The TiFOON Project – Time and Frequency Over Optical Networks

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Abstract

The unprecedented accuracy of modern optical clocks has spurred the development of matching frequency comparison techniques, with optical frequency transfer over fibre emerging as the method of choice. However, the generation and dissemination of the international reference time scale, as well as many applications outside metrology, require reliable and economically sustainable time transfer in addition to frequency transfer capabilities. To address these needs, a new EMPIR-funded project TiFOON – Time and Frequency Over Optical Networks - has been set up with the aim of advancing fibre-based frequency transfer capabilities in Europe towards a universal tool for time and frequency metrology and other demanding applications.

Introduction

Time and frequency measurements underpin a vast number of industrial and everyday applications. The European economy and wider society depend on advanced technologies such as satellite navigation, mobile communications and the energy grid, for which accurate timing is essential. Time and frequency are also the most precisely measurable physical quantities and play an important role in many areas of fundamental and applied research, including geodesy, precision spectroscopy, radio astronomy and tests of Einstein's theory of relativity. However, comparison of clocks and time scales with the required levels of accuracy and stability, and dissemination of time and frequency signals that meet the demanding needs of metrology and research infrastructures, remains a major challenge.

At present, the continuously-operating time and frequency links between National Metrology Institutes (NMIs) and other precise timing centres depend on two satellite-based methods [1]. One employs two-way exchanges of microwave signals between institutes via a geostationary communications satellite, and the other is based on simultaneous reception of signals from Global Navigation Satellite System (GNSS) satellites. However, the best time transfer accuracy that can be achieved using these methods is around 1 nanosecond, and their frequency transfer capability does not support comparisons between optical clocks at the levels of accuracy now being achieved by the clocks themselves.

Fortunately, optical fibre links offer a solution to this problem. In recent years the transfer of time and frequency over fibre has been shown to deliver the best achievable performance, well beyond the capabilities of satellite-based solutions using microwave signals. Fibre links have been established between several European NMIs developing optical clocks, and have been configured to perform optical frequency comparisons between the clocks in support of a future redefinition of the SI second [REFS]. Despite this, the number of institutes connected by these links remains small, the addition of time signals remains difficult, and there are still many obstacles to the establishment of a sustainable Europe-wide fibre network that can satisfy the time and frequency requirements of both research and industry. This paper describes a new European collaborative project, TiFOON (Time and Frequency Over Optical Networks), that was started in June 2019 with the aim of overcoming many of these challenges.

Rationale for the TiFOON Project

Progress in time and frequency is being driven by the development of optical atomic clocks, which offer 2-3 orders of magnitude better performance than the current generation of atomic clocks, and European NMIs and universities are actively engaged in optical clock research [2]. Only optical fibre techniques allow optical clocks to be intercompared at the accuracies achieved by the clocks themselves, and some dedicated fibre links have been established within Europe. However, these links currently support only frequency comparisons, not time transfer, and do not meet the broader requirements of European research organisations and industry for precise time and frequency [3, 4].

The development of both optical clocks and fibre-based comparison techniques has been strongly supported through the European metrology programmes EMRP and EMPIR, including the recent OC18 (Optical Clocks with 1E-18 uncertainty) and OFTEN (Optical Frequency Transfer – a European Network) joint research projects [5, 6]. A complementary activity, CLONETS (Clock Network Services), has been funded by the European Commission through the Horizon 2020 programme to define the requirements for time and frequency dissemination over fibre in Europe and promote the establishment of a sustainable fibre network capable of delivering time services [7].

These projects are ending during 2019, leaving Europe in a world-leading position in these fields, and two new EMPIR projects have been formulated to address some of the remaining challenges. One of these, ROCIT (Robust Optical Clocks in International Timescales), aims to develop optical clocks into reliable systems able to contribute regularly to both local and international time scales [8]. The TiFOON project is complementary to ROCIT, and will address the improvements needed to transform optical fibre links into a robust tool for simultaneous time and frequency comparisons and dissemination across Europe [9].

The TiFOON consortium brings together long-established players in the field, including all European NMIs with existing optical fibre links to each other, and a number of smaller NMIs and external partners contributing specific skills essential to the project. The overall objective of the 3-year project, which started in June 2019, is to transform the existing fibre-based frequency transfer capabilities in Europe into a sustainable, universal tool for both time and frequency metrology, matching the unprecedented accuracy of modern optical clocks and extending beyond the NMIs to meet the needs of end users such as fibre network operators, research infrastructures and industry.

Figure 1: the logos of the institutes, universities and companies participating in the TiFOON project.

Objectives of the project

Within the TiFOON project, a range of research activities are planned that will improve the capabilities of fibre-based methods for time and frequency transfer and demonstrate the benefits they can deliver to European research infrastructures.

The use of international optical fibre links for optical clock frequency comparisons is still far from routine, requiring frequent intervention by experienced staff to maintain operation. An aim of TiFOON is to improve the robustness of the links so that they can operate over extended periods without manual adjustments. Performance-limiting factors will also be identified and addressed, with the aim of matching the expected performance of improved optical clocks in less than one hour of measurement time.

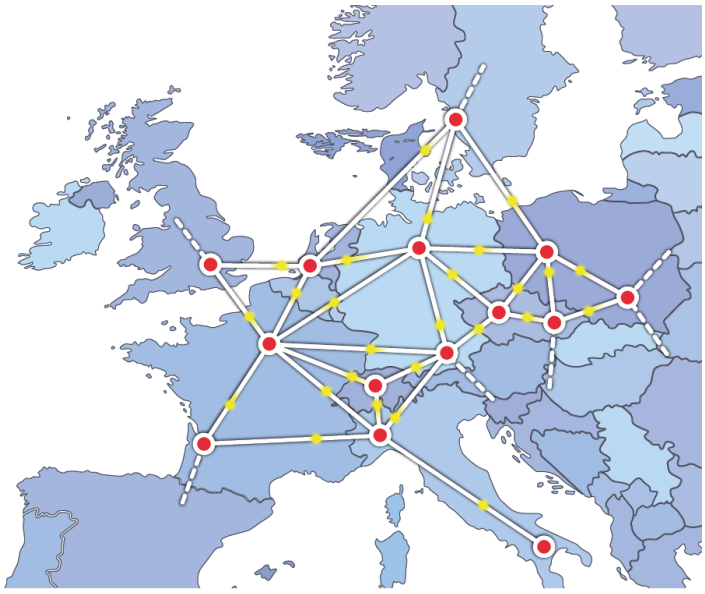

Figure 2: schematic map illustrating the concept of a European optical fibre network connecting the European institutes involved in optical clock development and some other research facilities that require accurate time and frequency.

Access to spectrum on optical fibre links is expensive, and a key objective is to develop methods and equipment for combining optical carrier, radio frequency (RF) and time signals within a single telecommunication channel, or wavelength band. The optical carrier can be used for optical clock frequency comparisons and the RF signal to disseminate standard reference frequencies such as 10 MHz. For each signal type, the target accuracy is better than can be achieved by existing satellite-based methods. Novel concepts of time transfer over fibre with the potential of reaching sub-picosecond accuracy will also be explored.

A related area of investigation is the compatibility of optical time and frequency transfer with simultaneous data traffic in the same fibre. Network operators need to see convincing demonstrations that time and frequency signals do not affect data traffic before they will consider sharing their fibres, and it is equally important to determine the conditions under which time and frequency signals can operate without disruption over communication fibres. Compatibility tests will concentrate on commercial telecommunications equipment deployed in national research and education networks (NREN) and the pan-European network GÉANT.

The NMIs and other institutes developing optical clocks are not the only users of ultra-stable frequency and timing signals. TiFOON is engaging with other European research infrastructures to demonstrate

the benefits of disseminating time, as opposed to pure frequency. In particular, the project will investigate novel applications in geodesy and Earth observation, including essential functionalities for the proper transfer of time between widely spaced geodetic markers.

Conclusion

Long-distance optical fibre links have been demonstrated to support both optical frequency transfer and time transfer with higher accuracies than any other available method. A network of fibre connections between European NMIs and other research institutes is starting to emerge, but much work remains to be done to improve the reliability of the techniques and to enable them to operate through telecommunications networks alongside data traffic.

The TiFOON project will address many of the remaining challenges in developing the technologies needed for reliable and high-performance time and frequency dissemination over optical fibre links. It is another step towards a pan-European fibre network for time and frequency dissemination, and it will help ensure that European businesses and society are the first to benefit from optical timing.

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