NPL*Time*® - *certified time for the financial sector*

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A proof-of-concept trial was conducted by NPL and ICE to implement and validate the NPL*Time*® *'trusted time' service. This resilient, UTC traceable service provides a time signal to the end user that is independent of GPS and certified by the National Physical Laboratory (NPL) as being traceable to UTC(NPL) at the end user. The offset of the signal from UTC(NPL) and its stability have been measured. The solution was proven to be capable of achieving 100 nanosecond synchronisation to UTC(NPL).*

Introduction

Precision timekeeping underpins the modern world. Applications from telecommunications to satellite navigation, surveying and transport systems are underpinned by precise timing, and to enable these systems to operate correctly the same stable and accurate reference time scale must be in use everywhere.

There is no single master clock for the world – the consequences of it failing would be far too severe. Instead, the international time reference is maintained by 70 time laboratories around the world and is based on the average of some 400 atomic clocks. That diversity provides both resilience (the loss of a single clock or even a national time laboratory would have little effect) and accessibility (each major industrial nation contributes to the timescale, and hence has direct access to atomic time). The international time scale is processed in monthly blocks by the International Bureau of Weights and Measures (BIPM), located in Paris, and is named Coordinated Universal Time, or UTC. One consequence of this procedure is that UTC only exists as a 'paper' time scale, and the only direct physical representations of UTC are the time scales operated by the contributing laboratories.

As the United Kingdom's National Measurement Institute, the National Physical Laboratory (NPL) in Teddington, south-west London, is the only precision timing centre in the UK and fulfils a vital role by maintaining the national time scale, known as UTC(NPL).

Intercontinental Exchange (ICE), NPL's partner in the proof-of-concept (POC), is a network of regulated exchanges and clearing houses for financial and commodity markets, including the New York Stock Exchange and ICE Futures.

NPL and Time Dissemination

The group of atomic clocks at NPL keeps the nation's time accurate to within a few nanoseconds (billionths of a second) of UTC, providing a firm basis for precision time measurement across all sectors of business and industry in the UK.

To maintain close alignment between UTC(NPL) and UTC, NPL operates primary frequency standards. These are caesium fountains, providing the UK with a realisation of the SI (International System of Units) second at the highest level of accuracy. The primary frequency standard in operation at the end of 2014, NPL-CsF2, achieves an accuracy equivalent to 1 second in 158 million years. The primary frequency standards contribute to UTC formulation and UTC(NPL) by ensuring the 'second' durations within the time scales correspond as closely as possible to 9,192,631,770 cycles of the hyperfine transition in caesium-133 atoms that defines the SI second.

NPL is also developing the next generation of optical atomic clocks that will be accurate and stable to 1 second in 14 billion years, the lifetime of the Universe.

All precise time measurements should be traceable back to UTC, whether through UTC(NPL) or some other realisation, and accurate time-stamping relies on continuing synchronisation to a reference time source. If the synchronisation to that source is lost, a local clock can provide 'holdover' for a short period, dependent on the quality of the clock and the required synchronisation accuracy. However, even the best clocks will eventually drift out of the required range.

Apart from managing the UK's timescale and contributing to UTC formulation, NPL actively disseminates UTC(NPL) to the nation, and has been doing so for several decades. Its MSF 60 kHz radio time signal was broadcast from Rugby Radio Station until 2007, and subsequently from Anthorn in Cumbria. This signal plays a key role in synchronising clocks across the UK and into continental Europe to within 10 milliseconds of UTC. NPL also provides a dial-in time service and an NTP (Network Time Protocol) service over the internet, both capable of synchronising computers to typically 10 millisecond accuracy. In addition to these methods for time dissemination, NPL operates GPS common-view links with a small number of customers, and performs more specialised GPS comparisons and Two-Way Satellite Time and Frequency Transfer (TWSTFT) with other national measurement institutes.

Proof Of Concept Methodology

NPL operates a time dissemination link over dark fibre infrastructure from Teddington in south-west London to a hub in Telehouse North, in London's Docklands. The NPL*Time*® demonstrator system set up at ICE was linked to NPL by dedicated fibres via the hub in Telehouse North, providing a direct time feed from NPL to ICE that was independent of GPS and resilient to GPS interference such as jamming and hijacking. Under the full NPL*Time*® service, the time feed would be monitored and certified by NPL. A schematic diagram of the POC is shown in figure 1.

NPL and atomic timekeeping

In 1955 the first atomic clock that was much more regular than the Earth itself, or any other type of clock then in existence, was brought into operation at the National Physical Laboratory. Constructed by Louis Essen and Jack Parry, it was based on measurements of a particular resonance of the caesium-133 atom.

Over the next few years the frequency (or rate) of the NPL caesium clock was compared with the duration of the astronomical second determined by the United States Naval Observatory. As a result of this work, in 1967 the second in the International System of units of measurement (SI) was redefined as the duration of 9 192 631 770 periods of that particular resonance of the caesium-133 atom.

The fibre link between NPL and Telehouse North is a 74-kilometre dedicated dark fibre pair. The trial employed ICE-owned DWDM equipment operating over approximately 80 kilometres of dark fibre between Telehouse East and ICE, while the link between Telehouse North and Telehouse East was provided by around 300 metres of patch fibres.

The demonstrator system utilises equipment, supplied by Meinberg GmbH, that conforms to the Precision Time Protocol (PTP) version 2 standard. This protocol, also known as IEEE1588-2008, is a packet-based time transfer method that continuously measures round-trip latency in order to synchronise devices on a network. The system comprises a PTP grandmaster (GM) clock at NPL and a server at Telehouse North synchronised as a client to the NPL GM and in turn acting as a GM to downstream clients, in a similar way to a PTP boundary clock.

The grandmaster at NPL was fed with a 1 pulse-per-second (1PPS) signal from UTC(NPL), and synchronised the PTP client at Telehouse North over the dedicated fibre link. During the POC, the synchronisation quality of the client was determined by comparing it with a transportable caesium clock. The clock was first measured against UTC(NPL) while located at NPL. It was then taken to Telehouse North under power, and the time offset between its 1PPS output and the 1PPS signal generated by the client was measured using a time interval counter (a Stanford model SR620). Finally, the clock was returned to NPL and again compared with UTC(NPL) to determine its drift during the measurement period.

In the second phase of the trial, a similar measurement using a transportable caesium clock was carried out at ICE, to investigate the stability of the PTP client synchronised over an installed DWDM fibre link. Since it was not possible to leave the clock at ICE for an extended period, a longer data set was obtained by comparison with a 1PPS signal derived from a GPS receiver at ICE.

No NPL*Time*® customers were involved directly in the proof-of-concept (POC); it was purely a technical exercise. However, the POC does effectively demonstrate a typical customer experience.

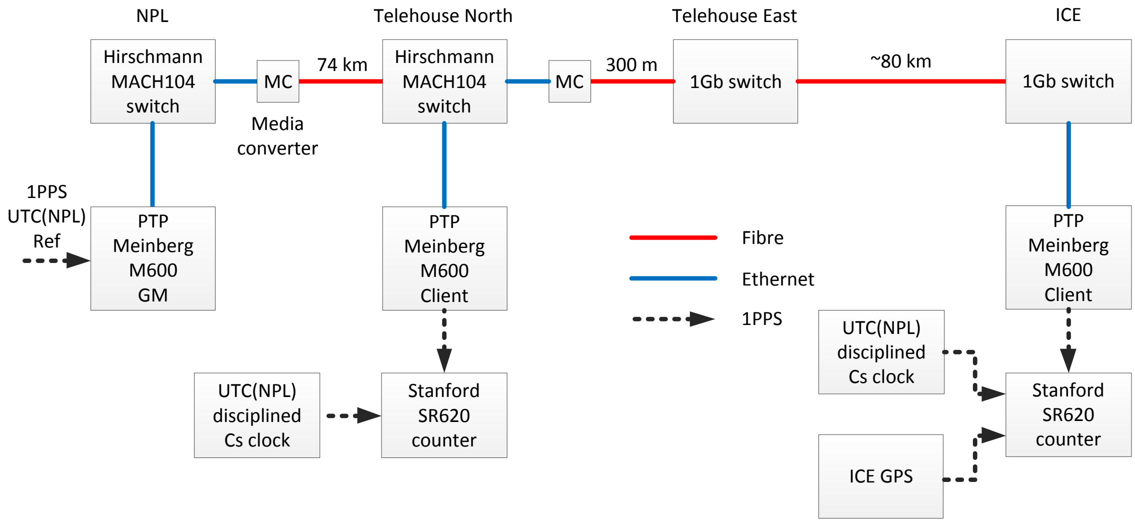

Figure 1: NPL*Time*® delivery method used in the POC.

Results

A schematic diagram of the trial is shown in figure 1. Clock measurements were carried out first at Telehouse North, and the measurements at ICE were performed some weeks later. In each case, the measurements collected from the time interval counter have been analysed to determine the PTP client stability over the short term (jitter) and long term (drift). The time offset from UTC(NPL) of the PTP client at Telehouse North was also determined.

Time offset from UTC(NPL) of the NPL*Time*® *signal at Telehouse North*

The time offset from UTC(NPL) of the 1PPS output from the NPL*Time*® unit, a Meinberg M600, was measured using the transportable caesium clock and was initially found to be approximately 180 ns. This difference arose from different outward and return delays in the fibre link and asymmetries in the PTP equipment, and was removed by programming the appropriate correction into the PTP client.

Stability of NPL*Time*® *at Telehouse North*

The 1PPS output signal from the NPL*Time*® unit, synchronised to NPL over the fibre link, was measured over 12 days against a 1PPS signal from the transportable caesium clock, again using an SR620 time interval counter. The results are shown in figure 2. The linear drift of the caesium clock during the 12 day period has been removed from the plot, and the residual slow drift can also be attributed largely (possibly entirely) to the clock. The mean offset from UTC(NPL) of around 180 ns was later removed by the calibration procedure. The short-term fluctuations of around 20 ns peak to peak result from the PTP disciplining process.

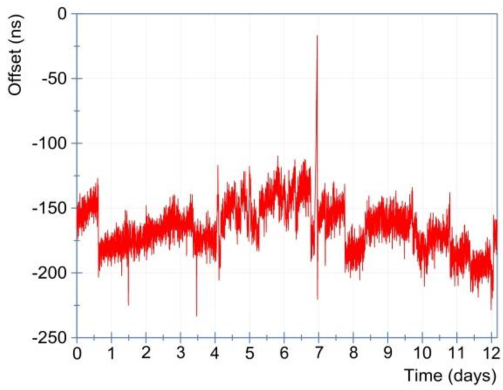

Figure 2: Time offset between 1PPS signals from the UTC(NPL)-disciplined caesium clock and the NPL*Time*® client, measured over 12 days.

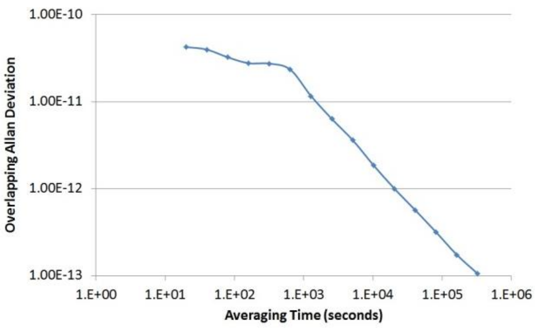

Figure 3: NPL*Time*® Allan deviation (instability vs averaging time) as measured against the UTC(NPL)-disciplined caesium clock.

A stability plot of the results, computed as an overlapping Allan deviation, is shown in Figure 3. Over several days the instability of the NPL*Time*® signal is of the order of 10 ns. Figure 4 shows that the signal jitter, or variation in the time interval between adjacent 1 second pulses, is 200 picoseconds.

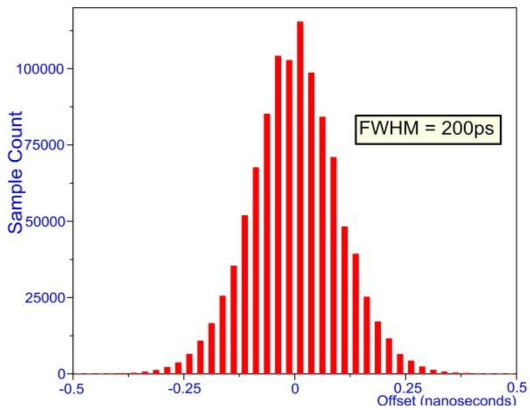

Figure 4: Pulse to pulse (1 second) jitter characteristics of the NPL*Time*® signal, measured over 12 days.

Stability of NPL*Time*® *at ICE*

The stability of the signal measured at ICE against a GPS-disciplined oscillator, with the mean offset removed, is shown in Figure 5. There is no discernible long-term drift in the time signal over the 15 days. The short-term stability is slightly poorer than was observed at Telehouse North due to the additional contributions introduced by the extra 80 km of fibre and the DWDM equipment.

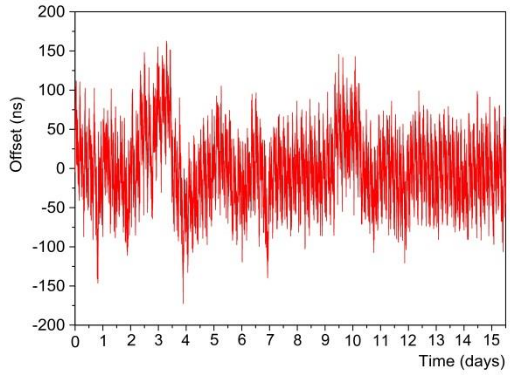

Figure 5: Time difference between the 1PPS signals from the PTP client and the ICE GPS receiver, measured over 15 days. The mean offset has been removed.

Accuracy and Traceability

NPL*Time*® is traceable to UTC via UTC(NPL). The traceability chain provides an unbroken sequence of comparisons to a reference (in this case UTC), together with the uncertainty in each link. The accuracy of the NPL*Time*® signal is a measure of its offset from UTC, while the uncertainty is a measure of how well that offset is known.

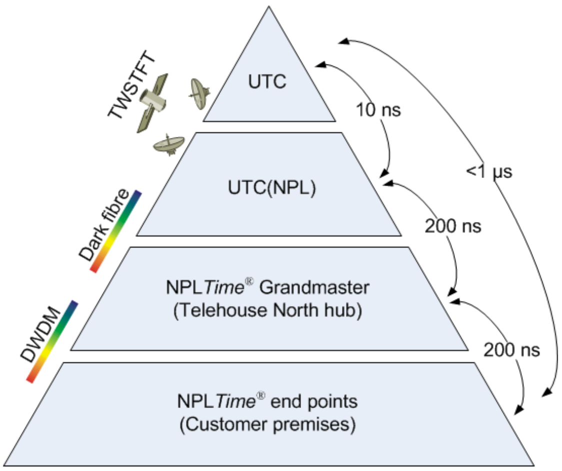

Figure 6: Traceability pyramid relating UTC to the NPL*Time*® end points, with the link accuracies indicated on the right. The link from UTC(NPL), the real-time implementation of UTC, to the customer demarcation point is entirely over optical fibre and does not include GPS.

Figure 6 shows the unbroken traceability chain to UTC. At the end points on the NPL*Time*® network, the signals from the NPL*Time*® units at the demarcation points are certified to be traceable to UTC with an accuracy of 1 microsecond (1 µs) or better. System capability, as assessed by the long-term stability of the NPL*Time*® signal, is at or below the 200 nanosecond level.

Conclusions

- A PTPv2 client installed at ICE was successfully synchronised to a grandmaster located at NPL over more than 150 km of dedicated fibre links.
- Measurements of the NPL*Time*® signal at ICE over more than 15 days showed no long-term drift, and the fluctuations from the mean offset remained within +/-100 nanoseconds for almost the entire period.
- A constant offset of around 200 nanoseconds, due to link asymmetry, was measured between the NPL*Time*® signal at Telehouse North and UTC(NPL).
- Calibration procedures can be used to measure and correct the time offsets of PTP endpoints arising from the link asymmetries.

Timing for the financial sector

Precise and accurate timing plays a critical role in the financial sector, underpinning the time-stamping of trades, synchronisation of systems and the measurement of network latency for process optimisation. The rapid expansion of computer-based high frequency trading (30% of equity trading in the UK, 60% in the USA) has increased the need for synchronisation of trading systems and traceability to UTC, and this need is being reflected in upcoming regulations such as MIFID II. In 2012, the Department for Business, Innovation and Skills commissioned a foresight study into the future of computerised trading, headed by Sir John Beddington. One of the key priorities for action identified in the Beddington report is the role that standards need to play in the sector, in particular high resolution, synchronised time-stamping, in order to help prevent trading irregularities and aid forensics.

As well as being employed extensively around the world for navigation, the Global Positioning System (GPS) serves as a timing source in every industrial sector. The GPS satellite signals are synchronised to GPS time, the internal system time scale, which in turn is traceable to UTC through the US Naval Observatory's time scale UTC(USNO). Such receivers serve as the primary timing references for the computer networks within the majority of financial institutions.

Any GPS-based timing solution is vulnerable to interference causing a loss of reception of the weak satellite signals, whether that interference is man-made or natural, malicious or inadvertent. Jamming (denial of service by swamping the GPS signals) and hijacking of the GPS signals have been identified as key risks to industry. The introduction of additional GPS frequencies and the development of similar satellite navigation services by Europe (Galileo), Russia (GLONASS) and China (BeiDou) will make such attacks more difficult but will not eliminate the risk.

The need for a robust solution for timing dissemination is being addressed by NPL*Time*®*, NPL's precise time over fibre development. This new service provides a UTC-traceable time signal, certified at the end user (as opposed to the source) over a fibre network. With its remit and capability as the UK's national measurement institute, NPL is perfectly placed to deliver such a UK timing standard to the financial sector.*

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