Transmission of Timing Sensitive Information Using Photonic Services

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Josef Vojtěch, CESNET, Czech Republic
josef.vojtech(salamander)cesnet.cz
Co-authors: Vladimír Smotlacha, Pavel Škoda
- CESNET z.s.p.o.,
- czechlight.cesnet.cz/en

Authors participate on following projects:
- Large infrastructure CESNET, www.ces.net
Transmission of Timing Sensitive Information Using Photonic Services

Outline

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

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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
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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
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Advanced Network Applications

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

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

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

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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)
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

![Graph showing spectral distance and wavelength comparison]
Results

Red: time difference UTC(TP) – UTC(BEV) measured using optical link
Green: measured using GPS CV
Blue: published at BIPM Circular-T
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Results

**Red:** optical transfer - linear regression over 780s

**Green:** GPS CV

Significantly smaller short term noise
Better stability than both GPS methods
Tdev 30ps @ 20s averaging,
130 ps vs. 800 ps for 1000s averaging
Optical networks allows new types of applications

Photonic services are the way to implement transfers for them

Transmission of accurate 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
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Thank you for kind attention!

Questions?

Interested in Photonic services!?

josef.vojtech(salamander)cesnet.cz
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
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

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.
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
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”
Photonic services, their enablers and applications

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).
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).
**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.
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
Photonic services, their enablers and applications
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
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
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.
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Time transfer
fluctuation ~130 ns (temperature changes about 12 deg C)
residual asymmetry < 2 ns (resp. TDEV 8.7 ps / 500 s)
Photonic services, their enablers and applications
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
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)

Data signal regeneration

Optical amplifier

Source: G. Santarelli et al, “Transmitting ultra-stable optical signals over public telecommunication networks”

Bypass: bidirectional amplifiers + OADM (+ AOM?)

Station: every 400 km - 600 km
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
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Frequency transfer

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

  470-km optical link

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

  Ultrastable signal
  1542.14 nm (ITU 44)
  Internet Data:
  1550.12 nm (ITU 34)
  1542.94 + 1543.73 nm (ITU 43 & 42)

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

  Deviation $5 \times 10^{-15}$ at 1s averaging
  $8 \times 10^{-19}$ at 10000s averaging
Ultra-stable frequency transfers: MPQ-PTB Germany

Max-Planck-Institut für Quantenoptik (MPQ) in Garching and Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig,

2009 – dedicated fibre 146km/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 $5 \times 10^{-15}$ in a 1-second integration time, reaching $10^{-18}$ 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
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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Photonic services, their enablers and applications

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