Photonic services, their enablers and applications

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Innovation through participation

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- Author and co-authors with affiliation [1] participate on following projects:
  - GÉANT - GN3 (www.geant.net)
  - Large infrastructure CESNET (www.ces.net)

Outline

- Motivation
- Real-time applications
- Overview of photonic services, advantages and disadvantages, general applications and possible implementation over fiber networks
- Demonstrations
  - Precise time transmission
- Precise frequency transmission
- Acknowledgement
- Q&A

Motivation

- For the **interaction with external processes** (processes running outside network) where timing of interaction limits quality or even the acceptability of network application real time network services are needed.

- Remote access to unique instruments
- Control of unique instruments including real-time
  - Location/Cost
  - E.g. telescopes, medicine instruments, optic clocks
- Remote real-time data collection (e.g. early warning)
- Remote collaboration (esp. interactive)

Real-time

- **Real time has nothing to do with high speed, but with timeliness constraints**
- 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.

Real-time applications

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- Hard real time applications – penalty for not meeting constraints is unacceptable (e.g. remote control of surgical robot)
- Soft real time applications – penalty for not meeting constraints is mild, result is degraded but acceptable (e.g. interactive HD videoconferencing)
- Firm real time applications – infrequent missing of constraints are tolerable, but usefulness of result after deadline is zero (e.g. data collection for weather forecast)
- 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.
- Optical networks can provide fixed latency of transmission and for reproducibility of experiments.

Photonic service

- 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 service

Advantages

- Transparency to transmitted signals
- 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 service

- 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 tests were already successful, e.g. concurrent 100G and precise time transmission and ITU-T also has produced recommendation G.698.2 - “Black link”

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).

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).

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.

Possible implementations

- Dark fiber (unlit fiber)
  - + full spectrum available
  - + freedom in deployed equipment
  - - very expensive esp. over long distances (deprecations/rental fees, maintenance….)
  - - difficult putting into service and troubleshooting

Possible implementations

- Dark channel – dedicated unlit bandwidth in fiber (e.g. traditional equipment overbridged)
  - + freedom in deployed equipment
  - + reduction in cost
  - - may exist interaction with other parallel transmissions
  - moderate putting into service and troubleshooting

Possible implementations

- All-optical lambda – lambda passing through transmission system
  - + minimal cost
  - + simple troubleshooting and maintenance
  - - unidirectional channels (isolators in EDFAs, WSSs)
  - - noise and interaction with parallel transmission

Demonstrations

- **Over high definition video (e.g. 3D Full HD, 2K, 4K) broadcast**
- Utilization of all-optical lambda
- 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 (130km/80mil by fibre), transmission latency <1ms
  - To Brno,CZ (550/340mil 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

Demonstrations

- **Time transfer**
- Utilization of all-optical lambda over DWDM
- Alternative to Common View GPS method
- Transmission of time marks (pulses modulated on optical carrier)
- Started by loop tests and GPS assisted transmission over standard DWDM systems, 2010
- Optical loop 744km/462mil, two unidirectional channels
- 12 EDFAs, G.652, G.555, one span aerial fibre on power distribution poles, high dilatation.

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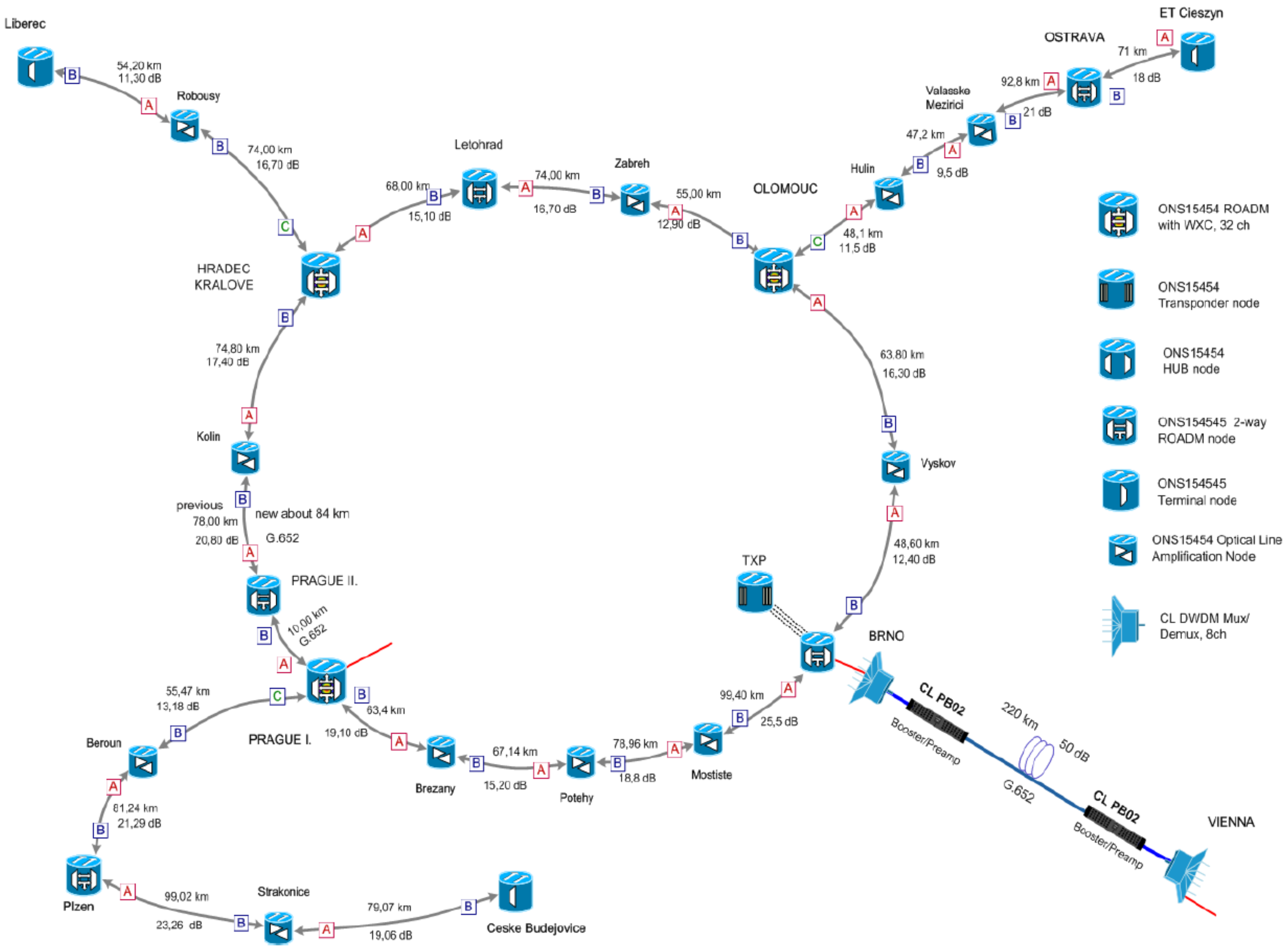
Time transfer



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Time transfer

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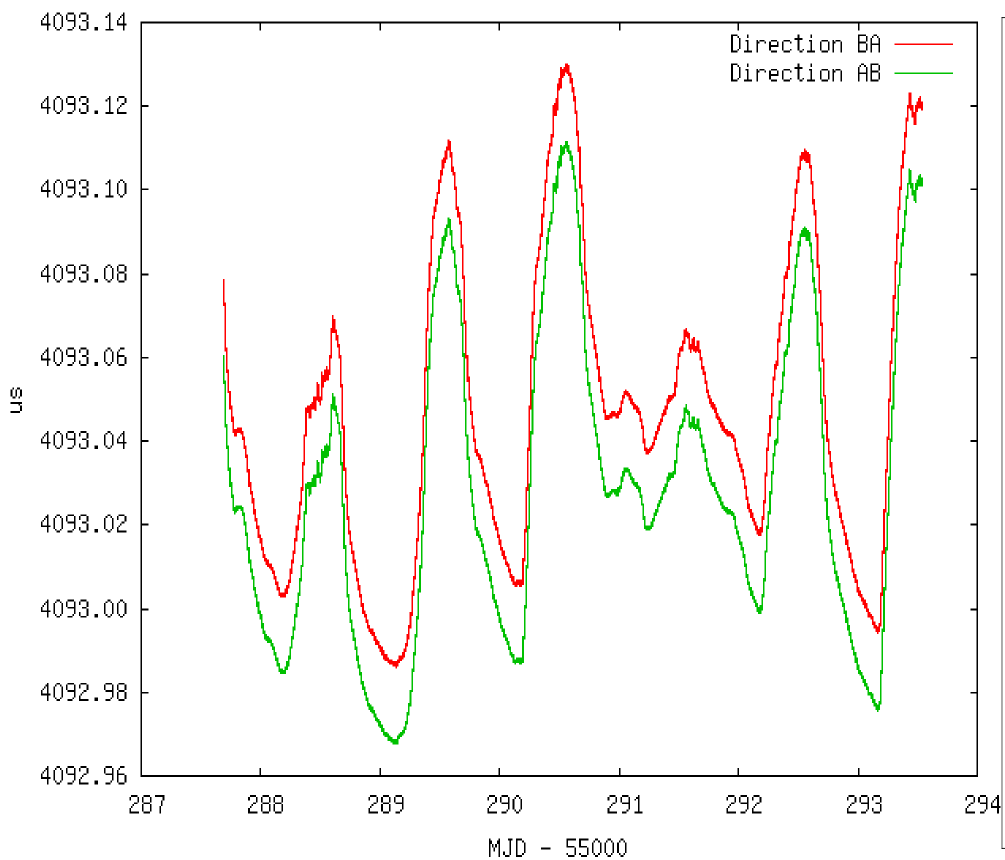

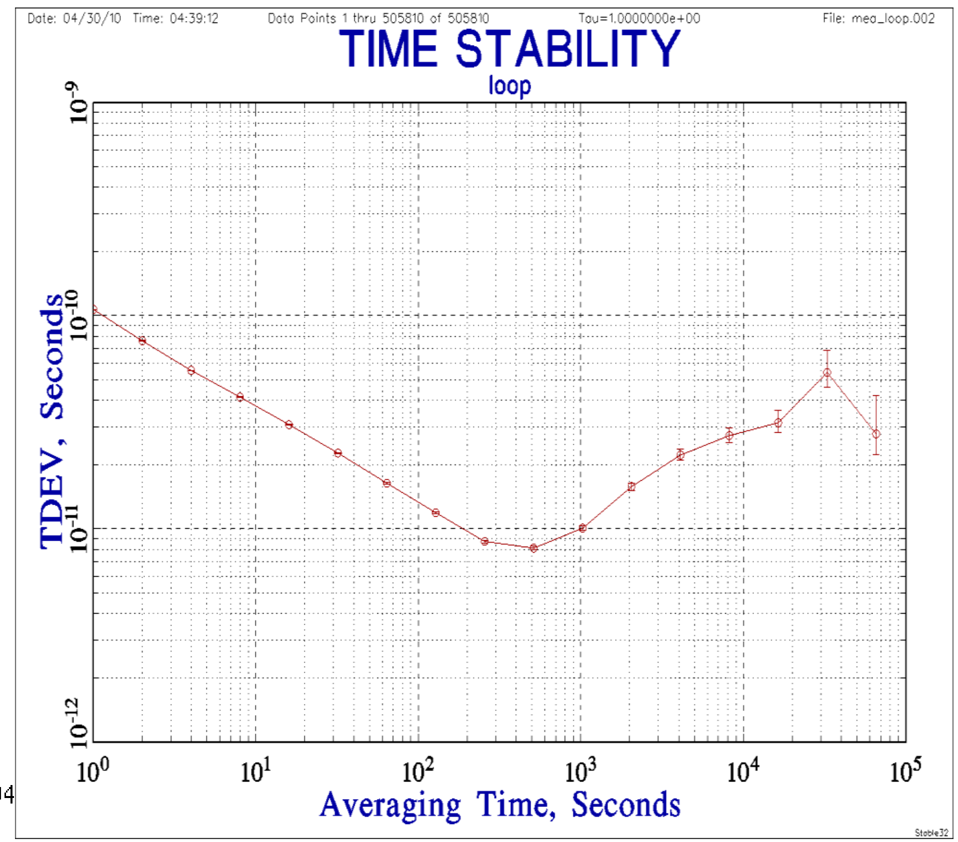

- fluctuation ~130 ns (temperature changes about 12 deg C)
- residual asymmetry < 2 ns (resp. TDEV 8.7 ps / 500 s)

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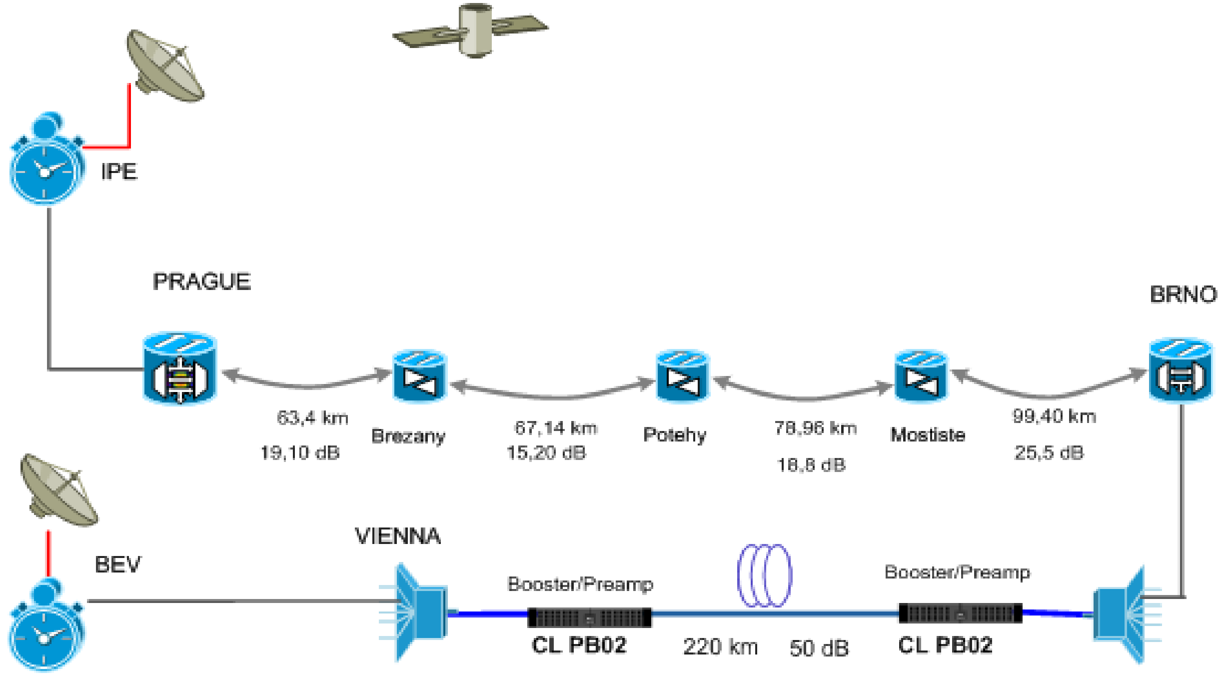
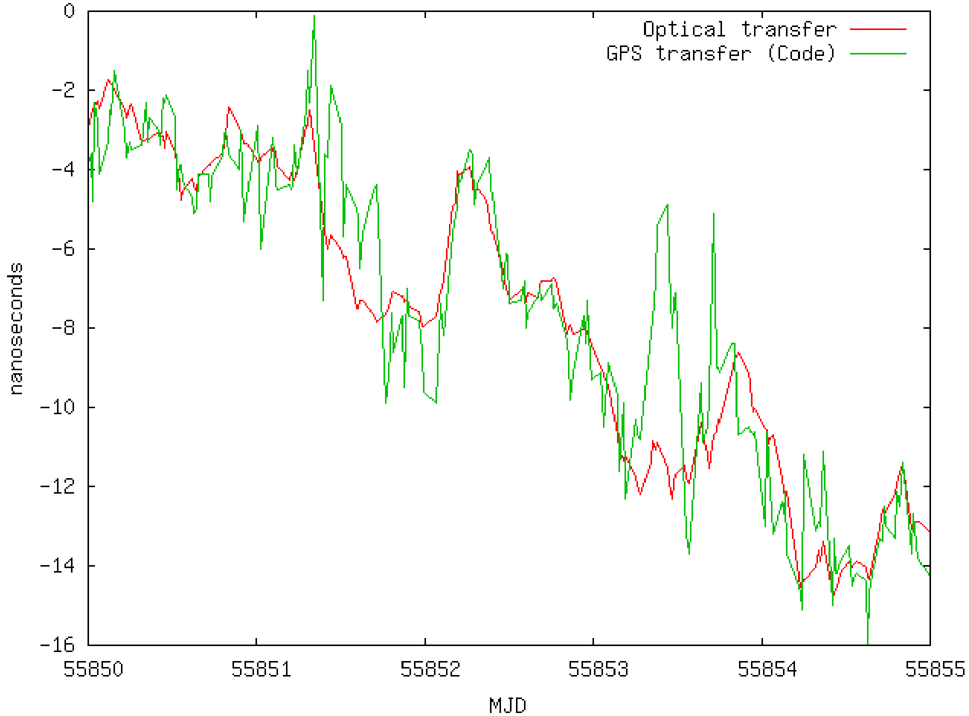
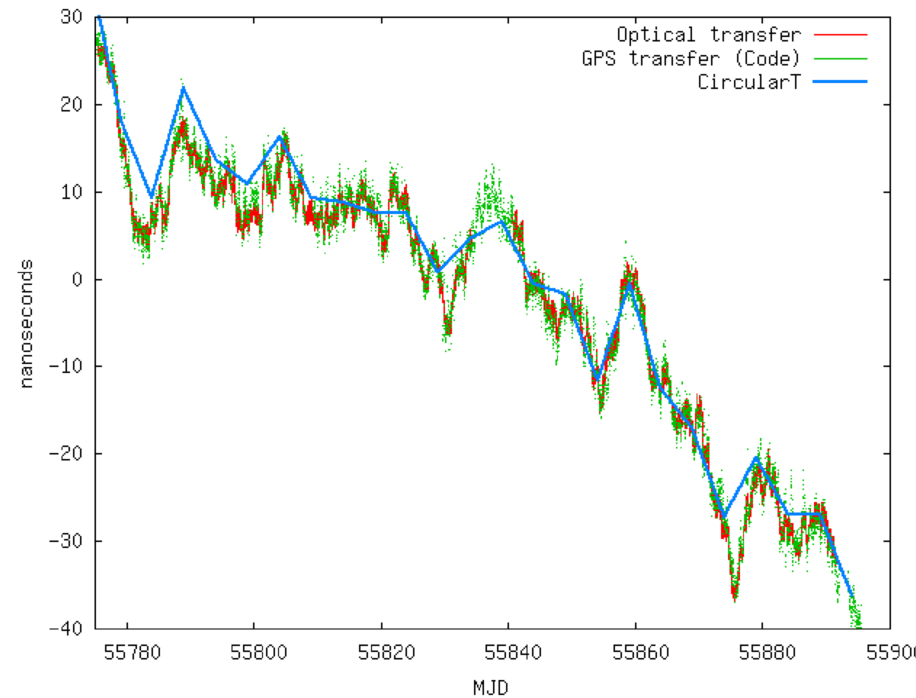
Time transfer

- Comparison of time scales UTC(TP) and UTC(BEV), Caesium beam 5071A/001 atomic clocks, in operation since Aug 2011
- 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/340miles (including 220km/137miles NIL) 137 dB



Time transfer





Red: optical transfer - linear regression over 780s

Green: GPS CV

Red: optical time transfer

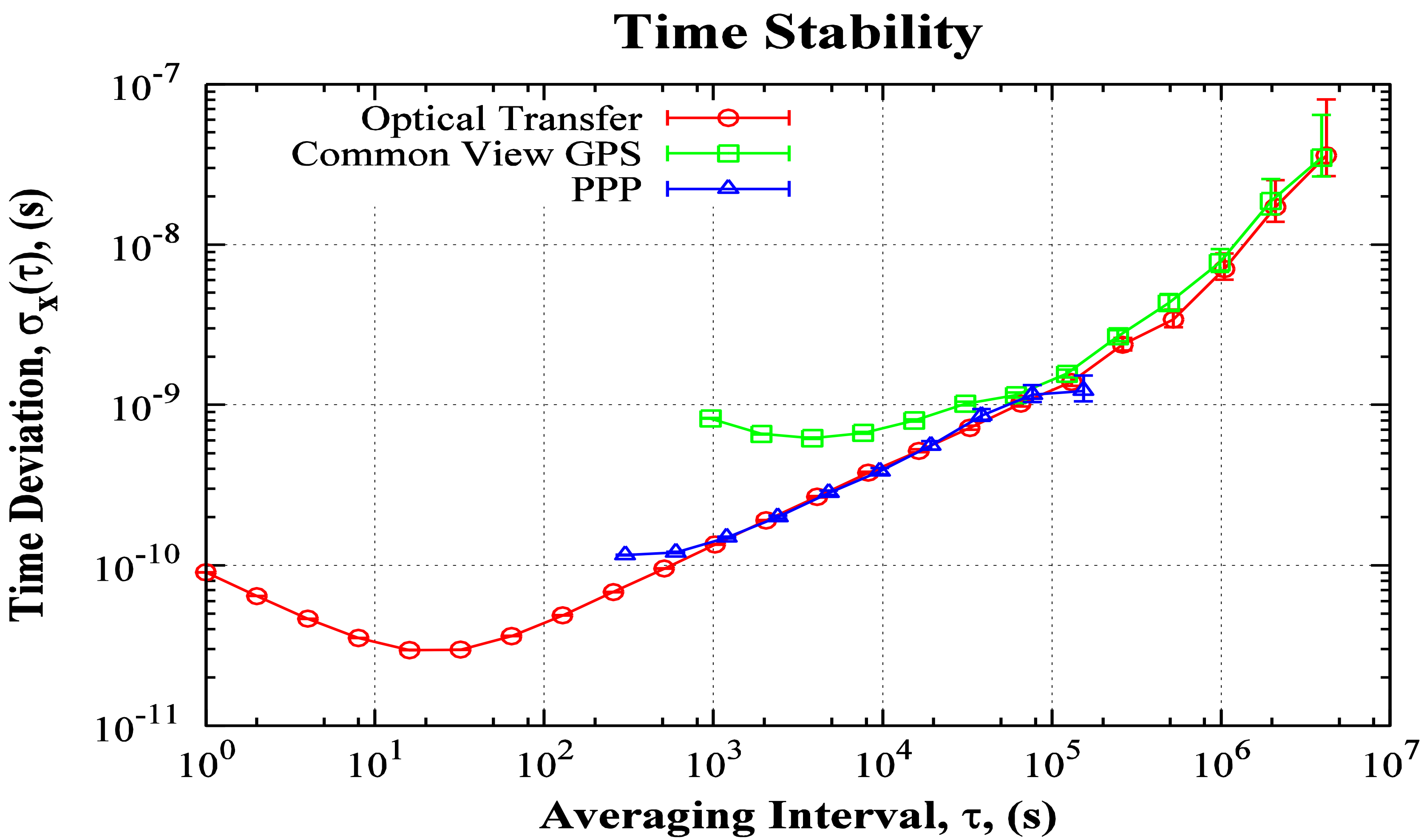
Green: GPS CV

Blue: Circular-T data

http://www.bipm.org/jsp/en/kcdb_data.jsp

Significantly smaller short term noise

Time transfer

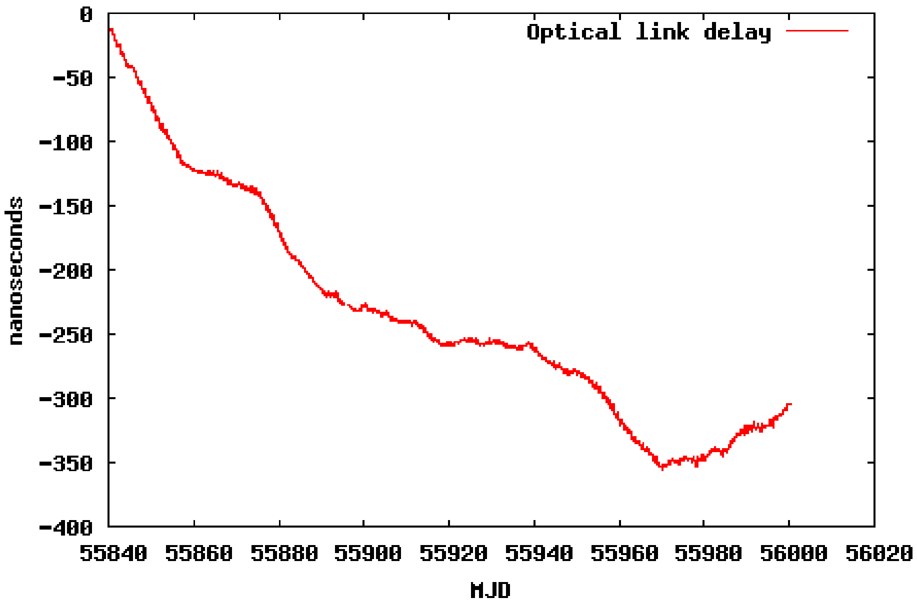


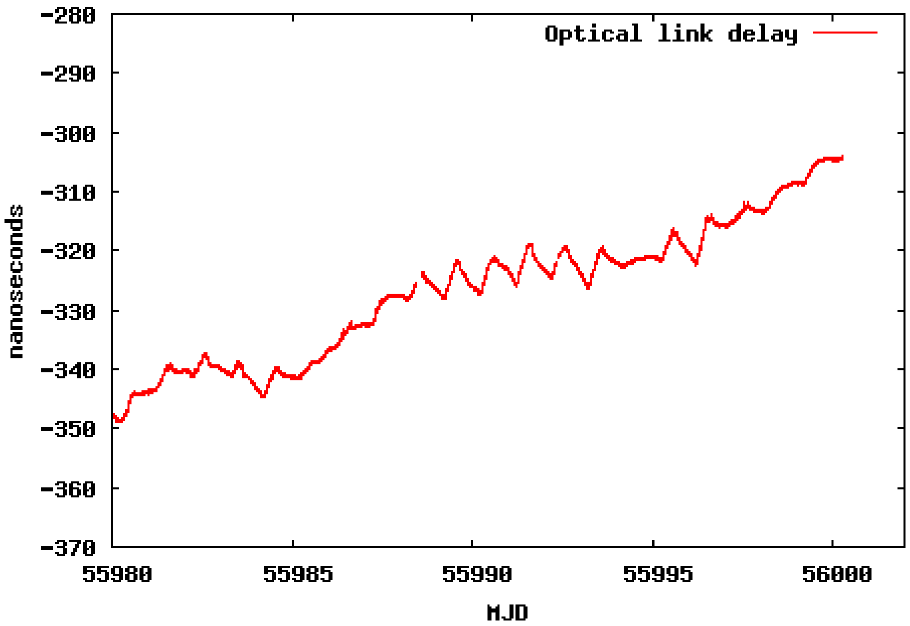
Smaller noise than both GPS methods

Tdev 30ps @ 20s averaging,

130 ps vs. 800 ps for 1000s averaging

Time transfer





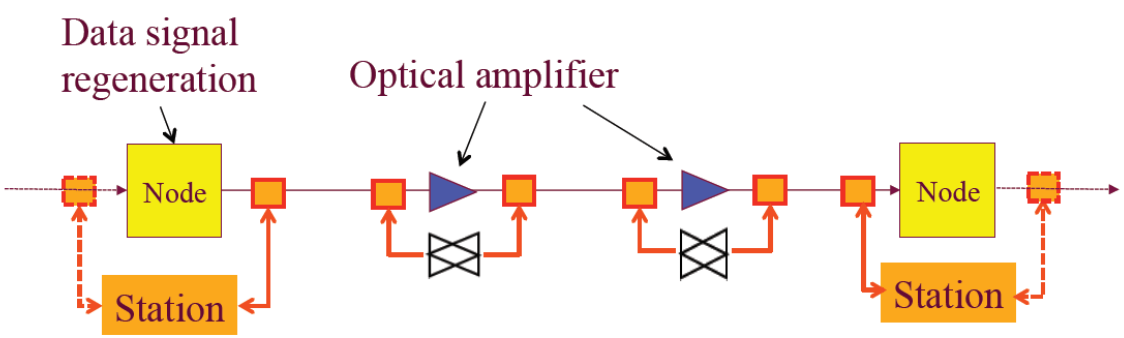
Propagation time changes

Left: Seasonal October 7 2011 - March 14 2012 approximately 350ns, $1.3 \cdot 10^{-4}$ of avg. delay 2788 μs

Right: Daily changes 4-7ns

Frequency transfer

- **Ultra-stable frequency transfers on live network RENATER**
- Utilization of dark channel
- Transmission of ultra-stable CW optical frequency itself (in region of 1550nm)
- Needs exactly same path for both directions noise correction and propagation delay fluctuation compensation
- Telco unidirectional 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

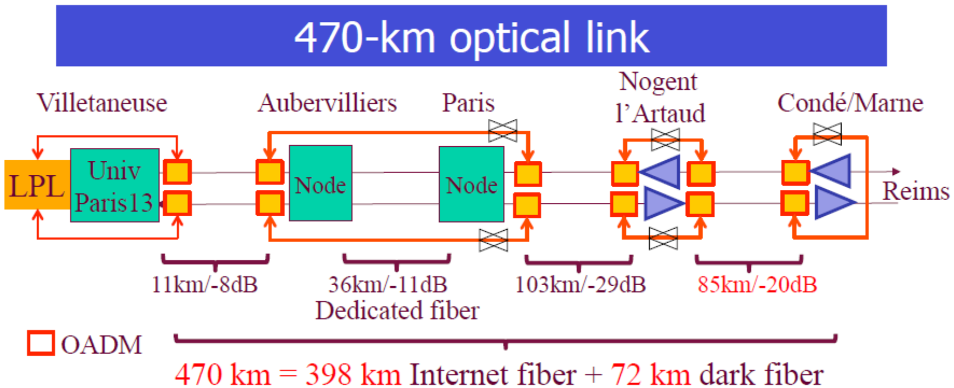
Bidir EDFA

Frequency transfer

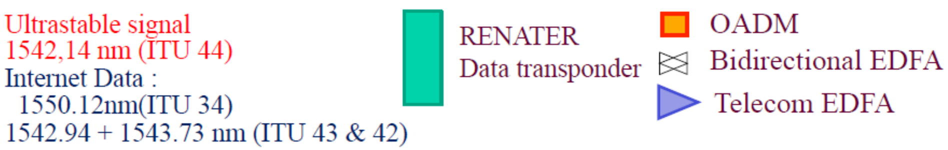
- **Ultra-stable frequency transfers on live network: RENATER + LNE-SYRTE (Système de Référence Temps Espace) + LPL (Laboratoire de Physique des Lasers)**
- 2009 - 90km/56miles DF loop test only
- 2010 - LPL-Nogent l'Artaud-LPL
  - 300km/186miles loop (228km/142miles over DWDM system), 100dB attenuation, 4 bidirectional EDFAs
- 2011 - LPL-Condé/Reims-LPL
  - 470km/292miles loop (398km/247miles over DWDM system), 136dB attenuation, 5 bidirectional EDFAs
  - 540km/336miles loop (470km/292miles over DWDM system), 6 bidirectional EDFAs

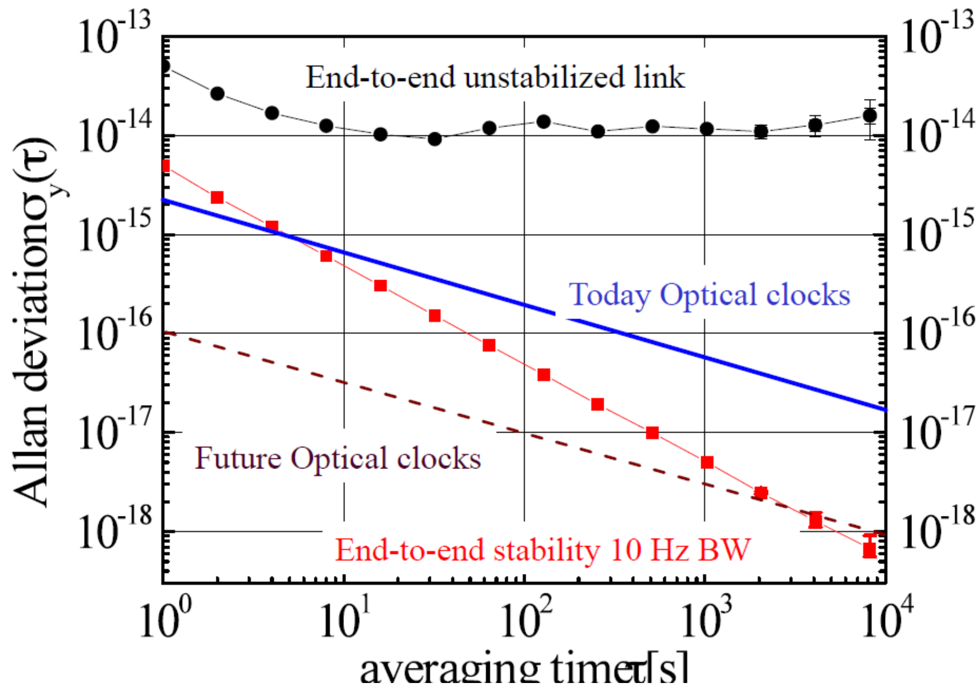
Frequency transfer

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



- One-segment link – 12 OADM
- 136 dB attenuation compensated by 5 bidirectional EDFAs (+100 dB)





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

Frequency transfer

- **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/90miles
- Dedicated fibre, 920km/572miles, 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**

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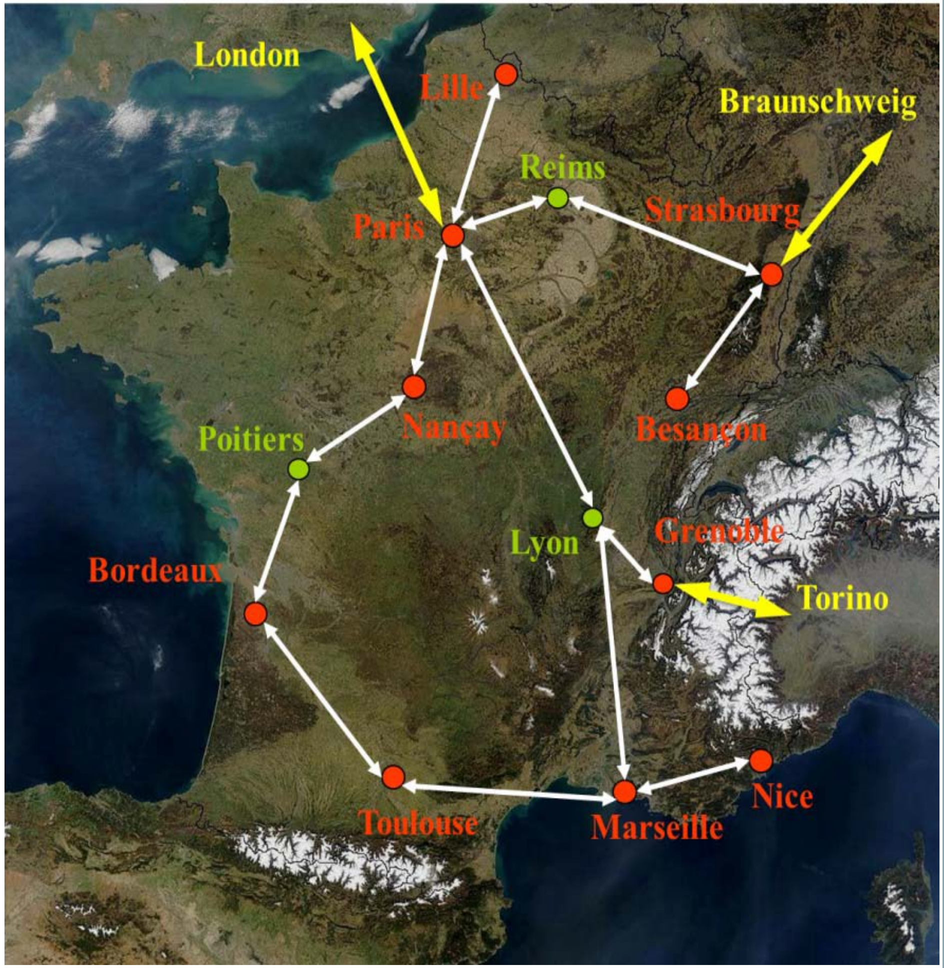
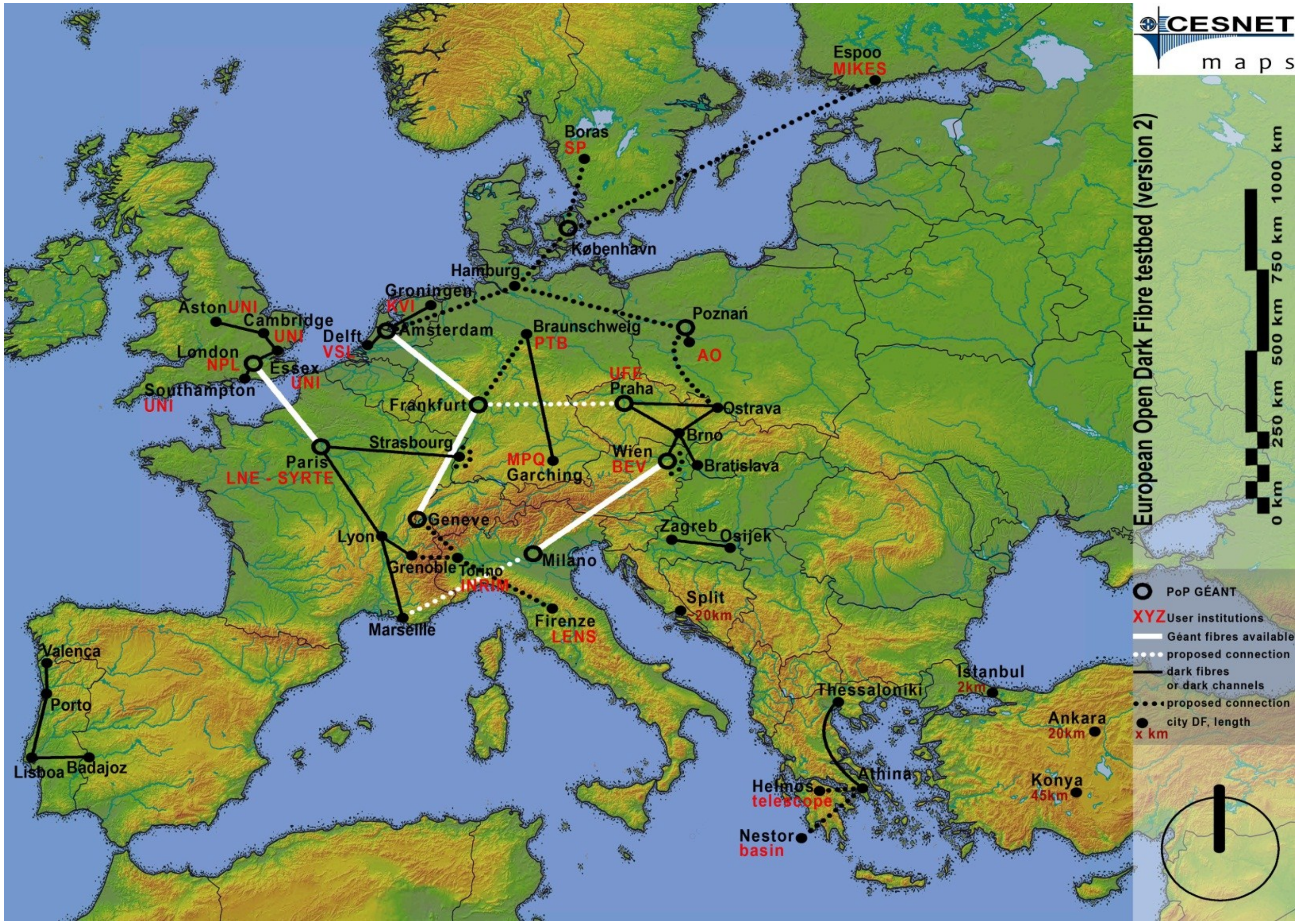
Planned

- LPL-Nancy-LPL 1100km/684miles with one regenerator station
- LPL-Strasbourg-LPL1476km/713miles 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, their enablers and applications
Planned

- Dark fiber and dark channel proposed testbed



- Optical clock

NPL, INRIM

SYRTE, PTB

Acknowledgement

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Q&A

- Thank you for kind attention!
- Questions?
- Interested in Photonic services!?

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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),

Invitation cont.

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- 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/
presentations of CEF Networks workshop 2007 http://www.ces.net/doc/seminars/cef2007/
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- LOLA (LOw LAtency audio visual streaming system) http://www.conservatorio.trieste.it/artistica/ricerca/progetto-lola-low-latency/ircam-lola-forweb.pdf?ref_uid=e98cac4a9c6a546ac9adebc9dea14f7b
- Technical Annex to Final Report: AAP20 Hapto-Audio-Visual Environments for Collaborative Tele-Surgery Training over Photonic Networking http://www.photonics.uottawa.ca/HAVE/docs/public_progress_reports/C4_AAP20_HAVE_Public_Final_Report_Technical_Annex.pdf