Latest news from NEAT-FT, a joint research project of the EMRP

Background

The aim of the project NEAT-FT is to investigate new techniques for time transfer and for phase-coherent frequency transfer, to enable remote comparisons of optical clocks, using optical fibres. Furthermore, the feasibility of a European fibre network connecting optical clocks in Europe will be studied in close collaborations with potential fibre providers.

Scientific and technical objectives

NEAT-FT comprises 4 technical workpackages dedicated to frequency (WP 1 & 2) and time transmission (WP 3 & 4) between remote clocks. About 80% of the JRP's total person month and of the total cost are allotted to these 4 workpackages. WP 5 is dedicated to generate impact by establishing close collaboration with the stakeholders with the aim to foster the decision of funding a future European fibre network or of bi-directional connections of selected points of presence.

Expected results and potential impact

The JRP brings together the long standing expertise of nine leading European National Metrology Institutes (NMI) and CESNET as a representative of National Research and Educational Networks (NREN) to meet the scientific and technical needs for highly stable and accurate reference signals in fundamental physics, GNSS, geodesy, astronomy, and (space-) industry. With the joint activities of the JRP-Partners will provide an alternative to established satellite based T&F methods that allow improvement of clock comparisons at least by one order of magnitude.

Activities and highlights (June 2013 - May 2014)

- NEAT-FT passed the **mid-term review conference** and was ranked by external independent reviewers. The reviewers agreed with the Coordinator's assessment of a dominant technology position and high impact.
- The **first prototype of a Brillouin amplifier module** for high gain amplification (~40 dB) was finalised in December 2013. The field-able module includes a communication unit for remote control. Modules are now being installed and tested along the German part of the fibre link between Paris and Braunschweig.
- The prototype **Remote Laser Station** was tested in field experiments and duplicated four times for the Paris-Braunschweig link.
- A **novel time transfer technique** based on the propagation of a pulse train in fibre- **-** has been developed and tested over a 50 km spooled fibre demonstrating a timing jitter significantly below 1 ps and a timing accuracy of the absolute delay of 160 ps.
- We have focused on **testing of White Rabbit equipment over long distance**. In a 120 day comparison between GPS-PPP time transfer and the 1000-km long link White Rabbit time link in a live DWDM network, the performance and reliability of the fibre link were found to be excellent and the results were limited by the statistics of the GPS–PPP link.
- **Novel techniques for frequency transfer** were developed: frequency transfer via two-way phase comparison on a metropolitan link (47 km) reached sub-10^{-20} resolution; multiple user schemes for optical frequency dissemination were tested, and related schemes proposed for time-dissemination.
- **Two ultra-stable long distance frequency links** have been investigated in-depth: a 1840 km link (Munich-Braunschweig-Munich) and a doubled 640 km link Torino-Firenze. Both links use bi-directional Erbium doped fibre amplifiers with remote control. For the stabilised frequency links, a relative

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frequency accuracy better than 10^{-18} was demonstrated, and phase analysis repeatedly yielded frequency fluctuations below 10^{-18} already within 10 minutes of measurement time. Further long-distance links are currently under development to connect European NMIs, see white lines in figure 1.

- **The national link LIFT** has been extended from INRIM to the Italian-French cross-border at the tunnel of Frejus. The link will be operational by the end of July 2014. This link will support activities within the JRP ITOC by providing the basis for a proof of principle experiment on relativistic geodesy.
- **REG AGH** has built a system for long-distance time and frequency transfer that is now ready for the field experiments at the location of the JRP Partner. Potential localizations of further experiments have been discussed with JRP members.
- **REG UoS** developed a regenerative amplifier for optical frequency transfer based on optical injection locking. Stable optical injection locking over 3 days was achieved by using electronics phase locked loop (PLL). The portable prototype built with 19-inch rack boxes shall be tested at a JRP partner site. Additionally a wavelength converter based on optical frequency comb generator, OFC was developed. The wavelength converter covers a frequency band of 1.2 THz (9.6 nm) with a net gain of 32 dB.
- **REG CNR** investigated Distributed Raman Amplifier, DRA in co- and counter-propagating configuration. A first laboratory experiment was carried out on a dedicated fibre at the premises of JR partner INRIM (Turino, Italy) demonstrating that the DRA does not add extra noise to the optical link, allowing one to bridge very long fibre spans in bidirectional links without the need of intermediate stations.
- **ESRMG IMBiH** received training at NPL on frequency metrology including frequency stability and phase noise concepts as well as on generic and specialized laboratory equipment.

The achievements have been presented at the European Frequency and Time Forum, EFTF 2014, in Neuchatel. http://www.eftf-2014.ch/programme.php.

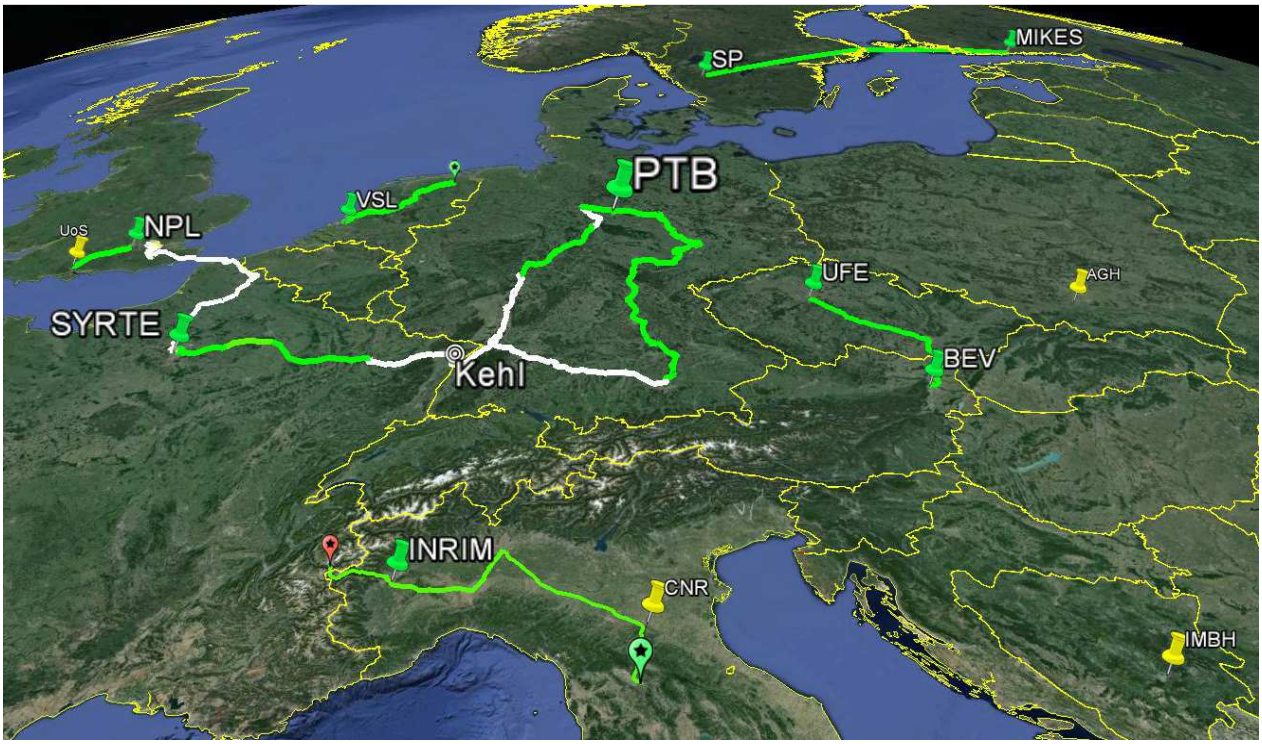

Fig. 1: Existing fibre links (green, in May 2014) and links under development (white). NEAT-FT Partners are indicated by green pins. Yellow pins indicate research excellence grants, REG, collaborating with NEAT-FT

Overall, the project advances quite rapidly. The results of the JRP will help the NMIs to perform better clock comparisons within Europe, and to disseminate highly accurate and stable frequency and timing signals to the user community for groundbreaking science and innovation. Some members of the potential user community are already included in the list of collaborating institutes.

Project Details:

List of publications related to NEAT-FT:

1. S. M. F. Raupach, *et al.*; *"Subhertz-linewidth infrared frequency source with a long-term instability below 5 times 10^{-15}",* Appl. Phys. **B 110**, 465 (2013)
2. S. Droste, *et al.*; *"Optical-Frequency Transfer over a Single-Span 1840 km Fiber Link",* Phys. Rev. Lett. **111**, 110801 (2013)
3. C. Clivati, *et al.; "Distributed Raman optical amplification in phase coherent transfer of optical frequencies",* Photonics Technology Letters, IEEE , **25**, 1711 (2013)
4. C. E. Calosso, *et al.; "Frequency transfer via a two-way optical phase comparison on a multiplexed fiber network",* Opt. Lett. **39**, 1177 (2014)
5. A. Bercy, *et al.; "In-line extraction of an ultra-stable frequency signal over an optical fiber link",* J. Opt. Soc. Am. **B31**, 678, (2014)
6. S. M. F. Raupach and G. Grosche; *"Chirped Frequency Transfer with an accuracy of 10^{-18} and its Application to the Remote Synchronisation of Timescales",* IEEE Transactions on UFFC **61**, 920, (2014)
7. G. Grosche; "Eavesdropping time and frequency: phase noise cancellation along atime-varying path, such as an optical fiber", Opt. Lett. **39**, 2545 (2014)

- **Participants:**

  For contact with members of the consortium see:

  http://www.ptb.de/emrp/neatft_contact.html

- **Advisory board:**

  For contact with the advisory board see:

  http://projects.ptb.de/emrp/1263.html

- **Information about technical work packages:**

  http://projects.ptb.de/emrp/neatft_work.html

- **Information about major achievements:**

  http://www.ptb.de/emrp/neatft_project.html

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JRP start date and duration:	June 2012, 36 month
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