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Clock Network Services

Zsófia Heckenast, Jochen Kronjaeger, Leon Lobo

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Summary

Timing is critical to many infrastructures, both directly and indirectly, including telecommunications, positioning, energy and the finance sector. Most of these sectors currently use GNSS services to provide timing, and this service has been shown to have inherent risks due to non-resilience and unreliability, from either natural or man-made causes. Transferring timing and frequency services over fibre optic cabling (Clock Network Services – CLONETS) is a potential solution to this unreliability whilst still providing the required service. Further development will be required on the technical and agreement aspects of sharing fibre, and the infrastructure for this needs to be developed coherently across Europe. A co-ordinated strategy will be developed and implemented to allow for a pan-European network of fibre optics for time services. This document highlights the potential for the system and the need for further work and resource in this area, in order to develop and commercialise time and frequency dissemination over optical fibre.

Context

Today, timing is more important than ever. Many European economies and wider society depend on advanced technologies such as satellite navigation, smart phones and an energy grid that gives uninterrupted power on demand. At their core, these and many other systems are possible through accurate timing and positioning services. From everyday uses such as telling the time on a mobile phone, positioning and location applications, to synchronisation of radio and sending of data in telecommunications, accurate timing is essential.

While time was originally measured against the movement of the Earth, today we measure time against the movement of electrons in atoms, which is more accurate and consistent. Atomic clocks are now so accurate that they have been used as a standard of time for nearly half a century, and a new generation of quantum clocks could be several orders of magnitude more accurate still. These clocks already have a wide range of prospective applications across sectors including finance, transport, telecommunications and energy.

The global navigation satellite system (GNSS) currently provides most timing services, of which the US Global Positioning System (GPS) is one of the more well-known examples. GNSS satellites are equipped with atomic clocks to deliver timing, and services are synchronised around the world using this information. Users with a compatible receiver, such as the receiver in a smartphone, can use the satellite data to determine their position, velocity and precise universal and local time. Accuracy is important for many of these applications. For example, position is determined by trilateration of a set of time signals from three or more separate satellites, and an error of one microsecond in time can lead to a position error of 300m.[1]

GNSS capability underpins much of everyday modern life in the Europe, as in all modern economies. The free-at-point-of-use and global availability features of the civilian open service has driven a growing proliferation of applications and use of GNSS. The various applications are described in more detail below.

Sector-based need and requirements

While a large number of sectors have the need for central and synchronised timing requirements, these differ in the amount of accuracy required.

[1] https://www.thalesgroup.com/en/worldwide/news/atomic-clocks-and-importance-being-time

Telecommunications

Information within telecommunications is sent in packets, often via several different networks, to be recombined at the final destination. These networks need to be operating at exactly the same time for maximum efficiency, and therefore need to be synchronised, with the possibility that data is lost if they are not. In order to minimise data loss, the International Telecommunication Union sets a maximum difference in speed between two networks of 0.025 microseconds.[2] This accuracy of synchronisation is currently only possible through atomic clocks, and is provided through GNSS. Within the telecommunications industry, timing is required for the cellular telephone system at a microsecond level, in Network Time Protocols in milliseconds, in Precise Timing Protocol at sub-microsecond accuracy, while IP based applications like streaming also require timing services.[3]

In addition, traffic demands on mobile networks are expected to increase rapidly with the development of the Internet of Things, as billions of devices and sensors are expected to start connecting to the internet, making timing and synchronisation even more important.[4,5]

The timing requirements will also increase with the advent of 5G. Targets for 5G positioning are to be accurate to <1m, and this could require timing synchronization to between 65 and 250 nanoseconds depending on the application.[6]

Finance

Within the financial sector, increases in the pace of trading and billions of financial transactions per day mean that accurate time-stamping is increasingly important. Three different levels of traceability have been required since 3rd January 2018 in line with the MiFID II directive[7]: 100 microseconds to UTC for high frequency trading, milliseconds for electronic trading and 1 second for voice trading.[8] These standards will become fundamental to prevent several separate transactions from carrying the same timestamp. The timestamps will bring accuracy to the market, preventing market abuse both inadvertently and fraudulently, while helping with the forensics of trading anomalies. The synchronisation of networks and different trading systems will also protect against fraud, for example by ensuring that trades are not anticipating the release of confidential data. While most countries use GNSS timing for this, the UK's National Physical Laboratory has developed NPL*Time®*, a fibre-based service that offers the financial sector a certified time signal, independent of GNSS.[9]

Case Study: NPL*Time®*

The NPL*Time®* commercial service provides a time signal to the end user over optical fibre that is independent of GPS and certified by NPL as being traceable to UTC(NPL) at the end user. The signal is delivered with an accuracy of 1 microsecond to UTC at the end user. With the entire traceability chain to UTC being on fibre, the solution offers a highly resilient alternative to GNSS systems.

[2] https://www.itu.int/rec/T-REC-G.811-199709-I/en
[3] https://www.gps.gov/governance/advisory/meetings/2012-08/powers.pdf
[4] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/564946/gs-16-18-quantum-technologies-report.pdf
[5] http://www.nature.com/news/the-bandwidth-bottleneck-that-is-throttling-the-internet-1.20392
[6] https://www.gov.uk/government/publications/satellite-derived-time-and-position-blackett-review
[7] https://www.fca.org.uk/mifid-ii/1-overview
[8] http://www.npl.co.uk/upload/pdf/time-traceability-for-the-finance-sector-factsheet.pdf
[9] http://www.npl.co.uk/commercial-services/products-and-services/npltime/

Energy

The energy sector is another critical infrastructure that requires accurate timing services. The National Grid is required to be at a ~50Hz system frequency at all times, with real time balancing between supply of energy and demand. Automatic generation and response to shifting demand needs to happen within seconds to ensure that the energy supply remains constant. Phasor Measurement Units (PMUs) help monitor the electrical grid for instabilities, surges and disturbances, taking tens of measurements per second at various locations that need to be time-stamped to evaluate the measurements. These require accuracy to synchronise on the order of 500 *nanoseconds*/0.5 *microseconds* to effectively monitor the grid, and less than 1.7 *microseconds* to identify fault location.[10] In addition, as renewables are representing a growing percentage of the electricity market, and are naturally intermittent resources, the grid will need to respond even faster to increases and decreases in energy production, balanced against demand. Smart grids will mean accurate timing and synchronisation are even more essential to enable a secure, reliable and affordable energy supply.[11]

Science

Fundamental science projects also need accurate timing. Firstly, this is for helping in the development of the next generation of atomic clocks. These are now more accurate than GNSS time, and in order to compare with clocks in other laboratories will need an alternative form of comparison. Signals transported over optical-fibre networks have been demonstrated to be orders of magnitude more accurate than GNSS radio signals, and this accuracy is required to compare the most accurate newly developed optical atomic clocks.[12]

Other aspects of research need accurate clock services, such as tests of fundamental physics. As these currently rely on atomic clocks for accuracy, they can only be performed in 'metrology' laboratories. Accuracy greater than that provided by GNSS is required for this research, and optical fibre links could provide access to accurate timing to a greater number of laboratories for this type of research, thus maximising the resources produced by metrology laboratories.

International collaborations such as the Square Kilometre Array telescope also have highly accurate timing requirements. The array will combine data from a million antennas around the world, and time stamps will be required to allow the effective combination of the data, with relative clock stabilities on the order of 1 part in 10^{12} required.[13]

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[10] https://rntfnd.org/wp-content/uploads/Energy-Sector-V51.pdf
[11] http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1500-08.pdf
[12] CLONETS submission
[13] https://skatelescope.org/signal-processing/

Case Study: Refimeve

This ambitious French project aims to distribute an ultra-stable frequency generated by Observatoire de Paris, the French National Metrological Institute for time and frequency, throughout France to 17 other laboratories.[14,15]

Refimeve uses the national research and education optical fibre network RENATER to transmit clock signals in the form of laser light at a wavelength of 1542nm, compatible with telecommunication fibres. It also involves a number of industrial partners to push forward the commercialisation of specialised equipment to disseminate the clock signals.

Transmission tests on a subsection of the network (round-trip 540 km) have demonstrated an uncertainty of 2×10^{-19}, equivalent to 0.1s in the age of the universe, and more than 1000 times better than GPS. This system will thus give the possibility to compare the next generation of optical atomic clocks whose accuracy is approaching the 10^{-18} level.[16]

This major national research initiative and collaboration of €6.7M[17] is seen as the first step to build a network at the European level, and is closely linked to research carried out within the European Metrology Research Programme, NEAT-FT[18], and its successor under the European Metrology Programme for Innovation and Research, OFTEN.[19]

Current State of Play

Currently there is significant international reliance on GNSS for timing services listed above, which depends on space-borne atomic clocks to provide precise timing signals. However, GNSS is vulnerable to failure and disruption, including through deliberate interference.

Interference could include faulty uploads, deliberate interference due to jamming or spoofing of signals, and solar superstorms, which have the potential to disrupt the entire GNSS system. An interruption of, or inaccurate GNSS timing would impact a large number of infrastructures, including navigation and emergency services. GPS jamming has been carried out by North Korea to disrupt services in South Korea, and malicious use of jamming is a risk with continued GNSS use.[20]

A report by the UK Government Office for Science recommended that the UK should review its critical services dependent on GNSS timing signals, and mitigate the risks by analysing how long they should be capable of operating with back-up or holdover technology.[21] A report building on this work was recently published by the same team, describing the breadth, scale and implications of current reliance on GNSS.[22]

The National Physical Laboratory and the National Cyber Security Centre should support the development of standards for GNSS-resilient timing infrastructure, working with industry, the research community and the relevant standards bodies where appropriate. They should also support the drive for the harmonisation of standards internationally, recognising that in the case of clocks, the applications landscape is complex and involves a number of different standards bodies.

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[14] http://www.refimeve.fr/index.php/en/presentation-eng/description-of-the-project.html
[15] https://www.renater.fr/IMG/pdf/RAPPORT_RENATER_2012_Anglais.pdf
[16] https://phys.org/news/2016-02-accurate-optical-single-ion-clock-worldwide.html
[17] https://www.univ-paris13.fr/refimeve/
[18] https://www.ptb.de/emrp/neatft_home.html
[19] https://www.ptb.de/emrp/often_home.html
[20] http://www.bbc.co.uk/news/world-asia-35940542
[21] https://www.gov.uk/government/publications/quantum-technologies-blackett-review
[22] [22] https://www.gov.uk/government/publications/satellite-derived-time-and-position-blackett-review

A subsequent report by London Economics on behalf of Innovate UK and the UK Space Agency assessed the overall economic impact on the UK of disruption to GNSS, reported to be at £5.2bn for 5 days of disruption - over £1bn loss per day.[23] The biggest sectors estimated to be impacted were Road, Maritime and Emergency services, while a number of other sectors indicated resilience and sufficient holdover measures to last for 5 days, such as financial services and telecommunications sectors. However, as GNSS signals can be faked as well as disrupted, this study does not provide an exhaustive list of impacts.

The US Department of Homeland Security has also commissioned a number of reviews into the impact of GPS disruption, and found that 11 or their 16 critical infrastructure sectors were critically dependent on GPS for timing.[24,25] A report by NDP Consulting found that the direct economic benefits of GPS technology on commercial GPS users in the US was estimated to be over $67 billion per year, while 3.3 million jobs in the US rely on GPS technology. A full GPS disruption was therefore estimated to cost commercial GPS users $87.2 billion per year, reducing productivity and hindering competitiveness.[26]

An alternative system therefore needs to be found to provide the various parts of the GNSS service. The proposal is for time and frequency (T&F) to be disseminated through fibre optics-based terrestrial systems. These systems cannot be as easily tampered with, and would provide a timing back-up to GNSS, while at the same time provide sufficient levels of accuracy and enable further development of optical clocks.

Fibre optics based ‘clock’ network services (CLONETS) provided over optical fibre networks, such as NPL*Time®* or Refimeve[27], would change the status quo of how time and frequency are currently disseminated in Europe, providing more accurate, GNSS-independent services. As this network would not face the same vulnerabilities as GNSS, it would provide a resilient service, serving as a backup or even primary reference for sectors such as finance, energy and telecommunications and other infrastructures still using GNSS for T&F. The service could also be used to compare optical clocks, help define UTC, and answer the needs of the research community, both in metrology and in other areas of research.

In addition to clock network services, a number of other options also exist for GNSS-independent T&F services. These include the enhanced LOng-RAnge Navigation (eLoran) system, using ground-based radio navigation to provide location and timing services. While the signals are regional, with a range of 800 miles, the signals are less susceptible to jamming as the signal is over a million times stronger than GPS signals.[28] However the stability and accuracy of eLoran is comparable to GPS at best[29] and it therefore will not satisfy the need for higher precision time and frequency distribution and will not be adequate for comparing or disseminating optical frequency standards.

Other options include mobile quantum clocks, which could provide high accuracy synchronisation and accuracy, but at the cost of only intermittent comparison.

Holdover clocks are also a possibility for many applications that use GNSS, where local clocks would be able to provide a back-up function for a limited amount of time until GNSS or current timing services are again

[23]https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/619545/17.3254_Economic_impact_to_UK_of_a_disruption_to_GNSS_-_Showcase_Report.pdf
[24] http://gpsworld.com/innovation-enhanced-loran/
[25] https://rntfnd.org/wp-content/uploads/2013/09/GPS-Timing-Criticality-Volpe-Paper-2008.pdf
[26] http://www.gpsalliance.org/docs/GPS_Report_June_21_2011.pdf
[27] http://www.refimeve.fr/index.php/en/presentation-eng/description-of-the-project.html
[28] http://gpsworld.com/innovation-enhanced-loran/
[29] http://gpsworld.com/innovation-enhanced-loran/, Linn Roth et al., “Enhanced or eLoran for time and frequency applications”, Proceedings of the IEEE International Frequency Control Symposium and Exposition 2005

functioning. However, field-deployable clocks suitable for commercial use tend to compromise on stability and accuracy in return for compactness and robustness. Depending on the required stability and accuracy, it may also be more cost effective to remotely disseminate rather than physically deploy a high-performance standard.

Challenges for fibre-based T&F dissemination

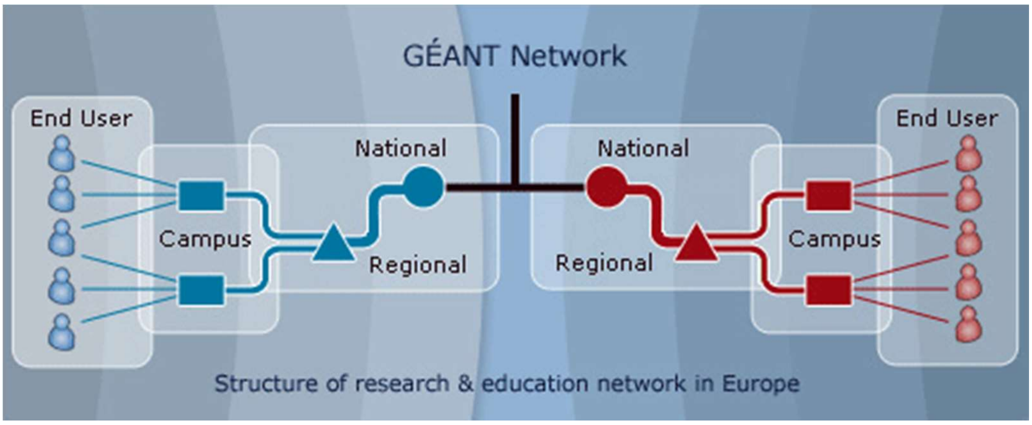
Current dissemination of UTC time is from UTC-accredited labs and other local sources such as caesium clocks. It can be distributed through GNSS, in the UK through the radio signals in the MSF time service, and through fibre. There are however a number of challenges associated with the dissemination of time through optical fibres, which would need to be addressed as part of the continued work in this area.

Technical Challenges

The technology for lower-performance time and frequency dissemination, such as NPL*Time®* has been developed and is commercial, providing timing services sufficient for the financial market. However, this service is several orders of magnitude less precise than the service required for high performance systems such as optical atomic clock comparisons. Equipment for higher performance systems such as optical carrier transfer is currently at Technology Readiness Level[30] 5-7 and is only starting to be commercialised. Lab and field trials have demonstrated the capability for outstanding performance. The main technical challenges are in improving the reliability and manageability of the equipment.

One key challenge is that standard internet connectivity (“bandwidth”) cannot be used to transmit high performance T&F services. Top performing services require physical (“photonic level”) access to the fibre, and even moderately-performing services conforming to internet standards, such as NPL*Time®*, rely on compatible equipment to be installed everywhere along a link. Sharing of optical fibre between T&F services and regular data is possible through spectrum sharing. However this can only be realised in close cooperation with the fibre operator, and often requires physical changes that need to be taken into account at the planning stage of a new data link.

National Research and Education Networks (NRENs) have been established across the world, providing ultra high-speed internet as well as innovative, non-standard services, exclusively for research and education needs. This allows researchers to collaborate across communities on a huge range of different projects. The Gigabit European Academic Network (GÉANT) provides the pan-European backbone for these collaborations.



[30] https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Illustration of cross-domain supply chain of data communications in GÉANT[31]

The CLONETS programme advocates a partnerships of NMIs and NRENs to create a cost-effective T&F fibre network based on spectrum sharing. NRENs are expected to be more amenable to innovative uses of fibre than commercial operators, and a number of European NRENs already have gathered experience sharing their network with T&F services. The Refimeve project above uses the French network RENATER for dissemination, and both the Polish and Czech networks have extensive experience with radio frequency-based T&F services.

Commercial Challenges

While national measurement laboratories own and provide initial timing services, they partner with telecommunication companies to provide the commercial service. This can be problematic due to the strict service level agreements that would exist between the laboratory and the telecom company – break–off and hand-off points would exist, where the management of timing passes from the laboratory to the telecom company, thus breaking the confidence chain needed for many accurate timing applications. NPL*Time®* has a unique agreement that works around this issue, by partnering with a network but maintaining control of timing all the way to the end user.

The existence of these agreements does however also provide a strong advantage to having timing services provided through fibre as opposed to GNSS. While GNSS is free and simple to access, companies accessing and using the service do not have individual service level agreements, and do not have any guarantees of accuracy, availability and resilience.

Outcomes

A number of benefits would be generated from the implementation of the CLONETS infrastructure.

Firstly, an entirely independent infrastructure would be put in place, providing resilience in comparison to GNSS for critical national infrastructures. Instead of providing calibration for devices, the system would provide direct dissemination of industry standards from the point of origin to the point of use, with in-situ calibration from the national standard.

This would enable new research and development, both in the development of atomic clocks but also other areas of science such as satellite data and earth observation, and would provide benefits directly in the form of jobs created and also in the form of economic impact.

Further research and development is needed to commercialise the technical requirements for dissemination on optical fibre between measurement laboratories, national research and education networks and telecommunication companies who currently own the fibre network.

By using more accurate timing, we would have better correlation of data over geographically distributed systems, thus enabling more collaborative research across nations.

Economic Impacts

The estimated economic impact has been reviewed by taking into consideration current markets in GNSS, telecommunications and energy.

Looking at the GNSS market, European companies, if boosted with a new dissemination and synchronization service via optical fibre, would be able to take a technological advantage over worldwide competition.

The total budget for the core GPS program of the US in Fiscal Year 2012, including both military

[31] https://geant3plus.archive.geant.net/Network/Research-and-Education-Networks/Pages/Home.aspx

and civil funding, was over USD 1.5 billion. The European GNSS Agency (GSA) expects the market for GNSS to grow by about 11 % p.a. over the next decade. This report estimates that about 3.6 billion devices were in use around the globe in 2014, and by 2019 this is expected to increase to 7 billion devices, giving on average one device per person on the planet. Globally enabled GNSS markets are forecasted to grow to approximately EUR 250 billion per annum by 2022, with core revenues expected to reach EUR 100 billion in 2019.

The telecommunications market is also expected to grow in the next decade from a current USD 46.7 billion market; while the smart electrical grid market also has a bright outlook, expected to surpass USD 400 billion by 2020.

The proposed CLONETS infrastructure will stimulate European industry in various ways. Firstly, Europe will get larger market shares in the development of network-grade commercial devices for T&F transfer. Secondly, the reliable T&F fibre infrastructure would secure infrastructure vital to industry in general (power grids, telecommunications). Thirdly, it will enable new products and services (and thus new industries) in, for example, local GNSS-augmentation systems. Taking on even a fraction of the T&F requirements of these markets would provide returns in the millions, and if using technologies over optical fibre links could increase the European share by only 1%, Europe could expect to gain EUR 6000 million by 2022.[32]

In addition to the expected market benefits, the economic impact of such timing infrastructure would be seen in terms of the mitigation against potential losses caused by interrupted GNSS, which for the UK alone is estimated to be around £5.2 billion in losses over 5 days.[33]

Costs and RISKS

Costs

Current costs for a potential clock services network can only be estimated from existing infrastructures.

The NPL*Time®* service and associated technology is unsuited for higher performance applications. For these, the current London to Paris connection is leased at c.£100k/ year from a commercial service provider, and this cost can be expected to increase significantly with the planned inclusion of major NRENs, all major National Measurement Institutes in Europe and in the long term commercial customers.

As highlighted above, it is not possible to use standard internet, and it is uneconomical in the long run to lease fibres from other commercial providers.

A European-wide collaboration with the NRENs is considered the only viable system to enable time dissemination over optical fibre, and the exact mechanisms and technical details for large-scale sharing of this system need to be developed, and are in fact part of the CLONETS preparatory work.

Risks

A number of risks are present in this proposal to set up a pan-European network of long distance optical fibre links. Currently used fibre links for telecommunications cannot be used for timing services, and dark fibre networks are required.

[32] CLONETS report
[33] https://londoneconomics.co.uk/blog/publication/economic-impact-uk-disruption-gnss/

Supply Chain Development: There is a risk around the readiness of a supply chain for this infrastructure, as there is currently no form of competition in the provision of systems or infrastructure for this type of work. In the UK, JANET provides 8,500 km of optical fibre connection, but only between a limited number of academic communities.[34] In Europe, GÉANT provides a similar service for over 50 million users, connected across multiple countries in Europe.[35] While connecting users across fibre, this network does not currently provide T&F services, and implementing this service would involve leasing sections at an unsustainable cost, with potentially a separate network required.

Cyber Threats: While fibre networks are more difficult to disrupt that GNSS signals, there are still threats to cyber security at the many points of contact on the network. These will need to be regulated and secure, to ensure that the raw signals are not disrupted. Part of the work to prepare an infrastructure would need to involve reviewing the security of the service.

Fibre can be manipulated and tapped at contact points, although disruption and interference of this sort is much easier to detect than for GNSS because of the 'closed circuit' aspect of the system. Fibres can also be destroyed or cut, which can have a wide-spread impact on a very large number of users. However the advantage of fibre over GNSS in terms of cyber security is that interference will be relatively easy to detect compared to local GNSS disruptions, through time-of-flight measurements.

Holdover devices would need to be in place at intermediate points in the system, and these would be able to provide cover for several weeks, although most service level agreements would guarantee a one-day recovery.

Conclusions and future work

- Timing service requirements are widespread throughout many infrastructures, and there is a huge potential impact if GNSS, currently providing that service, proves unreliable or vulnerable.
- The dissemination of T&F over optical fibre has been suggested as one option to provide a back-up service to GNSS, while also serving the needs of the research community.
- The CLONETS project aims to: *Support the development of a pan-European optical fibre network for time and frequency dissemination, connecting key metrology institutes, national research and education networks, key industry players and financial institutions, to sources of highly accurate, synchronised and calibrated time.*
- This network would support the above mentioned research facilities in the further development of atomic clocks and fundamental physics research, and would in addition provide support to a multitude of lower-performance time services, such as the telecommunications industry and the financial sectors. It would alleviate our reliance on GNSS for timing, and could insure against losses on the order of billions if GNSS was disrupted.
- Challenges exist to develop the technology and to commercialise this at the highest performance requirements, and further resource will be required to enable this transition.

[34] https://www.jisc.ac.uk/janet
[35] https://www.geant.org/Networks/Pan-European_network/Pages/GEANT_topology_map.aspx