Towards Terabit per Second Optical Networking

Photonic Services

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- GÉANT - GN3 ([www.geant.net](http://www.geant.net))
- Large infrastructure CESNET ([www.ces.net](http://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

• 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
- Belnet
- BREN
- CARNet
- CYNET
- CESNET
- EENet
- RENATER
- DFN
- GRNET
- NIIF
- HEAnet
- IUCC
- GARR
- SigmaNet
- LITNET
- RESTENA
- MARNet
- University of Malta
- MREN
- SURFnet
- Austria
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Estonia
- France
- Germany
- Greece
- Hungary
- Ireland
- Israel
- Italy
- Latvia
- Lithuania
- Luxembourg
- Macedonia
- Malta
- Montenegro
- Netherlands
- NORDUnet
- PSNC
- FCCN
- RoEduNet
- AMRES
- SANET
- ARNES
- RedIRIS
- SWITCH
- ULAKBIM
- JANET

#### Associate NRENs

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

[http://www.geant.net/About_GEANT/Partners/pages/home.aspx](http://www.geant.net/About_GEANT/Partners/pages/home.aspx)
Photonic Services
GÉANT: At the heart of the Global R&E Village

http://global.geant.net/
● Created 2004
● Connects 13 countries, almost 800 universities
### 59 NRENs outside Europe connected to GÉANT

#### Americas
- CANARIE
- CEDIA
- CoNARE
- CUDI
- ESNet
- INNOVA|RED
- Internet2
- NISN (NASA)
- NLR
- RAAP
- RAGIE
- RAICES
- RAU2
- REACCIUN2
- RedCyT
- RENATA
- REUNA
- RNP
- USLHCNet
- CANARIE
- CEDIA
- CoNARE
- CUDI
- ESNet
- INNOVA|RED
- Internet2
- NISN (NASA)
- NLR
- RAAP
- RAGIE
- RAICES
- RAU2
- REACCIUN2
- RedCyT
- RENATA
- REUNA
- RNP
- USLHCNet

#### Middle East & Africa
- ANKABUT
- ARN
- PaINREN
- KENET
- MARWAN
- Qatar Foundation
- SARInet
- TENET
- TERNET
- ANKABUT
- ARN
- PaINREN
- KENET
- MARWAN
- Qatar Foundation
- SARInet
- TENET
- TERNET

#### Asia & Oceania
- AARNet
- AfRENA
- AM NREN
- ASGC
- AzRENA
- BdREN
- CamREN
- CERNET
- CSTNET
- INHERENT/ITB
- AARNet
- AfRENA
- AM NREN
- ASGC
- AzRENA
- BdREN
- CamREN
- CERNET
- CSTNET
- INHERENT/ITB

#### Asia & Oceania (cont.)
- JGN2plus/NICT
- HARNET
- KazRENA
- KOREN/NIA
- KRENA-AKNET
- KREONET2
- LEARN
- MAFFIN
- MYREN
- NKN
- NREN
- PERN2
- PREGINET
- SINET3/NII
- SingAREN
- TANET/NCTU
- TARENA
- ThaiREN/ThaiSAR
- ThaiREN/UniNet
- TuRENA
- VINAREN
- JGN2plus/NICT
- HARNET
- KazRENA
- KOREN/NIA
- KRENA-AKNET
- KREONET2
- LEARN
- MAFFIN
- MYREN
- NKN
- NREN
- PERN2
- PREGINET
- SINET3/NII
- SingAREN
- TANET/NCTU
- TARENA
- ThaiREN/ThaiSAR
- ThaiREN/UniNet
- TuRENA
- VINAREN

#### Asia & Oceania (cont.)
- Japan
- Hong Kong
- Kazakhstan
- Korea
- Kyrgyzstan
- Korea
- Sri Lanka
- Japan
- Malaysia
- India
- Nepal
- Pakistan
- Philippines
- Japan
- Singapore
- Taiwan
- Tajikistan
- Thailand
- Thailand
- Turkmenistan
- Vietnam
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.
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
• 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
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.
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
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 Overview
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).
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.
• 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
Comparison of atomic clock scales cont.

Time difference UTC(TP) – UTC(BEV) measured using optical link (red), via GPS (green) and from BIPM Circular-T (blue). 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 averaging.
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
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 et al. "Transmitting ultra-stable optical signals over public telecommunication networks"

Bypass: bidirectional amplifiers + OADM (+ AOM?)

Station: every 400 km - 600 km

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
**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:
1550.12nm (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 5x10e-15 at 1s averaging
8x10-19 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 146 km

- Dedicated fibre, 920 km, 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 et 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-LPL 1476km 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
Interested in Photonic Services!?

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

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- 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),
- 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

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Thank you for kind attention!

Questions?

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Photonic Services

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Photonic Services

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