Report to the 21th Session of the CCTF

Study Group on Optical Fibre
of the Working Group on Advanced Time and Frequency Transfer
(SGOF - WG AFTF)

Davide Calonico, chair

In April 2015, the Study Group on the Optical Fibre Links for UTC (SGOF) under the CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WG-ATFT) has been created. The SGOF focuses on developments and achievements in the field of frequency and time transfer using optical fibres, aiming at the comparison of atomic clocks, the comparison of timescale, the dissemination of T&F standards and of UTC to users.

The constitution of the SGOF has been on a volunteer basis, and the group is open to further contributions. In July 2015, the Study Group achieved its present composition:
Members: Davide Calonico (INRIM, Chair), Wallin Anders (VTT-MIKES), Albin Czubla (GUM), Zhiheng Jiang (BIPM), Kun Liang (NIM), Lennart Robertsson (BIPM), Harald Schnatz (PTB), Vladimir Smotlacha (CESNET), Wen-Hung Tseng (CHT), Ken Ichi Watabe (AIST)
Other key persons: Felicitas Arias (BIPM), Feng Lei Hong, (NMIJ/AIST, Chair WG AFTF)

The objectives of the Study Group are (i) to make a review of the present status of the various optical fibre links with applications in time and frequency metrology, (ii) to study regulatory issues related to the availability of the services in a national context and the coordination between networks in different countries, (iii) to propose technical directives for operating procedures, formats, including hardware, software and administrative issues, (iv) to propose the appropriate recommendations for consideration of the CCTF and of the CIPM.
To achieve its objective, the SGOF elaborated a list of planned action, in particular:

a) Monitor the availability of new permanent links for UTC;
b) Survey about the data transfer format and the experience achieved so far;
c) Investigation on further structuration of fibre time links;
d) Study of possible mixed solutions with fibre and satellite links;
e) Use of redundant links for UTC;
f) Continuous contact with laboratories developing fibre links;
g) Permanent survey of non-NMI user of fibre links.
h) Proposal of a technical directive for operating procedures, formats, including hardware, software and administrative issues,
i) Study of the regulatory issues related to the availability of the services in a national context and the coordination between networks in different countries
j) Pushing international bodies to facilitate fibre links implementation

Since the CCTF 2015 the SGOF has met once, during the European Frequency and Time Frequency 2016 at York on 7 April 2016, when the Group started the planned activity, also inviting three speakers to illustrate recent achievements on fibre links.

In particular, H. Schnatz (PTB) described the EMPIR project OFTEN, “Optical Frequency Transfer European Network", which is realizing a set of fibre links in Europe connecting NMIs and other scientific laboratories active in radio-astronomy, geodesy, atomic and molecular physics.

Europe is the most active region regarding the development of fibre links. Today, NPL, SYRTE and PTB are connected, whilst SYRTE is completing a connection with INRIM. In Italy, INRIM is developing a backbone through the country, from North to South, that presently connects the main towns up to Rome and seven research institutes in radio-astronomy, atomic and molecular physics. In particular, INRIM demonstrated the first experiment of a coherent fibre link for radioastronomy.

A long haul is present in Finland, exploiting the time transfer over fibre, and between Czech and Austria, whilst also the Netherlands are very active in time transfer.

Poland has developed long hauls, connecting atomic clocks and a radioastronomical facility also. At the SGOF meeting in York Albin Czubla (GUM) illustrated the results from the “Optical fibre UTC link: GUM-AOS - a short characterization and report on 4 years continuous operation”, that indeed is the only example of regular reporting to UTC using fibre links with a relevant amount of data.

Tetsuya Ido (NICT) presented “Past, current, and future activity of the metrological fibre links in Japan”, showing the link activities in Japan, that are very intense and with high quality results, in particular in the Tokyo region, involving NICT, AIST/NMIJ, RIKEN and University of Tokyo. In particular, Japan realized the most accurate comparison among optical clocks and it is very active in the new field of chronometric geodesy, i.e. exploiting remote optical clocks connected by fibre link for the measurement of gravity potential difference. Similar experiments have been carried also in Europe, in Italy, Germany, France and UK. At the SGOF meeting, Gerard Petit (BIPM) presented the new established “Working Group under the auspices of the International Association of Geodesy on Relativistic geodesy: First steps towards a new geodetic technique”, that demonstrates the high interest for the new techniques of chronometric geodesy based on clocks and fibre links.

The group discussed about the scenarios, the possibilities and the issues illustrated within the presentation. The results of the work done so far address the following:

1. The optical fibre link techniques have grown fast, and offer unprecedented performances in term of stability and accuracy, both for time and frequency transfer. Over thousands of kilometres, a coherent fibre link can compare clocks with an instability contribution of few parts in 1e18 in 1000-10000 s, and a contribution to inaccuracy even below 1e-19.
   The number of existing links is increasing, in particular in Europe and Japan, where there are laboratories with accurate clocks at relatively small distances, connected by fibre.
   Also time transfer over fibre reports large advances, with different techniques, that today can offer an inaccuracy at the level of tens-hundreds of picoseconds and relative instability of parts in 1e15 in few hours, or less, depending on the technique.

2. The use of fibre links to report data for UTC is still not widespread, and only one laboratory in Europe is regularly connecting a remote atomic clock to UTC using this technique. For

these reason, presently it is not an issue the discussion of a particular format for reporting data to BIPM, and the usual format (two columns data) is still adequate till there will a group of links to use a common, maybe more elaborate format.
The implementation of fibre links for UTC shall be encouraged and pursued more carefully in the past to take benefit of a widespread optical fibre network.

3. Fibre links comparisons demonstrated to be the only suitable means to compare remote optical frequency standards. More comparisons shall now be realized in order to achieve the identified in the roadmap for the possible redefinition of the SI second, collecting more and more comparison of optical frequency standards with an uncertainty of parts in 1e18.

4. Nonetheless, there is not any project for an intercontinental fibre link. In the next years, the remote intercontinental comparison of optical frequency standard will become an issue. Intercontinental fibre links could be a possibility, but probably the use of advanced satellite/radio techniques shall be investigated and pursued to compare optical frequency standards at the right level of inaccuracy and instability.

5. Now fibre links demonstrated to be beneficial not only for primary metrology and NMI. Different stakeholders started to use optical fibre links to synchronize their equipment and/or to have a traceability to UTC. In particular, few companies for financial market timestamping, radio-astronomical facilities and particle physics facilities (CERN, NIKHEF, KM3NeT, SKA project). The engagement of the time and frequency metrology community with those stakeholders shall be strengthened. Presently, two permanent optical fibre link between NMIs and radio-astronomical facilities have been realized (Poland, Italy) and two permanent fibre link for financial users are present (UK, Italy). This kind of engagement should be pursued and encouraged, also for reciprocal knowledge transfer.

6. Optical fibre links enabled new scientific possibilities, and in particular we report here the demonstration of chronometric geodesy, for the precise measurements of punctual gravity potential differences between remote sites. The use of optical frequency standards and fibre link enables also to measure and monitor the time-variant components of the potential at unprecedented level.

In view of these results, the SGOF does not propose new recommendations, because even if large advances have been achieved, the Recommendation CCTF 6 (2015) is still valid, depicting the needs to be pursued.

Recommendation CCTF 6 (2015):

Development of national and international time and frequency links to improve methods for intercontinental clock comparisons and for dissemination to stakeholders

The Consultative Committee for Time and Frequency (CCTF),

considering

- that some optical frequency standards have already demonstrated fractional uncertainties in the low 10^{-18} and that the reduction in the uncertainty and instability of optical frequency standards developed in institutes around the world will continue,

- that long-distance comparison with optical fibre links has been demonstrated with a stability and uncertainty that is compatible with the best present and future optical frequency standards,

- the need for regular comparisons between these standards as an essential part of the preparation for a redefinition of the second and for other applications such as contributions to time scales, that the stabilities of time and frequency transfer techniques currently and routinely used for comparisons around the world, i.e. for the production of International Atomic Time (TAI), are insufficient for comparisons between the best optical frequency standards,

- the growing interest of the Earth science and geodesy scientific communities for chronometric geodesy, i.e. new applications of optical frequency standards for determining gravitational potential differences and improving Earth gravity models and reference systems with these measurements,

- the growing needs of industry for improving time and frequency capabilities using better transfer methods, in particular in the telecommunication and aerospace sectors.

recommends that

- National metrology institutes (NMIs), optical fibre network providers, space agencies, national governments, regional metrology organizations (RMOs), International Telecommunication Union (ITU) and other relevant bodies:

  - vigorously support research and development of time and frequency transfer techniques matching the stability and uncertainty of the most advanced frequency standards. These techniques may include optical fibre links, advanced satellite microwave links, optical ground to space and space to space links and transportable frequency standards, and advanced space clocks,

  - help secure sustainable infrastructure of selected continental and intercontinental links forming a global time and frequency metrology backbone

for these novel technologies,

- make provisions for these novel technologies to be transferred with the relevant accuracy to other fields of science, industry and society,

• the BIPM participates actively in these developments, notably by making preparations for exploiting, in time scale realization, clock comparison data issued from new time and frequency transfer methods.

• those laboratories contributing to UTC and performing continuous time comparisons via fibre links regularly submit their results to the BIPM Time Department.