THE BIPM/ IGS PILOT PROJECT: A MODEL FOR HIGH ACCURACY TIME DISSEMINATION IN THE FUTURE

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ABSTRACT

This paper describes a pilot project on high accuracy GPS time transfers, and its possible application for high accuracy time dissemination in the future, both in the UK and internationally.

1. THE BIPM/ IGS PILOT PROJECT

High accuracy time and frequency transfer is required for many applications, including telecommunications (1), radio and television transmission, navigation (2) and astronomy (3). The very highest accuracies are required for international metrology to allow inter-comparison of national time and frequency standards, and inside the UK by the highest tier of calibration laboratories for dissemination to lower accuracy users. Existing time transfer methods have their limitations. For instance the next generation of high stability clocks can only be compared using excessively long measurement times.

A pilot project (4) to investigate a new method of high accuracy time and frequency comparisons using the Global Positioning System (GPS) satellite constellation has been started by the International GPS Service (IGS) and the International Bureau of Weights of Measures (BIPM), which is responsible for generating the time scale Coordinated Universal Time, UTC, the international time standard. The project is called the "IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons Using GPS Phase and Code Measurements".

The IGS collects, processes and disseminates a variety of GPS-related products based upon data contributed from a global network of about 200 tracking stations equipped with dual-frequency code and carrier phase receivers. The National Physical Laboratory (NPL) maintains the UK national time scale, UTC(NPL) - currently derived from an active hydrogen maser clock - which is used to reference a GPS receiver. The pilot project similarly encourages major timing laboratories around the world to become IGS tracking stations, so that post-processing of their data can enable comparisons of their receiver's timing, and thus their clocks.

Currently many UK users of time receive their time reference one-way via GPS, but this is of limited accuracy (~100ns at any instant). GPS disciplined oscillators (5) improve stability but have a similar accuracy at best. However, these methods only utilise a part of the GPS signals - the C/A code - whereas this project uses all of the GPS signals - the C/A code on the L1 carrier, the phase of the L1 and L2 carriers, and the precise P codes on L1 and L2 (6).

2. RESULTS

NPL's data is analysed daily by the Centre for Orbit Determination in Europe (CODE), Switzerland, which is one of the regional analysis centres for the IGS. Other sites in the analysis include the US Naval Observatory, whose time scale UTC(USNO) is the reference for the GPS system, and the Physikalisch-Technische Bundesanstalt (PTB), Germany's national measurement institute. The CODE analysis gives the clock offsets referenced to PTB every five minutes. An example of the results for four days for the Transatlantic link NPL-USNO is shown in figure 1 below.

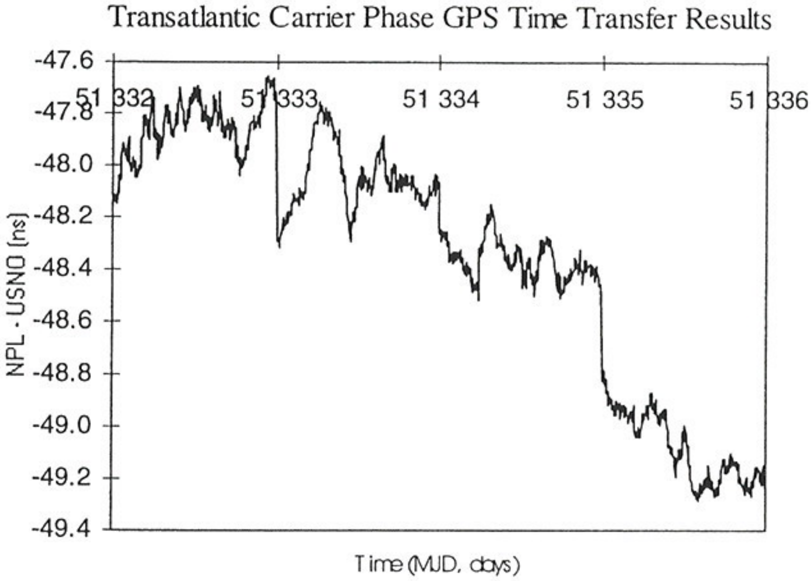

Figure 1, showing Transatlantic carrier phase GPS time transfer results.

For comparison, figure 2 shows the same results plotted alongside two other GPS time transfer methods, collected at the same time and referenced by the same clocks.

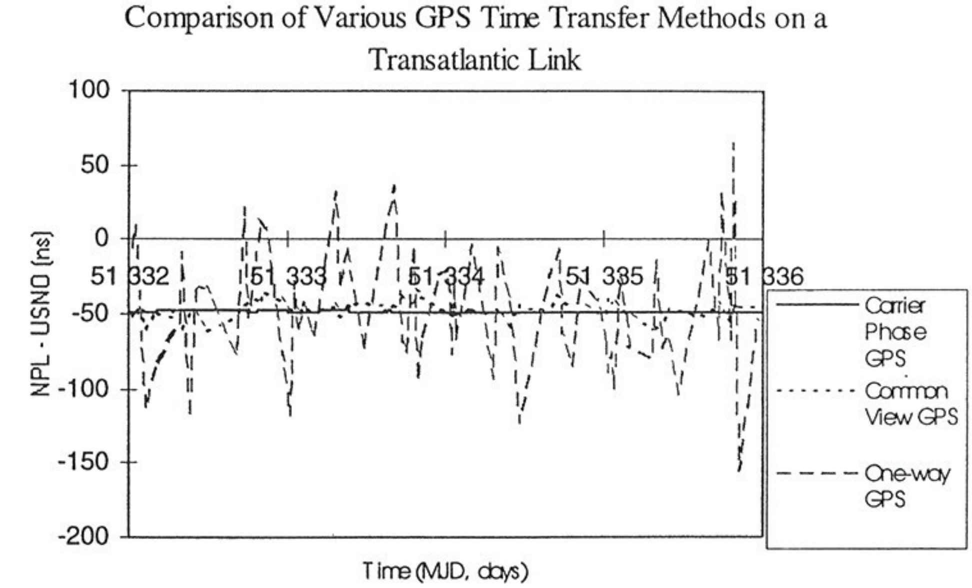

Figure 2, showing a comparison of various GPS time transfer methods on a Transatlantic link.

3. DISCUSSION

The results shown in figure 2, at better than 500ps peak-to-peak within each day, are over two orders of magnitude more precise than those due to one-way GPS time transfer, at 100ns. They are also more precise than the technique of GPS common view (6), in which two timing laboratories conduct simultaneous measurements of the same satellite, and process it to give the differences between their own time scales (along with any propagation delays, errors, etc.). Common view GPS is the main technique currently used for the time transfers used in the calculation of UTC. As well as the good precision, it appears from work done on other time transfer systems that sub-ns accuracies will be achievable.

These carrier phase methods could be used within the UK not only to disseminate UTC(NPL) with an unprecedented accuracy, but it could also allow high stability clocks at other UK sites to contribute to UTC(NPL), improving the stability of the national time-scale. For instance, the data from an active hydrogen maser could be used by NPL via a clock algorithm to form a composite UTC(NPL + external labs). Current GPS time transfer methods are not sufficiently precise to make this worthwhile for short measurement times because the time transfer noise dominates the clock noise up to many days.

There is a disadvantage to this method because the processed results are currently available with a latency of six days, compared to the real-time availability of one-way use. There is no fundamental reason, however, why this should not be significantly shortened - all IGS stations are fully automated, and there is a trend towards real-time data flows. For example, data from selected stations was collected and processed hourly during the recent total solar eclipse.

By contrast the international time scale, UTC, is currently available with a latency of up to six weeks, so the pilot project shows the possibility of calculating an international time scale much more quickly. The current limit to reducing latency for international links is two days because precise GPS satellite orbital information is required for the analysis, which currently takes the IGS that long to produce. However, predicted orbits could be used for baselines within the UK, reducing the latency to that required simply to gather, distribute and process the data. In the future this gives the possibility of replacing real-time 100ns peak-to-peak precision GPS time with 500ps peak-to-peak precision, available with a latency of hours.

NPL is currently developing its own software to analyse carrier phase GPS time transfer links. Software packages (such as Bernese used for the analysis shown above) are already available but they are optimised for geodetic applications, and not time transfer. For instance it can be seen in figure 1 that there are discontinuities of the order of several hundred picoseconds at the day boundaries. This is because the data is analysed by the current software in 24 hour blocks for the estimation of various parameters, such as the atmospheric conditions, and the current implementation does not give the highest priority to the continuity of the receiver clock time. Customised software can be expected to give more accurate time transfer results.

At the European level there will shortly be a requirement for a reference time scale for the European Geostationary Navigation Overlay System - EGNOS (7) - which will give differential corrections to GPS so that users obtain better accuracy and also integrity monitoring. Similarly the future European Union Galileo satellite navigation system will require a reference time scale, analogously to the US Naval Observatory's reference for GPS. The methods described in this paper could be used to provide a stable, precise, rapid time-scale based upon the major European timing laboratories to reference the EGNOS and Galileo system ground control stations.

Users will be able to receive high accuracy timing direct from a geostationary satellite when EGNOS is fully operational because a single directional dish aimed at the satellite would allow them to remain locked to that satellite's signals.

4. CONCLUSION

The IGS/ BIPM pilot project gives a useful model for possible future time dissemination, giving precision (and possibly accuracy) of better than 500ps. This could apply to high accuracy dissemination within the UK to the highest tier of calibration laboratories, to international metrology for speedier calculation and dissemination of UTC, and be used in the production of the reference time scales for EGNOS and Galileo. It will also be required to link the next generation of high stability clocks to improve the stability of UTC.

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