Ultra-stable frequency transfers on live network: RENATER**





Source: G. Santarelli at al"Transmitting ultra-stable optical signals over public telecommunication networks"

Deviation 5x10e-15 at 1s averaging
8x10-19 at 10000s averaging

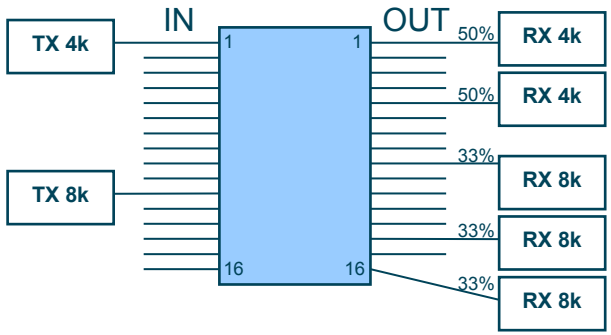
Photonic Services
Demonstrations

- **Ultra-stable frequency transfers: MPQ-PTB germany**
- Max-Planck-Institut für Quantenoptik (MPQ) in Garching and Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig,
- 2009 – dedicated fibre146km
- Dedicated fibre, 920km, 200 dB attenuation, bidirectional transmission and active stabilization
- 9x low noise bidirectional EDFA and Fibre Brillouin amplification with distributed gain
- Achieved stability 5×10e−15 in a 1-second integration time, reaching 10e−18 in less than 1000 seconds.

Ref: A. Predehl at al ”A 920-Kilometer Optical Fiber Link for Frequency Metrology at the 19th Decimal Place”, **Science 2012**

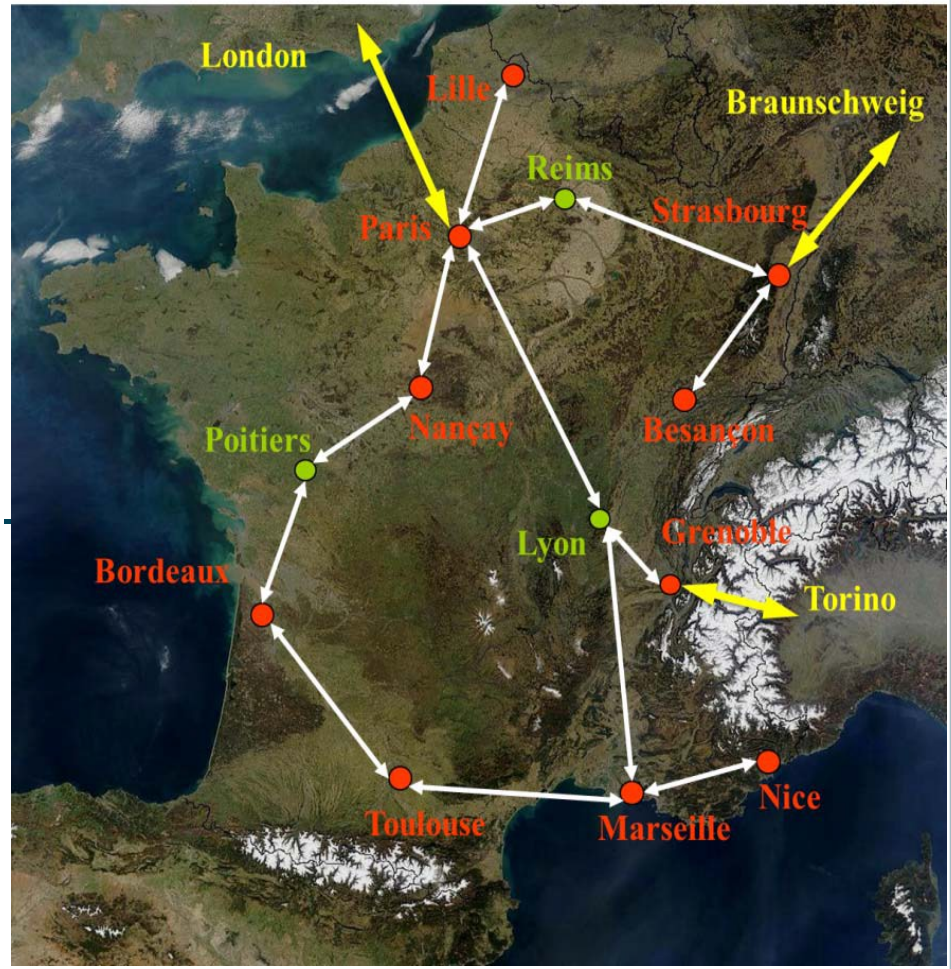
Photonic Services
Planned

- **CESNET: Over High definition video multicast with photonic path allocation**
- Over HD video transfer over dynamically allocated Photonic-path to demonstrate features of proposed Photonic Services
- Utilization of all optical multicast to deliver video to multiple locations
  - Dedicated device able of switching and multicasting (splitting ratios variable on the fly)



Photonic Services
Planned

- LPL-Nancy-LPL 1100km with one regenerator station
- LPL-Strasbourg-LPL1476km with three regenerator stations
- **RENATER: REFIMEVE+ Project:**
- RENATER, LNE-SYRTE and LPL laboratories applied for REFIMEVE for building of national infrastructure on RENATER fiber, able to disseminate ultra-stable frequency
- Planned start in 2012
- Interconnections on cross-border fibers would also be studied



Photonic Services
PS within GN3 project

- JRA1 T2 subtask "**E2E photonic services between user premises**"
  - Start 1/Apr/12, duration 12 months
- Objectives
  - provide feasibility and demonstration study of e2e photonic services between user premises
  - strengthen research collaboration with vendors experienced in photonic service deployment
  - evaluate feedback from GN3 NRENs concerning innovative transmission services
  - evaluate feedback from research projects interested in photonic services
  - demonstrate e2e photonic services between user premises if feasible in Y4

Photonic Services
PS within GN3 project

- NA4 T1 subtask "**Photonic services enable advance in research**"
  - Start 1/Apr/12, duration 12 months
- Objectives
  - promote photonic services as a future trend of innovative networking in Europe and beyond
  - support usage of photonic services in advanced research disciplines
  - dissemination of JRA1 T2 results
  - promote effective lighting of acquired dark fibres (also in less developed regions)
  - strengthen liaison with world-wide partners in innovative networking

Photonic Services
Acknowledgement

- Interested in Photonic Services!?

- For more information or collaborotion in Photonic Services please send an e-mail to:

josef.vojtech@cesnet.cz

Photonic Services
Invitation

- **7th Customer Empowered Fibre (CEF) Networks Workshop, Sept. 12-14th, 2012, Prague, Czech Rep.**
  - Photonic (all-optical) services, dark fibre channels, alien waves, fibre sharing and virtual fibre networks
  - Open dark fibre testbeds used for experiments and additional production traffic
  - Research projects and disciplines requiring photonic services or dark fibre connections (metrology, seismology, space observation etc.)
  - Update of dark fibre footprint used for Research and Education Community (campuses, regional, national or continental) and experimental facilities (testbeds),

Photonic Services
Invitation cont.

- Development of dark fibre footprint used for Research and Education Community (REC) in the world
- Multi-vendor lighting of CEF Networks, interoperability and vendor-independent description of transmission systems
- Deployments and testing of high-speed transmission systems
- Power consumption of transmission systems
- Real-time applications of wide-area all-optical networks
- CEF Networks support for Future Internet projects

presentations of CEF Networks workshop 2004 http://www.ces.net/doc/seminars/20040525/
presentations of CEF Networks workshop 2005 http://www.ces.net/doc/seminars/20050516/
presentations of CEF Networks workshop 2006 http://www.ces.net/doc/seminars/20060529/
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presentations of CEF Networks workshop 2010 http://www.ces.net/events/2010/cef/

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Photonic Services
Q&A

- Thank you for kind attention!
- Questions?
- josef.vojtech@cesnet.cz

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Photonic Services
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