# Publishable JRP Summary Report for JRP SIB02 NEAT-FT Accurate time/frequency comparison and dissemination through optical telecommunication networks

## Background

The aim of the project NEAT-FT is to investigate new techniques for phase-coherent comparison of remotely located optical clocks, separated by distances of up to 1500 km using optical fibre links. Within the scope of the JRP the equipment necessary for reliable operation of fibre links will be developed and all technological steps towards a full optical link infrastructure demonstrated. Beside frequency dissemination, new techniques for time transfer over optical fibre networks will be investigated in order to provide better timing signals than currently available with GPS receivers. For typical spans of up to 100 km the JRP aims to improve the accuracy down to about 100 ps. Furthermore, the feasibility of a European fibre network connecting optical clocks in Europe will be studied in close collaboration with potential fibre providers.

Leading European National Metrology Institutes (NMIs) and one representative (CESNET) from the National Research and Educational Networks (NREN) have joined to meet the scientific and technical needs for highly stable and accurate reference signals in fundamental physics, GNSS, geodesy, astronomy, and (space-) industry.

## Need for the project

The best optical clocks today reach a fractional accuracy of the order of $10^{-17}$ and this outstanding performance makes them ideal tools for various tests of fundamental physics. Moreover, optical clocks have now surpassed the best caesium-based atomic clocks in both accuracy and stability and are the most promising candidates for the expected redefinition of the SI unit of time, the second. However, adequate means to compare distant clocks at the highest level of accuracy are missing. Comparison is a vital issue for optical clocks development and to explore their fundamental limitations. However, as conventional satellite-based techniques do not reach the required performance alternatives must be developed.

There is an increasing demand by scientific organisations and universities for accurate links to NMIs for reference to the SI second. In typical research laboratories, high-resolution optical frequency measurement is limited by the accuracy of commonly-used rubidium clocks, which are referenced to UTC via GPS. In the longer term, it is likely that some of the most advanced applications of future atomic clocks will be space based, and their operation will require ground stations with access to ultra stable frequency references linked to the best available ground clocks. In this respect optical fibre links to such locations will become of central importance. Furthermore, those sites will allow linking the network to other continental networks (USA, Asia, Australia) using relay satellites and optical free space techniques that are being developed today.

## Scientific and technical objectives

The JRP addresses the following scientific and technical objectives:

- Novel techniques for frequency comparisons in the ~$10^{-18}$ range at 1 day measurement time using optical fibres and the necessary equipment such as repeater stations, amplification concepts and remote control systems will be developed.
- “The development of methods, protocols and techniques for accurate time dissemination” and “the consideration of different complementary methods and levels of accuracy reaching from a sub-1 ns level to the sub-µs level” will be carried out.
- “Applications that require or significantly benefit from remote fibre links” will be identified and considered in close collaboration with stakeholders with the aim of fostering the decision of funding a future European fibre network or bi-directional connections of selected points of presence.

### Expected results and potential impact

- An Early Stage Research Mobility Grant was awarded to Institute of Metrology of Bosnia and Herzegovina and started in November 2013.
- A third Researcher Excellence Grant was awarded to Consiglio Nazionale delle Ricerche (CNR), Italy and started in October 2013.

- The Italian project LIFT now connects INRIM in Torino with LENS in Firenze via Milano and the Radio-astronomical Center in Bologna. This link is 640 km long, and benefits from the outcomes of the WP 1 as it uses their improved remote EDFA's, now available as commercial product.
- Close collaboration with the JRP ITOC will allow for a first demonstration of relativistic geodesy between clocks at INRIM and a mobile clock at Modane underground laboratory, once LIFT is extended towards the French border.


Figure 1: Topology of LIFT, the Italian fibre link project.

- Collaboration with the European fibre network GÉANT has been established. Within the GN3plus project a fibre route between London and Paris GÉANT PoPs is now available. The GN3plus project ICOF started October 2013 and has a lifetime of 18 month. PTB, OBSPARIS and NPL with assistance from INRIM will perform comparisons between clocks at NPL and OBSPARIS. For more details see [http://www.geant.net/opencall/Network_Architecture_and_Optical_Projects](http://www.geant.net/opencall/Network_Architecture_and_Optical_Projects)


Figure 2: Fibre route from Paris to London (ICOF) via GÉANT (yellow) currently under development.

- Establishing a fibre connection between Braunschweig and Paris via a cross border link of RENATER and DFN in Kehl is currently one of the activities with highest priority.
- Roll out of the fibres in Germany on the new route has been started and all fibre strechtes from Braunschweig via Frankfurt to Kehl/ Strasbourg and the extension towards MPQ are now available. A first remote Fibre brillouin amplifier, FBA, developed within WP1 was recently installed for testing on this new route.


Figure 3: Novel fibre link between OBSPARIS and PTB. This link (yellow) will allow clock comparisons at the highest level. The extension towards MPQ is shown as blue line.

- Fibres between MPQ and PTB (green line in Fig.2) have been used to extend the link length to almost 2000 km. The relative frequency stability of the link is as low as $10^{-13}$ at one second integration time. It demonstrates the ability to achieve frequency comparisons between remote clocks with very high temporal resolution and accuracy. This considerable achievement was published in Physical Review Letter. This result paves the way towards novel applications of optical clocks in the field of relativistic geodesy.

- Following an advice of the international advisory board IAB the possibility to construct a time link between radio-observatories at Metsähovi and Onsala was investigated. In Finland the only viable way of accomplishing this goal is by using the Precision Timing Protocol White Rabbit, PTP-WR, to link MIKES and Metsähovi. However, the distance exceeds the typical range of PTP-WR and only standard unidirectional telecom channels are available.
- Thus a study on suitability of a standard DWDM network for PTP-WR was initiated by MIKES and a test link of about 1000 km distance between MIKES sites at Espoo and Kajaani has been set-up in close collaboration with the Centre for Scientific Computing Ltd. (CSC) i.e. the Finnish University Network and CERN.
- To our knowledge, this is the first time PTP-WR has been applied to a long haul system. This work is supported by VSL and SP, demonstrating the close collaboration within the JRP. These first steps towards the implementation of the White Rabbit protocol demonstrate the capability to extend the range of WR towards 1 000 km distance.

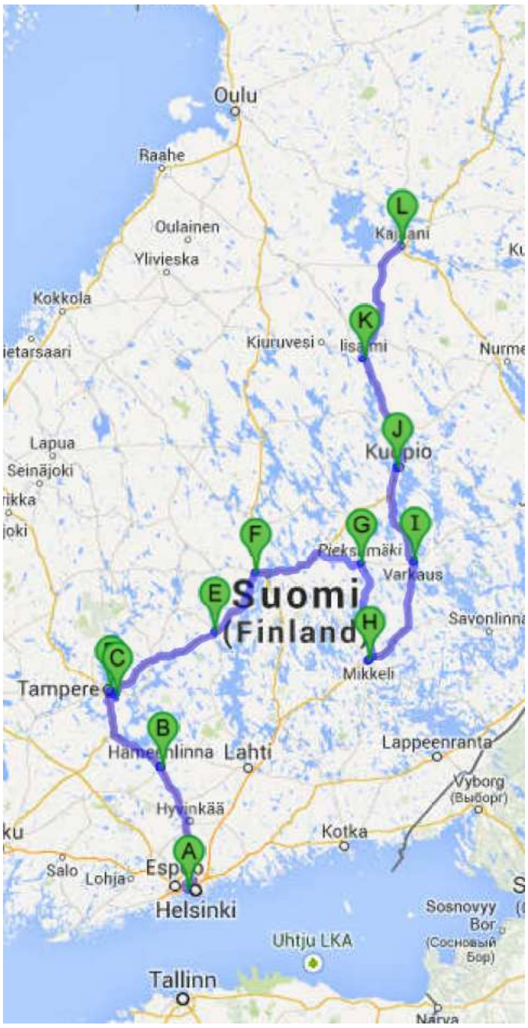


Figure 4: Novel fibre link in Finland between MIKES sites at Espoo and Kajaani for testing long-haul PTP-WR. This activity demonstrates the capability to extend the range of WR towards 1 000 km distance.

The results of the JRP will enable 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 collaborating with the JRP.

| | |
|---|---|
| JRP start date and duration: | June 2012, 36 months |
| JRP-Coordinator:<br>Harald Schnatz, PTB, Tel: ++49 531 592-4300 E-mail: Harald.Schnatz@PTB.de<br>JRP website address: http://www.ptb.de/emrp/neatft_home.html | |
| JRP-Partners:<br>JRP-Partner 1 PTB, Germany<br>JRP-Partner 2 BEV/PTP, Austria<br>JRP-Partner 3 INRIM, Italy<br>JRP-Partner 4 MIKES, Finland<br>JRP-Partner 5 NPL, UK | <br>JRP-Partner 6 OBSPARIS, France<br>JRP-Partner 7 SP, Sweden<br>JRP-Partner 8 UFE, Czech Republic<br>JRP-Partner 9 VSL, Netherlands<br>JRP-Partner 10 CESNET, Czech Republic |
| REG-Researcher 1<br>(associated Home Organisation): | Radan Slavík<br>UoS, United Kingdom |
| REG-Researcher 2<br>(associated Home Organisation): | Łukasz Śliwczyński<br>AHG, Poland |
| REG-Researcher 3<br>(associated Home Organisation): | Gabriele Bolognini<br>Consiglio Nazionale delle Ricerche (CNR), Italy |
| ESRMG-Researcher 1<br>(associated Home Organisation): | Fatima Spahic<br>Institute of Metrology of Bosnia and Herzegovina, Bosnia and Herzegovina |
| | |

***The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union***