Transmission of Timing Sensitive Information Using Photonic Services

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Innovation through participation

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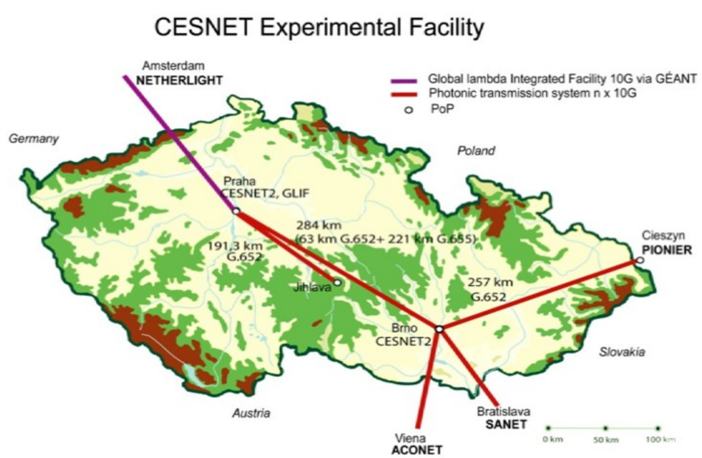
- Authors participate on following projects:
  - Large infrastructure CESNET, www.ces.net
  - GÉANT - GN3, www.geant.net

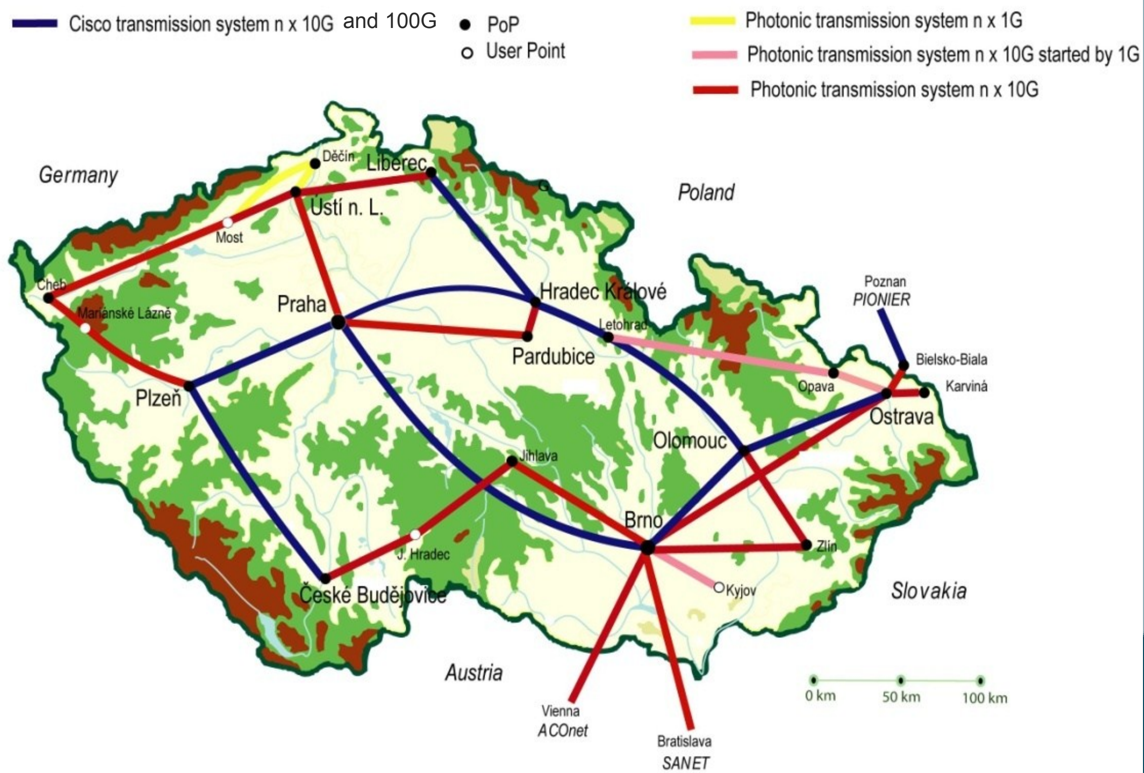
Outline

- Brief Introduction
- Advanced and Timing Critical Network Applications
- Photonic Service
- Accurate Time Transmission
- Conclusions
- Q&A

CESNET

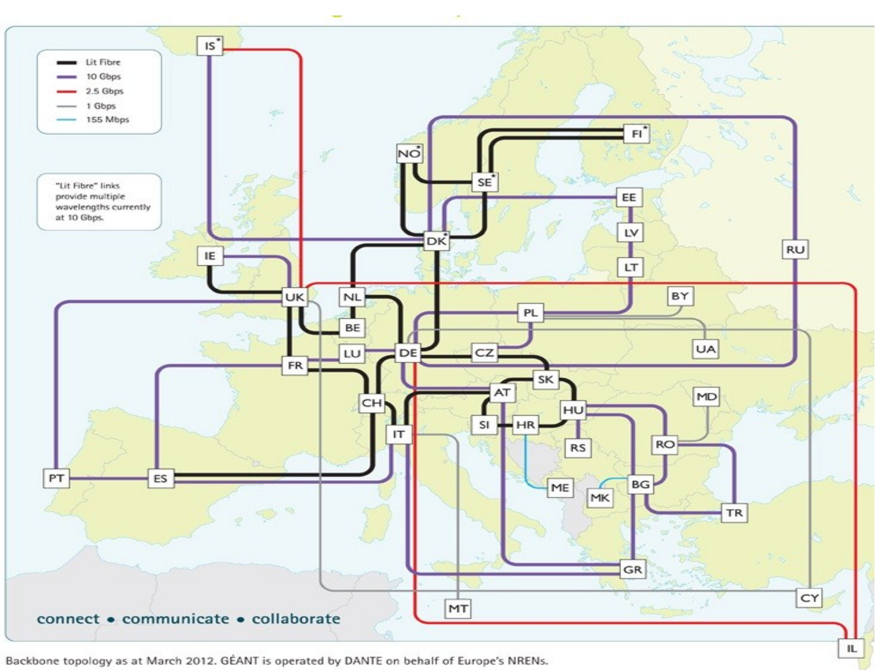
- **National Research and Educational Network Czech Republic**
- Non-profit organization
- Connects over 40 partners - universities, hospitals and research institutions
- Optical network DWDM based ~ 5000km lit fibers
- 250 researchers and staff

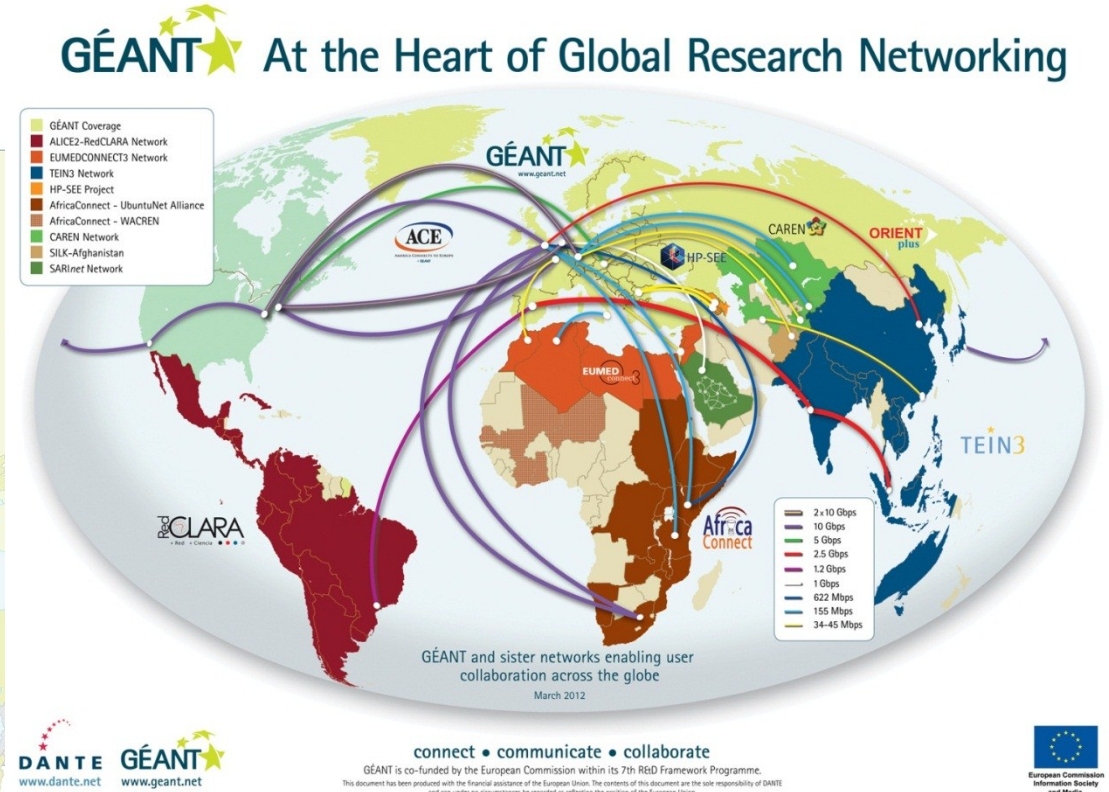




GEANT

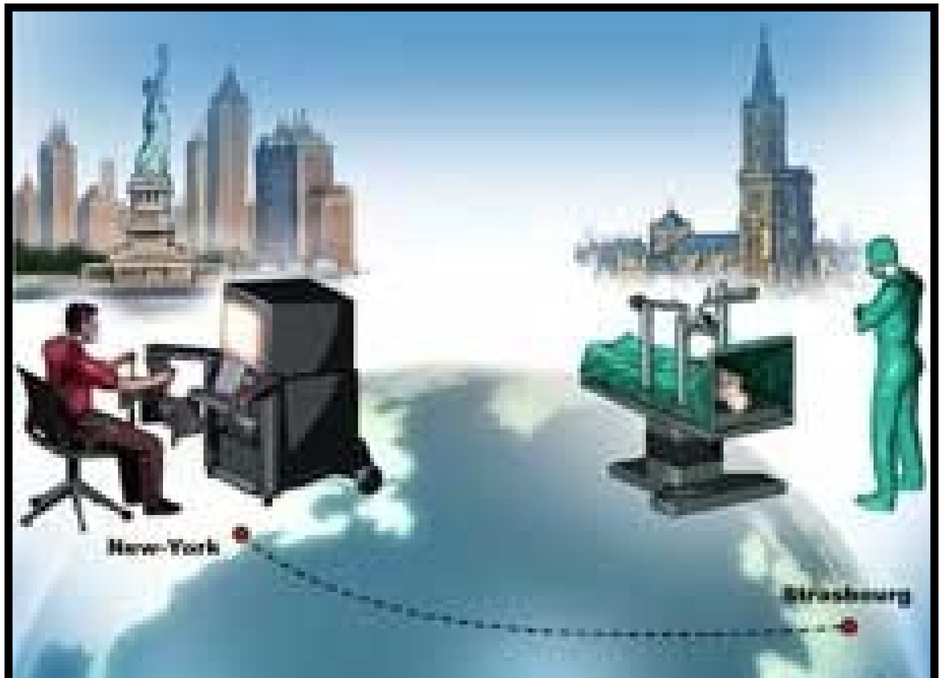
- 7th generation of the pan-European Research and Education Network infrastructure
- Connects 40 European countries, 40 million users, 8000 institutions
- 50,000km of infrastructure and 12,000km of lit fibre





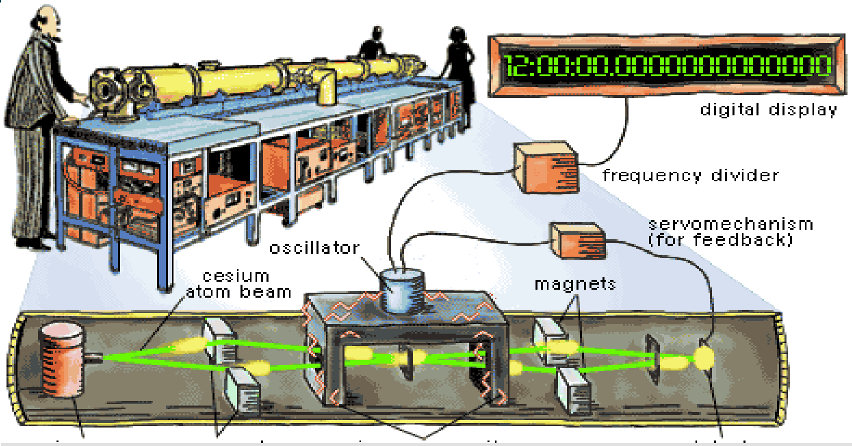
Advanced Network Applications

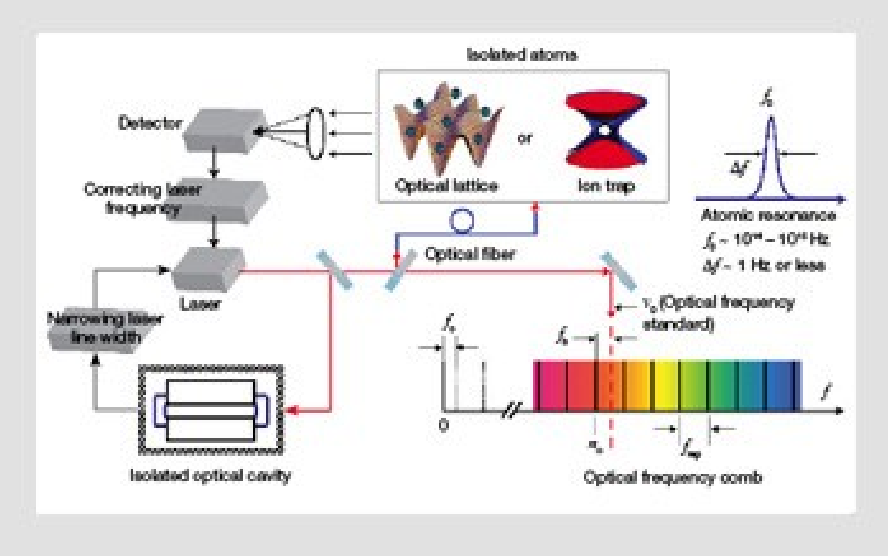
- Applications requires improved timing - low and limited latency
- Remote musician lessons
- Interactive 3D HD or 4K video
- Remote instrument control



Timing Critical Applications

- Stable latency is a must (including active stabilization)
- Accurate time transfer
- Ultra-stable frequency transfer
- Real-time applications
  - Early warning systems (e.g. seismic)
  - Real-time remote/vehicle instrument control





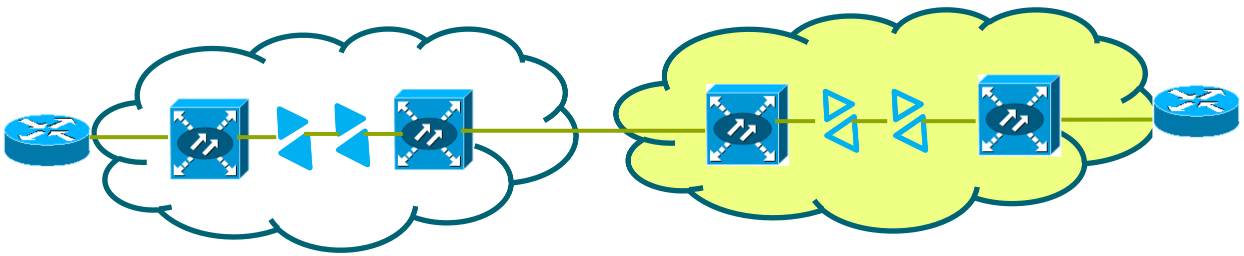
Atomic Clocks

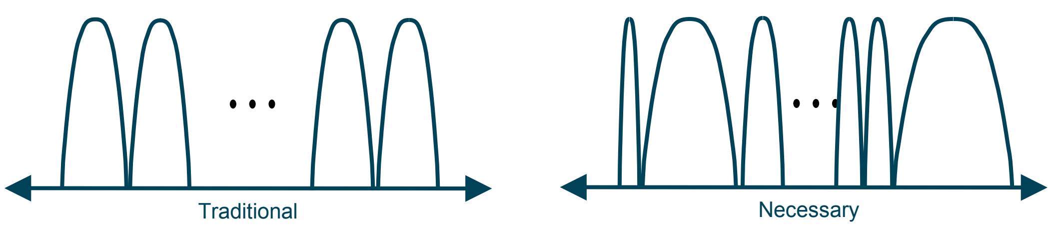
- Sensitive and expensive – difficult to transport
- Comparison of offsets over satellite transmission and GPS with limited accuracy
- Produces microwave frequency
- Clock output can be converted to time stamps, and transmitted over optical network

Cesium fountain clock at NPL UK, height of 2.5m

Photonic Service

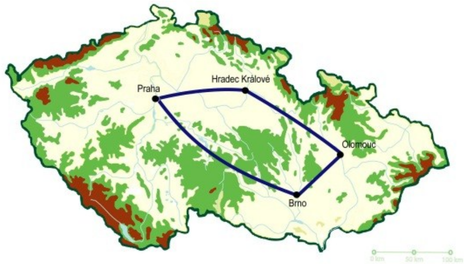
- Dark channel or all optical lambda
- Transparent
- Stable and minimal latency
- Defined by:
  - Optical light-path
  - Dedicated bandwidth
  - Fixed grid -> dynamic allocation





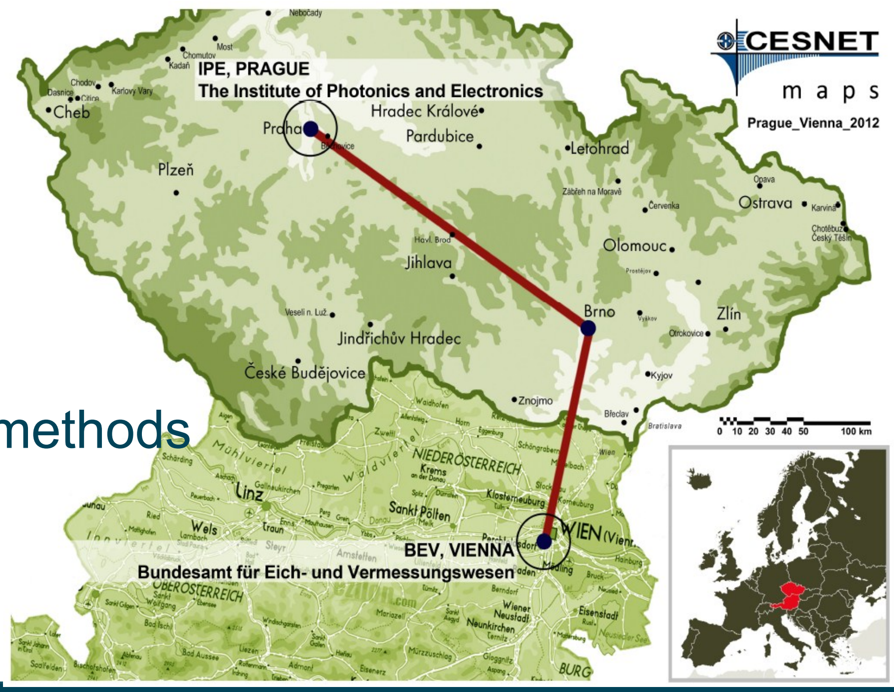
Accurate Time Transfer

- Transmission in loop tests – 2010
  - Loop of 774km each way over ONS 15454 MSTP
  - No influence on parallel 10G data traffic



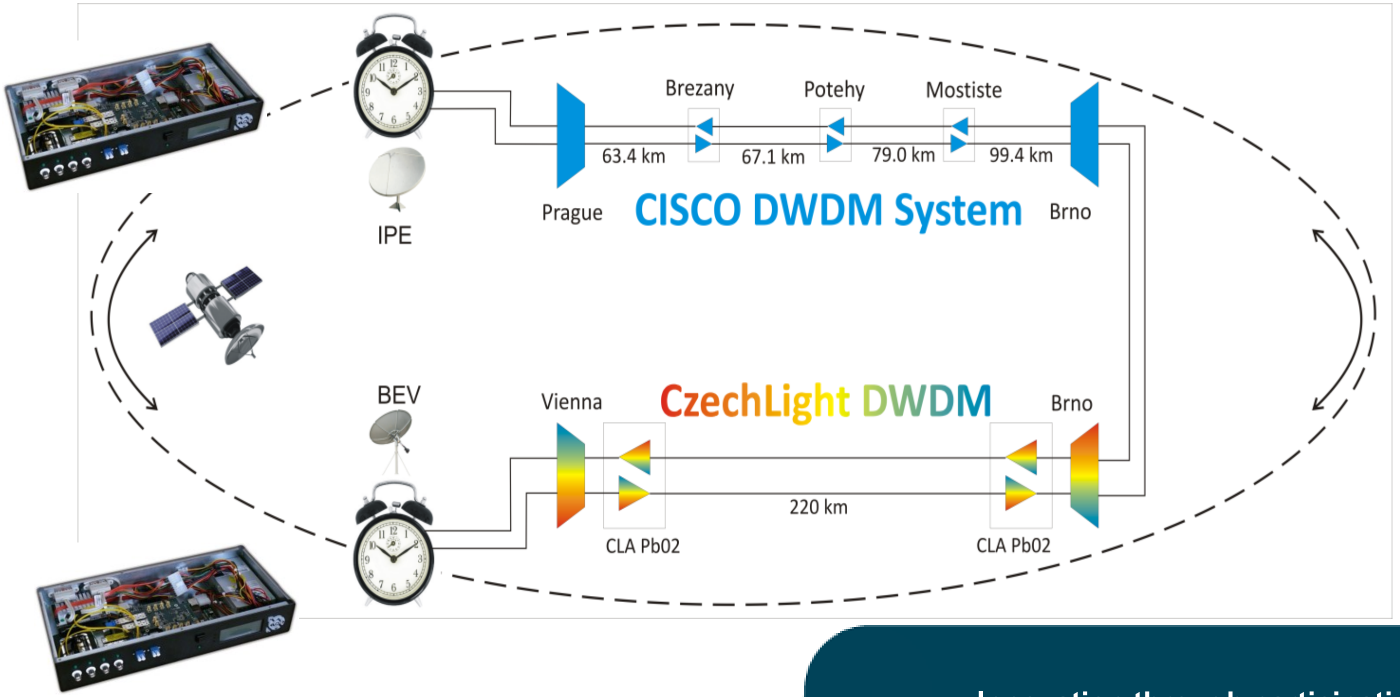
- Atomic clock comparison – test 2010, operational
  http://www.ces.net/doc/press/2010/pr100401.html

- Part of NEAT-FT project
  - All optical path (550km one way)
  - Bidirectional transfer
  - Over backbone operational data network
  - Simultaneous comparison with two GPS methods



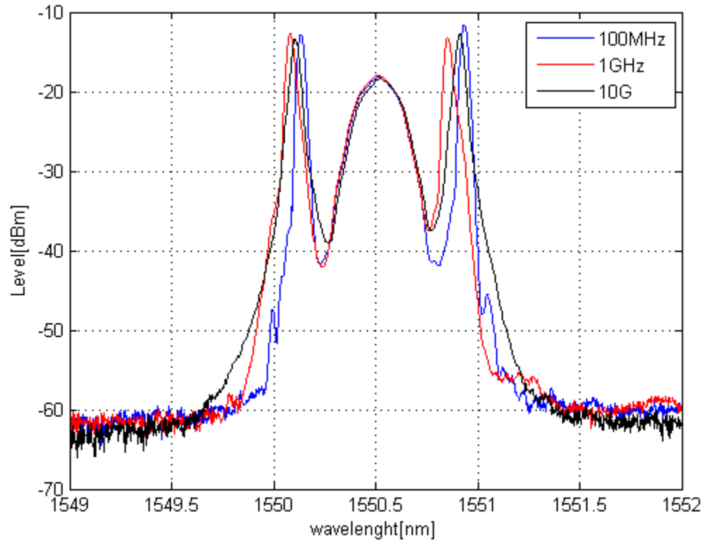
Accurate Time Transfer

- Comparison of time scales UTC(TP) and UTC(BEV), Cesium beam 5071A/001 atomic clocks, in operation since Aug 2011
- Path 550km = 137 dB one way, contains of 220km cross border fibre
  - Mixture of fibre types (G.652/655)
  - Mixture of transmission systems Cisco/OpenDWDM Czechlight
  - Mixture of CD compensation types (DCF, FBG)

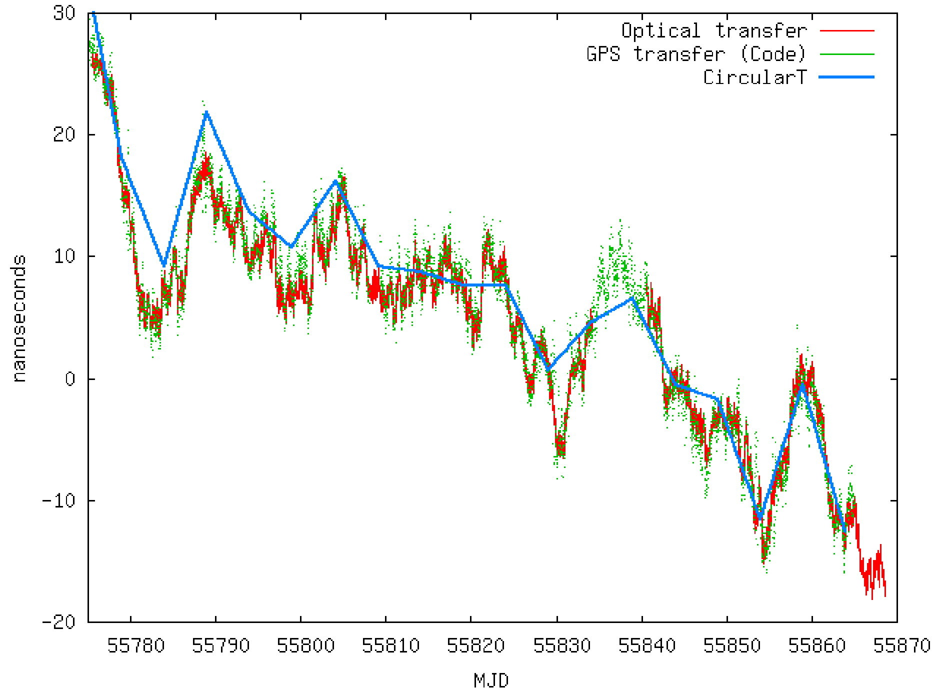


Accurate Time Transfer

- Parallel transmission of Accurate Time and 100G, in operation 2013
  - Parallel operation over 309km of G.655 fiber since 8 Feb 2013, no influence to BER
  - Lab and field verification 2011
  - Spectral distance of signals 20nm, whole C band is about 35nm
  - According our knowledge first and only parallel T/F and 100G transmission in operational network



Results



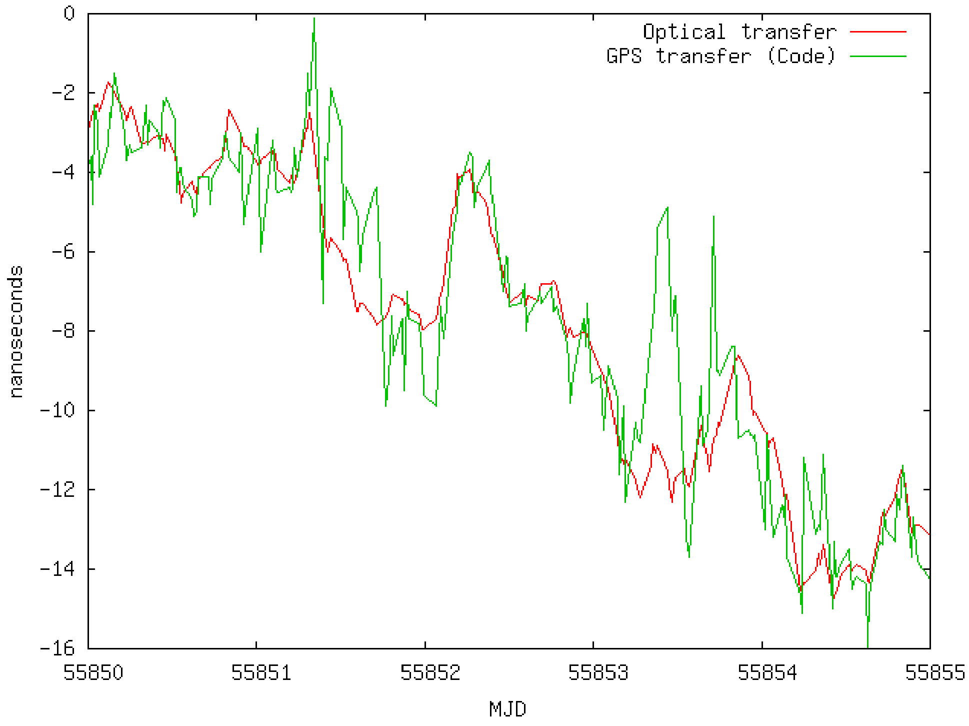
Red: time difference UTC(TP) − UTC(BEV) measured using optical link

Green: measured using GPS CV

Blue: published at BIPM Circular-T

CircularT offsets between sources of UTC http://www.bipm.org/jsp/en/kcdb_data.jsp

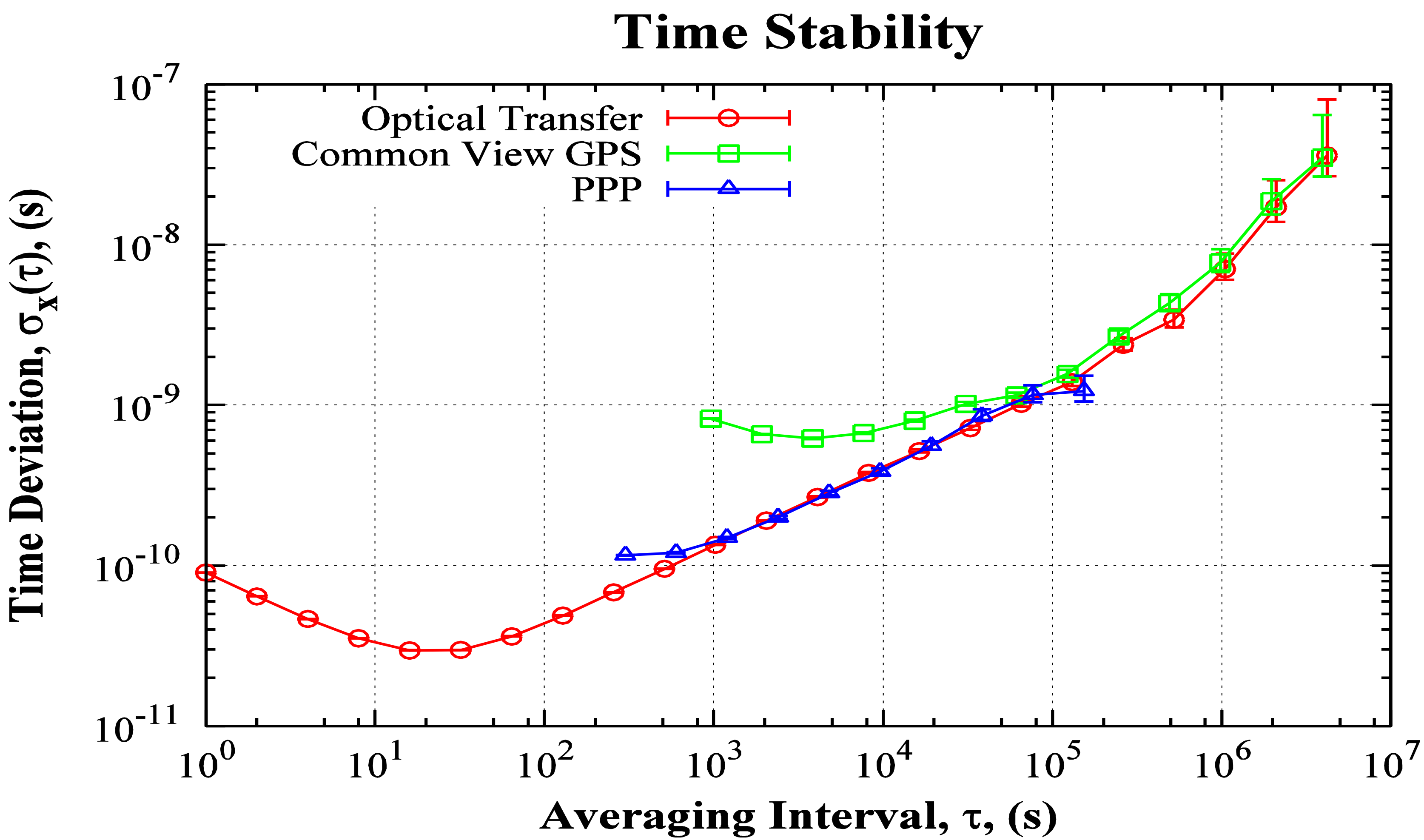
Results



Red: optical transfer - linear regression over 780s
Green: GPS CV

Significantly smaller short term noise

Results



Better stability than both GPS methods

Tdev 30ps @ 20s averaging,

130 ps vs. 800 ps for 1000s averaging

Conclusions

- Optical networks allows new types of applications
- Photonic services are the way to implement transfers for them
- Transmission of acurate time:
  - Needs just all-optical channel
  - Performs better than GPS based methods
  - Has no impact on other DWDM channels
  - Will work on improvement
- We are looking forward to learn about other time/frequency transfer experiments or about new network applications

Acknowledgements

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- This work was supported by the Ministry of Education, Youth and Sport of the Czech Republic as part of the *CESNET Large Infrastructure project LM2010005*

Q&A

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

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Demonstrations

- **Over high definition video (e.g. 3D Full HD, 2K, 4K) broadcast**
- 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

Motivation

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

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

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
  - + no interference with other transmissions
  - - 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

GÉANT

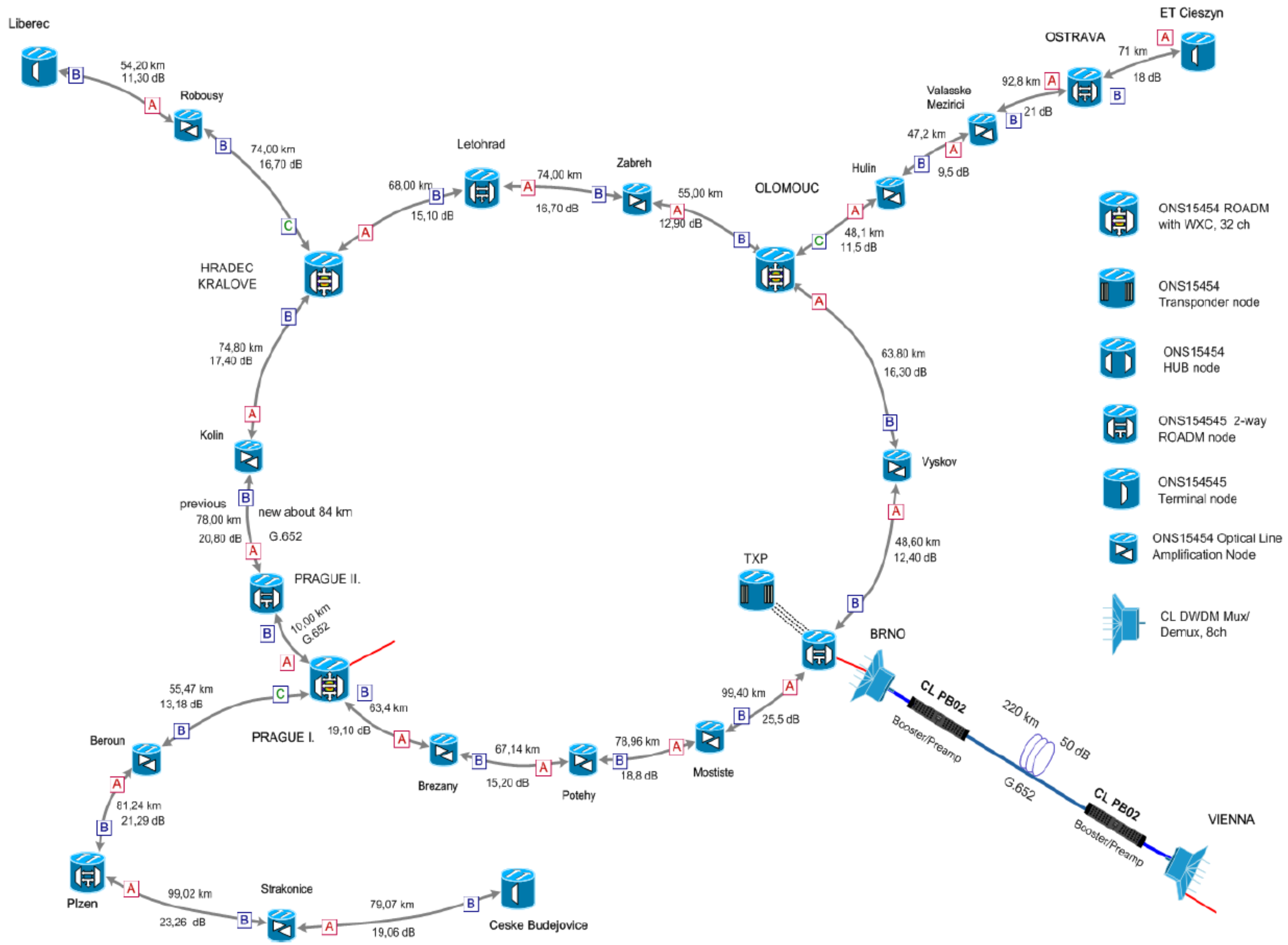
- All-optical lambda – lambda passing through transmission system
  - + minimal cost
  - + simple troubleshooting and maintenance
  - - unidirectional channels (isolators in EDFAs, WSSs)
  - - noise and interaction with parallel transmission

Demonstrations

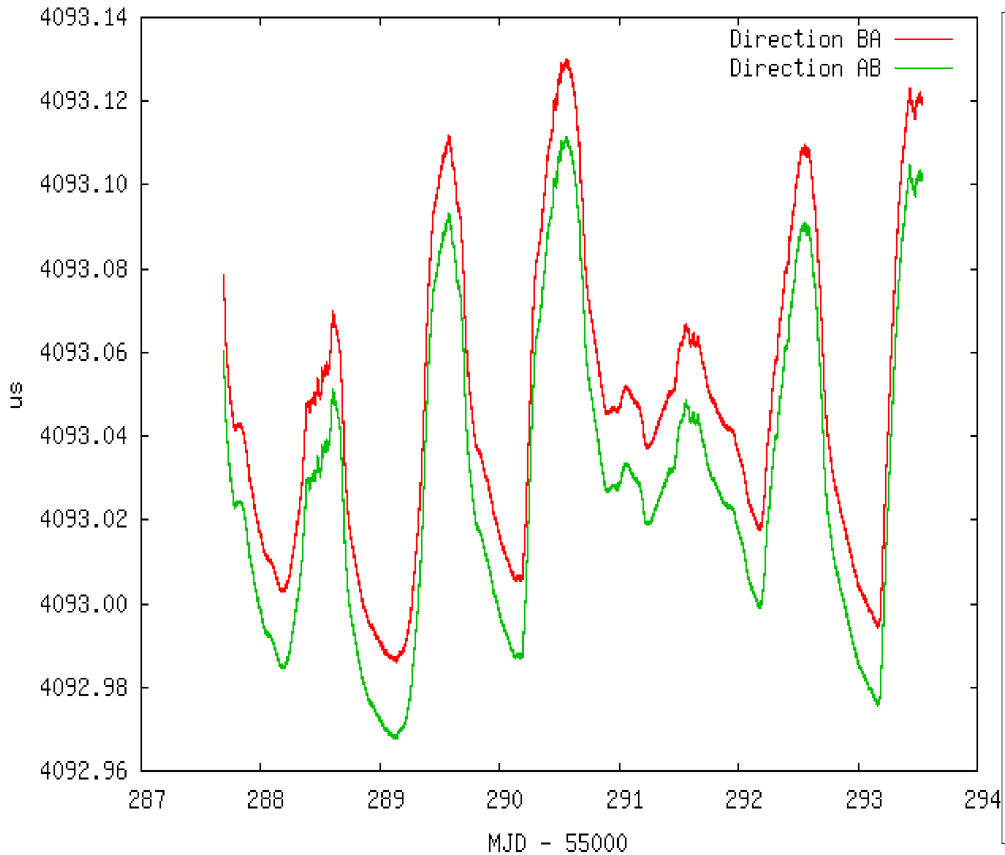
- **Time transfer**
- Utilization of all-optical lambda over DWDM
- Alternative to Common View GPS method
- Started by loop tests and GPS assisted transmission over standard DWDM systems, 2010
- Optical loop 744km/462mil, two unidirectional channels
- 12 EDFAs, G.652, G.555, one span aerial fibre on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

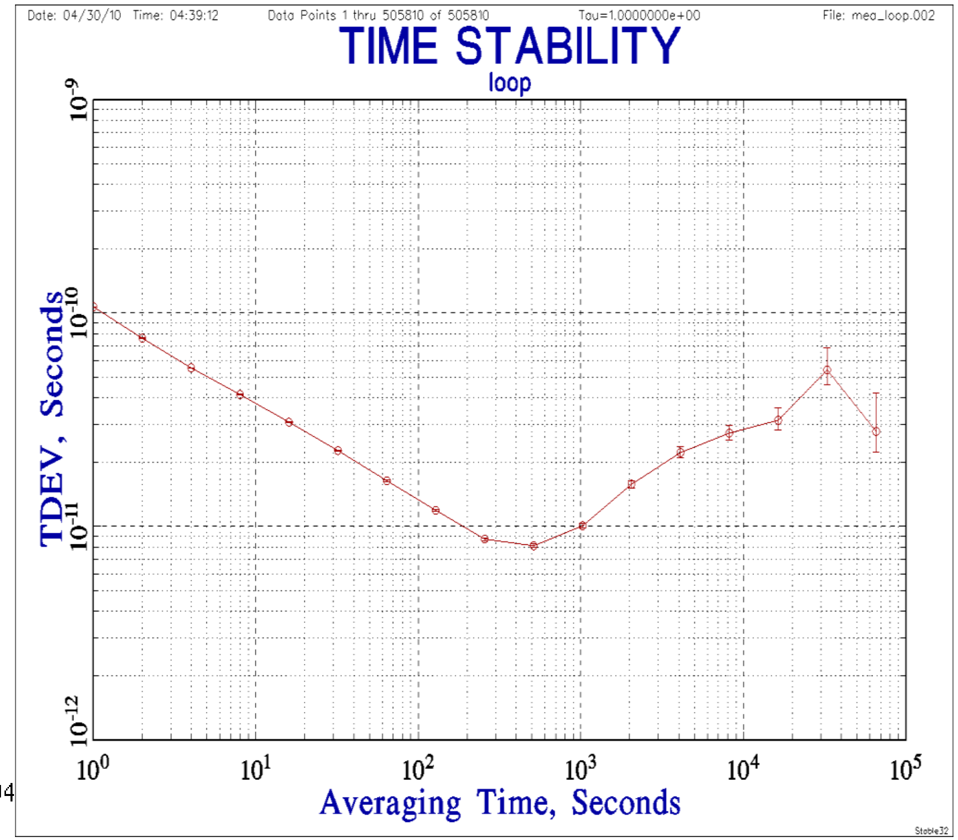
Photonic services, their enablers and applications

Time transfer



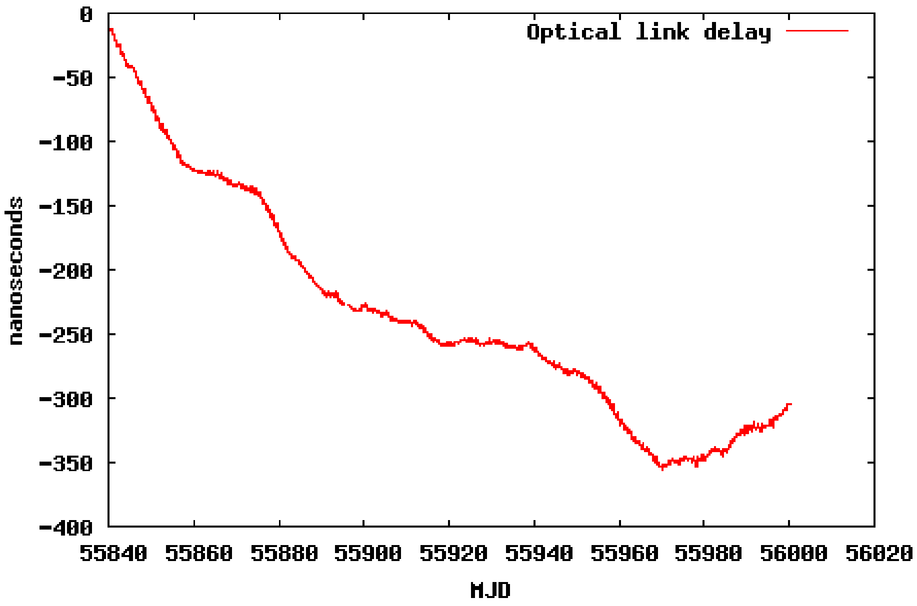
Photonic services, their enablers and applications
Time transfer

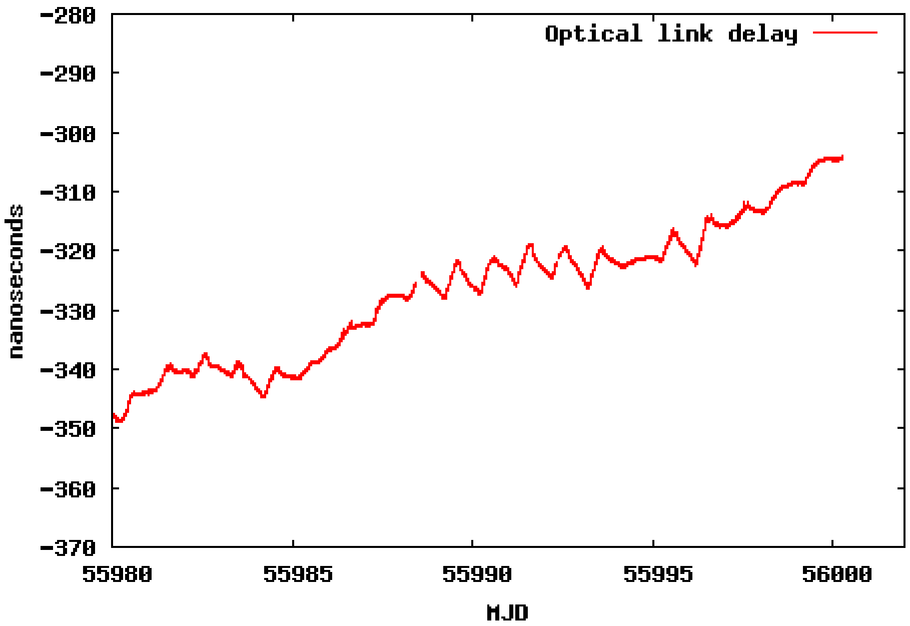




- fluctuation ~130 ns (temperature changes about 12 deg C)
- residual asymmetry < 2 ns (resp. TDEV 8.7 ps / 500 s)

Time transfer





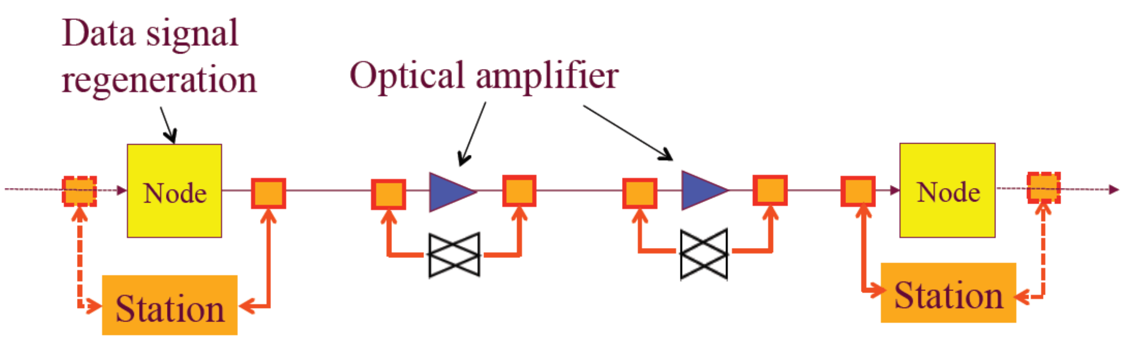
Propagation time changes

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

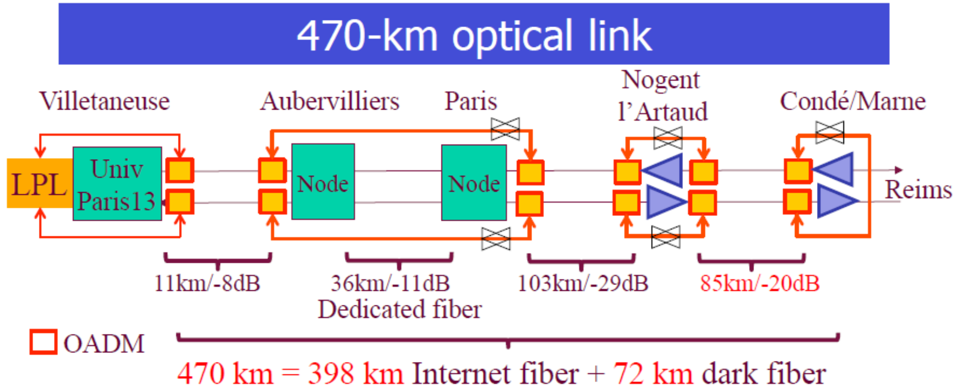
Bidir EDFA

Frequency transfer

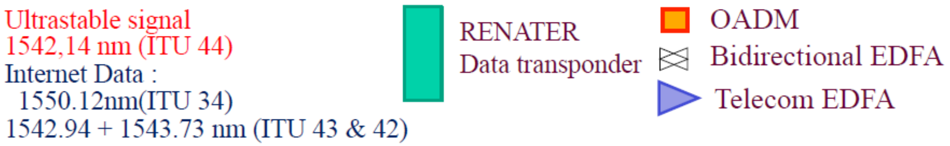
- **Ultra-stable frequency transfers on live network: RENATER + LNE-SYRTE (Système de Référence Temps Espace) + LPL (Laboratoire de Physique des Lasers)**
- 2009 - 90km/56miles DF loop test only
- 2010 - LPL-Nogent l'Artaud-LPL
  - 300km/186miles loop (228km/142miles over DWDM system), 100dB attenuation, 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

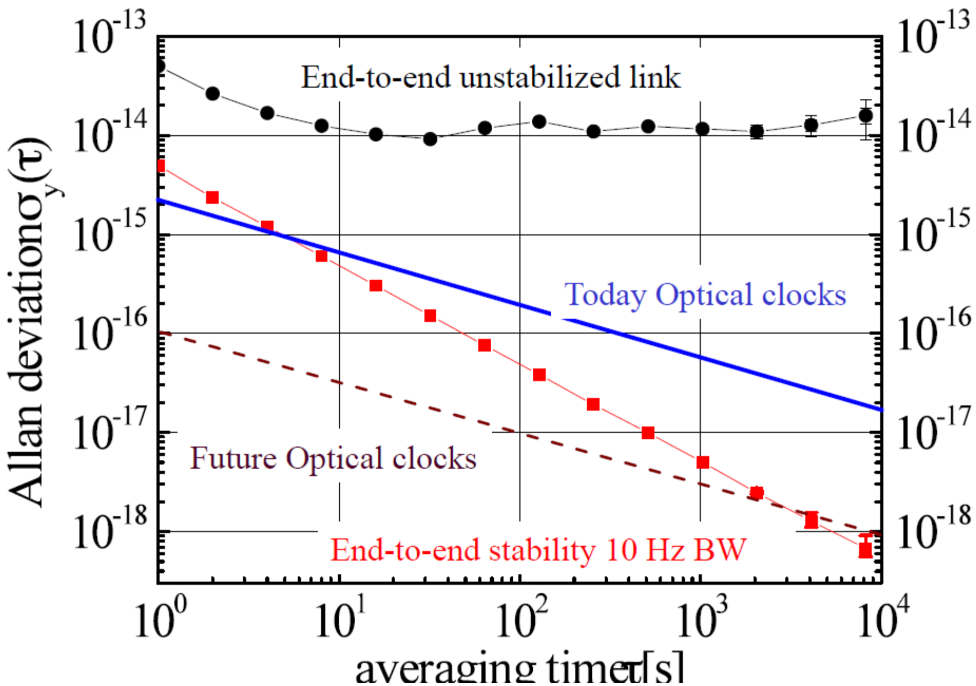
Frequency transfer

- **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

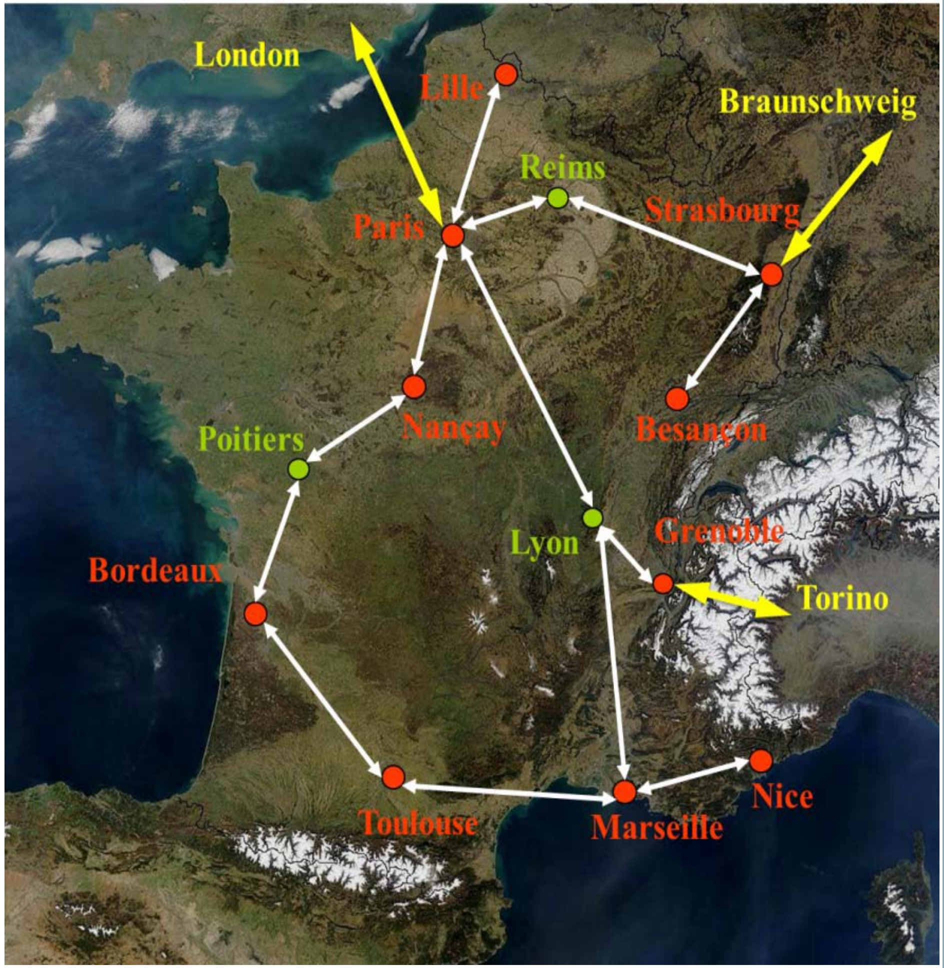
- **Ultra-stable frequency transfers: MPQ-PTB germany**
- Max-Planck-Institut für Quantenoptik (MPQ) in Garching and Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig,
- 2009 – dedicated fibre146km/90miles
- Dedicated fibre, 920km/572miles, 200 dB attenuation, bidirectional transmission and 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**

Photonic services, their enablers and applications

Plans

- 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



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