Simultaneous Accurate Timing & Frequency Transfer Over 540-km Through A Public Fiber Network

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Motivations

Frequency transfer over fiber has been demonstrated with uncertainties < 10^{-17} on distances of several hundred of km, with dark fiber and dark channel approaches [1-3]. The results are much better than satellite-based frequency comparisons, and open the way to accurate remote clocks comparison [4-8] and advanced tests of fundamental physics [9,10].

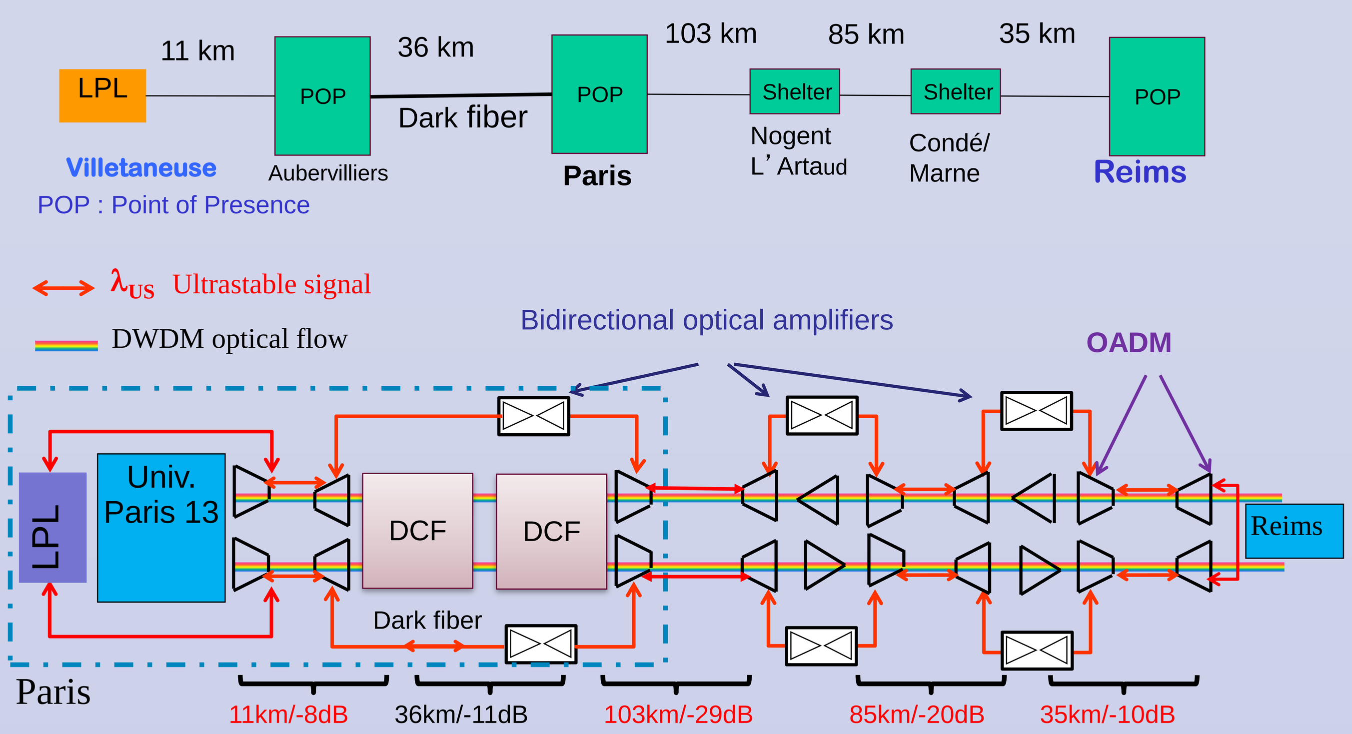
Accurate frequency plays also a key role for geodesy, high resolution radio-astronomy, modern particle physics, and for the underpinning of the accuracy of almost every type of precision measurement. For all these applications, accurate timing is also essential and gives the opportunity to precisely synchronise distant experiments.

Fiber-optical two-way time transfer methods have been demonstrated on dedicated links with an accuracy of the order of a few tens ps to a fraction of a ns [11,12]. Long distance accurate time dissemination is usually based on the signals of the Global Navigation Satellite System (GNSS), or dedicated geostationary satellites, with timing accuracy of the order of 1 ns in the best case [13,14].

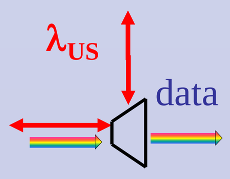
In this work we present a novel method to simultaneously disseminate an ultra-stable optical frequency and accurate timing over a public telecommunication network on a 540 km optical link simultaneously carrying Internet data traffic, using a dedicated "dark" channel.

Link architecture

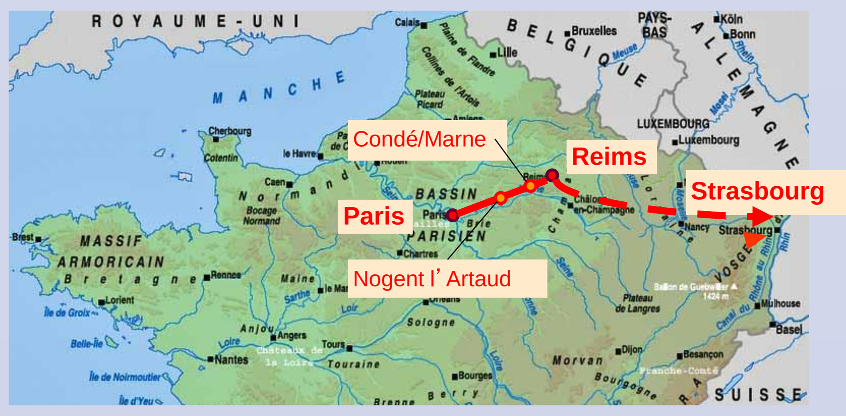
In collaboration with **RENATER** the National Research and Education Network (NREN) in France



- 16 OADMs (optical add drop multiplexer) to add and extract signal (100 GHz filter)
- Bidirectional continuous propagation
- One way attenuation>160 dB , 6 bidirectional EDFA
- (gain~100 dB)



540 km LPL-Reims-LPL optical link

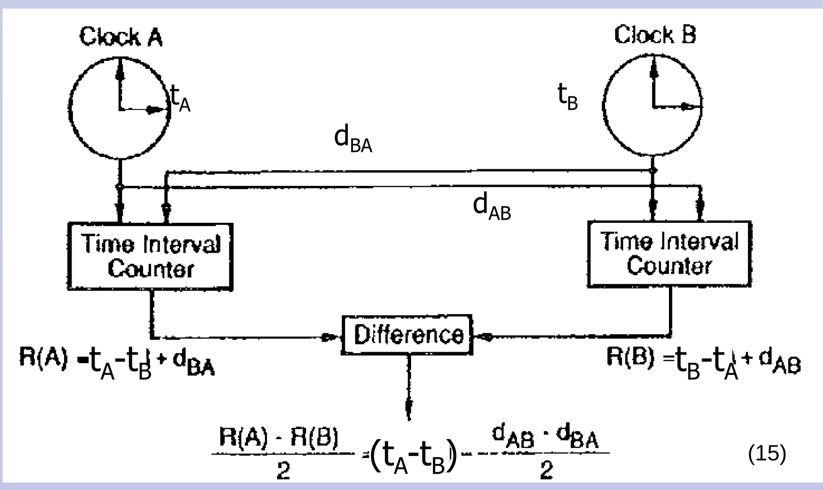


"Dark-channel" Fiber link = public telecommunication fiber with data traffic

Dense Wavelength-Division Multiplexing (DWDM) : Fiber is shared between multiple signals, each of them is attributed a 100 GHz optical frequency range (=channel).

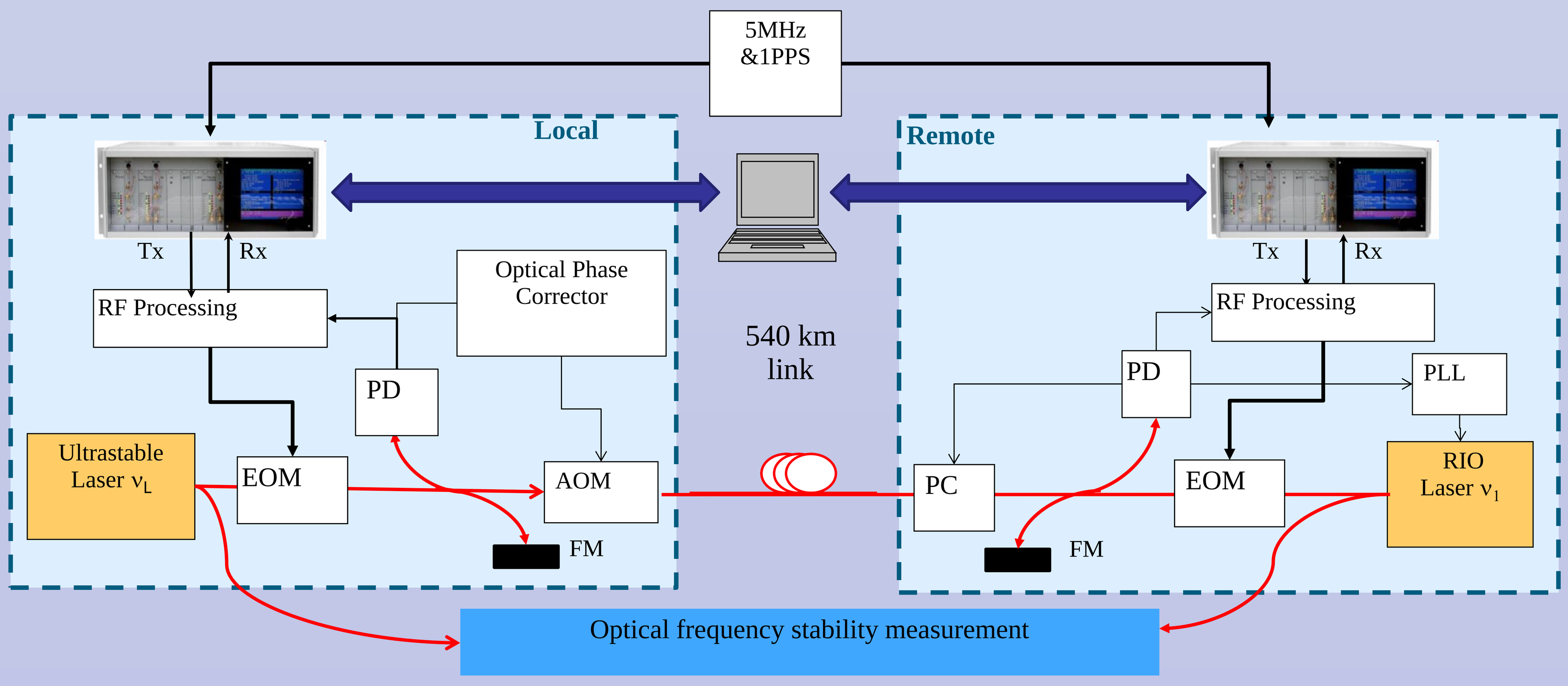
1 channel of the fiber is attributed to time and frequency transfer, channel #44 centered at 1542.14 nm. Other channels are used for data traffic. We use multiplexers (OADM) to extract the metrological signal from the data.

Experimental set-up



Delay $d_{ba}-d_{ab}$ = propagation delay + instrumental delay + Sagnac

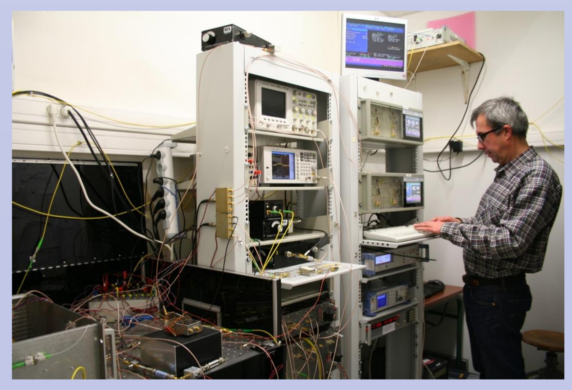
Calibrated/Calc Calibrated Calculated



Frequency transfer with « round-trip » method for fiber noise compensation

Two-way time transfer using Satre modems

Two ends at same place for calibration purpose

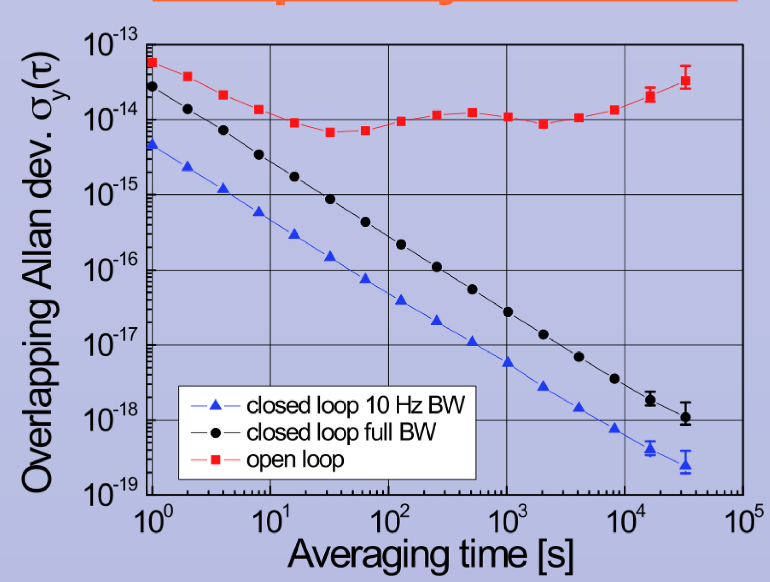


Picture of the experimental set-up.

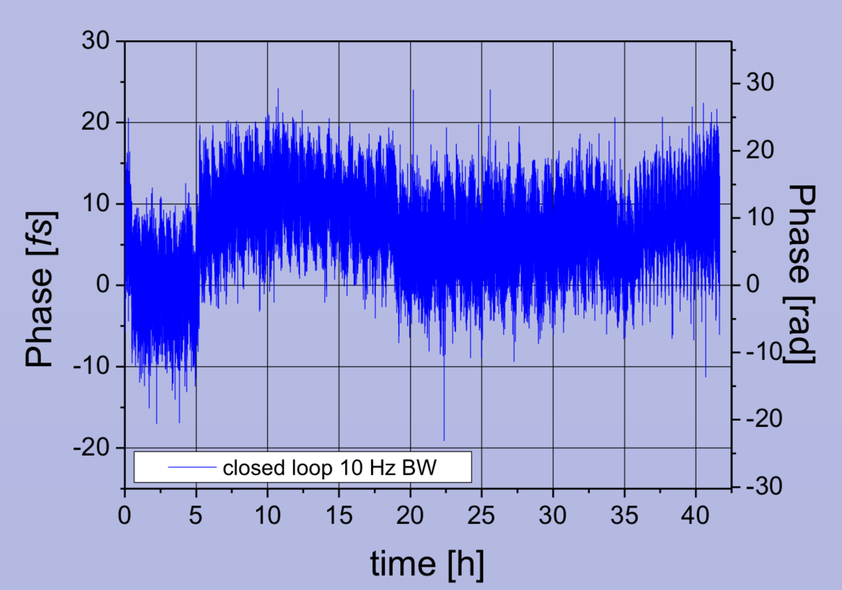
Experimental results

Frequency Transfer (3)

End-to-end stability

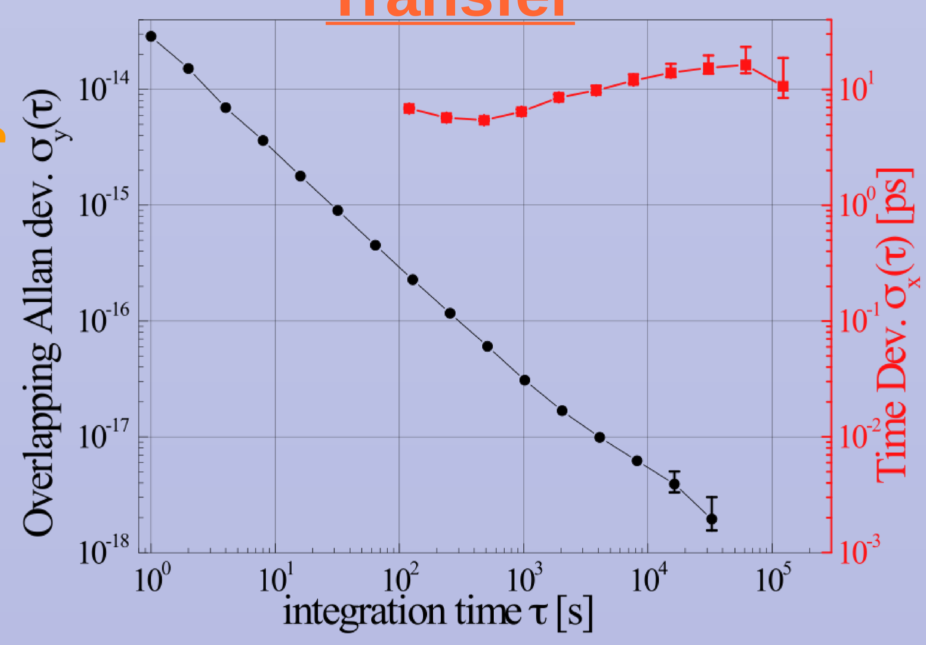


End-to-end phase variation

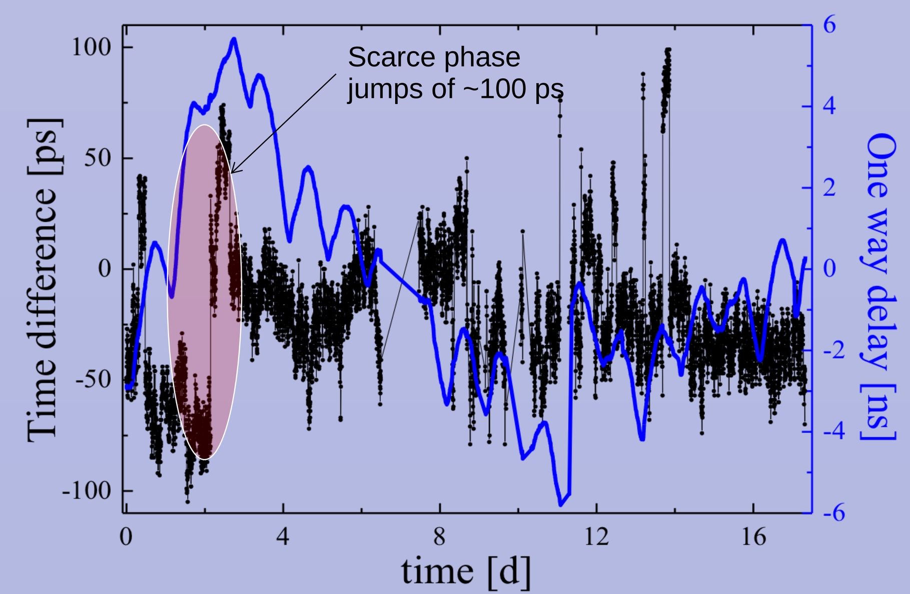


Time & Frequency Transfer (16)

Frequency and time transfer stability



Time delay measurements



- Delay calibration: Link's length was varied from 10 m to 94 km, 400 km and 540 km along the public tele-communication link with fixed overall attenuation (attenuators). The procedure was repeated with 25km, 50km, 75km, 100 km fiber spools.
- Differential delay variation < 50 ps
- Power sensitivity < 15ps/dB
- Fiber chromatic dispersion < 25 ps
- Polarisation mode dispersion (PMD) < 20 ps (network characteristics) < 50 ps (measurement)
- Sagnac = 0

Outlook

Time Transfer Through Optical Fibers is developing very fast. Stability and accuracy already outperforms satellite techniques. Heterodyne detection at links ends enables long-distance time transfer.

Time Transfer Through Optical Fiber has been demonstrated on a 540-km public telecommunication network. Random and scarce phase jumps debase the accuracy of the time transfer. These jumps are difficult to fix, and are maybe due to RF processing or to Satre's modem dysfunction ?

	GPS P3	GPS carrier-phase	GPS PPP	TWSTFT (2-Way Satellite T& F Transfer)	This work
Accuracy (ns)	3	3	3	1	0.25
Stability (@1d, ns)	0.2	0.1	0.08	0.04	0.02

Prospects :

- Future development at the European scale is possible
- Remote clock comparison and calibration
- Test of satellite links (ACES MW, TWSTT or GPS PPP)
- Application to time synchronisation in astrophysics or particle physics

References

1. K. Predehl *et al.*, "A 920-Kilometer optical fiber link for frequency metrology at the 19th decimal place", Science, 336, 441-444. (2012).
2. O. Lopez et al, "Cascaded multiplexed optical link on a telecommunication network for frequency dissemination" Opt. Express 18, 16849-16857 (2010).
3. O. Lopez *et al.*, Ultra-stable long distance optical frequency distribution using the Internet fiber network, Optics Express, Vol. 20 Issue 21, pp.23518-23526 (2012).
4. J. Guena *et al.*, "Progress in atomic fountains at LNE-SYRTE", IEEE Trans. on Ultras., Ferro. and Frequ. Contr., 59, 391-410 (2012).
5. S. Weyers *et al.*, "Distributed cavity phase frequency shifts of the caesium fountain PTB-CSF2", Metrologia, 49, 82 (2012)
6. H. Katori, "Optical lattice clocks and quantum metrology", Nature Photon., 5, 203 (2011) and references therein
7. M. D. Swallows et al. "Suppression of Collisional Shifts in a Strongly Interacting Lattice Clock", Science 331, 1043 (2011).
9. N. Huntemann *et al.*, "High-Accuracy Optical Clock Based on the Octupole Transition in $^{171}Yb^{+}$", Phys. Rev. Lett., 108, 090801, (2012)
10. T C. W. Chou et al "Optical Clocks and Relativity", Science, 329, 1630 – 1633, (2010)
11. D. Piester *et al.*, Remote atomic clock synchronization via satellites and optical fibers"Adv. Radio Sci., 9, 1-7, doi:10.5194/ars-9-1-2011, (2011).
12. P. Krehlik *et al.* **"**Fiber-optic joint time and frequency transfer with active stabilization of the propagation delay**"** IEEE Trans. on Instr. and Meas., DOI 10.1109/TIM.2012.2196396, (2012).
13. A. Bauch, et al. "Comparison between frequency standards in Europe and the USA at the 10^{-15} uncertainty level", Metrologia, 43, 109, (2006).
14. D. Piester *et al.*, "Time transfer with nanosecond accuracy for the realization of International Atomic Time", Metrologia, 45,185, (2008).
15. D.W. Hanson, "Fundamental of 2-way time transfers by satellite", Proceedings of the 43rd Annual Symposium oFrequency Control (1989).
16. O. Lopez *et al.*, "Simultaneous remote transfer of accurate timing and optical frequency over a public fiber network", Appl. Phys. B, october 2012, DOI 10.1007/s00340-012-5241-0

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