SP Technical Research Institute of Sweden, Borås, Sweden

Report on Activities to the 20th meeting of the Consultative Committee for Time and Frequency, September 2015

1. Staff

The staff involved in time and frequency work at SP is about 5-6 persons. The work includes time and frequency generation and dissemination, calibration, knowledge transfer and research as well as positioning, navigation, and atmospheric research using GNSS.

2. Clocks for TAI

SP presently contributes to TAI with up to 28 clocks (19 CS and 9 HM) maintained at four different locations in Sweden [1]. 6 clocks (4 CS and 2 HM) are located at the National time and frequency laboratory at SP headquarters in Borås (about 60 km inland from Gothenburg on the west-coast) were UTC(SP) is maintained. 8 clocks (6 CS and 2 HM) are located at the SP underground location in Stockholm [2] (about 450 km north-easts of Borås). 3 clocks (1 CS and 2 HM) are located at the Onsala Space Observatory, Onsala (about 60 km south-west of Borås) and the remaining 11 clocks (8 CS and 3 HM) are located at STUPI AB, a clock facility in Stockholm. The clocks located at the three remote sites are linked to UTC(SP) using GPS code observations. All 28 clocks are also supporting the rapid UTC time scale.

3. Time Scales

UTC(SP) is a real-time time scale and defined at the output connectors of an auxiliary output generator (AOG) that is phase-locked to a 5-MHz signal from one of the local clocks at SP, usually a hydrogen maser. The output is steered so that the time and frequency offsets between UTC(SP) and UTC are minimized. The steering parameters are estimated from an ensemble clock based on a Kalman filter [3, 4]. In a first step, in real time, these parameters are estimated from the 6 local clocks at SP. In a second step, about one month after the fact, the time difference between UTC(SP) and UTC, available from the BIPM and Circular T, is used as input to the Kalman filter which updates the clock states for more accurate steering. A redundant time scale is maintained at SP with the same approach but with other hardware. Similar time scales are also operated at the remote clock sites in Onsala and Stockholm using the local clocks at each site, respectively.

4. Remote Time and Frequency Comparisons

4.1. GNSS

SP operates several GNSS receivers capable of producing both code- and carrier phase observables. GPS and GLONASS data (CGGTTS and RINEX) from two receivers (SP01 and SP02) synchronized to UTC(SP) are sent to the BIPM on a daily basis, thus supporting with GPS data also the rapid UTC time scale. Software provided by Pascale Defraigne of ORB [5] is presently used to calculate the CGGTTS-formatted data. The

GPS-link of the receivers was relatively calibrated in a campaign among European laboratories in 2014 [6]. The GLONASS-links are not calibrated.

4.2. TWSTFT

SP operates since year 2003 a TWSTFT-station that in combination with GPS carrier-phase data (i.e. TWGPPP) is the main time transfer link for SP to UTC. TW-data are sent on a daily basis to the BIPM. The station was calibrated in a campaign among European laboratories using a mobile TW-station in 2014 (J. Galindo et al., report available at the BIPM website).

5. Time Dissemination

5.1. NTP

SP operates several local NTP servers [7] referenced to UTC(SP) for both IPv4 and IPv6, four at the facilities in Borås and two at the underground facility in Stockholm. SP provides in a similar way an authenticated NTP-service that uses NTPv4 autokey. Besides the NTP servers at SP facilities, three traceable NTP nodes [8] with a total of six servers are established at Swedish national exchange points for Internet traffic. Those nodes are securely placed within mined spaces below the ground and are considered critical infrastructure. The system’s timing is sustained by a local group of rubidium clocks linked to UTC(SP) using multi-channel common view.

5.2. Time code via telephone modem

From SP there is still a modem service available that serves UTC(SP) as European time code with latency estimation.

5.3. Speaking clock

A speaking clock service is distributed by TeliaSonera where SP provides, in Borås, a system with traceable synchronization and speech synthesis.

5.4. Local 10-MHz reference distribution via fibre

SP is responsible for maintaining 16 SI units (of the 17 within Sweden), and the realization of many of these requires an accurate and stable frequency signal. Furthermore, several testing and calibration facilities at SP need traceable frequency for their accredited measurements. From the time and frequency laboratory, there are fibre optical connections used for broadcasting a 10-MHz reference signal to these laboratories including among them the voltage primary standard laboratory and length and dimension laboratory. The system was recently upgraded to operate at 1310 nm through single mode fibre.

6. Geodetic GNSS station

The time and frequency laboratory has several GNSS antenna systems available. The main antenna is placed on top of a concrete pillar and connected via a power splitter to several receivers in the laboratory. One of these receivers, SPT0, is a part of the IGS network as well as SWEPOS (a Swedish reference network of permanent GNSS stations). SWEPOS (www.swepos.se) is used in a number of applications. Among them the study of land uplift in Sweden (Onsala Space Observatory) as well as real time kinematic (RTK) positioning at the centimetre level (National Land Survey of Sweden). Time and frequency applications take advantage of a system implemented for antenna- and antenna cable temperature control [1].

7. Research and Development

Some of the on-going R&D projects are briefly reported on below.

7.1. NTP-server

During the last three years, a new type of NTP-server has been developed by SP [7] in a project funded by the Swedish Post and Telecom Authority and based on a commercial time stamping network traffic analyser hardware for 1G and 10G Ethernet. Four of the servers mentioned in Section 5.1 are now in production use. The servers are designed based on four major goals: (1) 10GE line rate capability; (2) line rate throughput. On a LAN 10GE this would require about 10,964,912 packets per second per interface to be answered for real DoS (Denial of Service) protection; (3) accuracy and traceability of NTP timing. Timing for the server timestamps shall be accurate with numerically defined uncertainties. The new server design are capable of tracing the NTP timing and individual packets time stamping to UTC; (4) IPv6 capabilities and service flexibility. The design handles leap seconds announcement and correction without interruption.

7.2. NTP-logger

A method for monitoring and characterisation of NTP-servers has been developed [9]. The method is based on a calibrated reference NTP-server synchronised to UTC(SP) that continuously polls selected servers to be monitored. The data collected, in form of the standard NTP-protocol raw time stamps, is used to calculate the offset and round-trip delay between the reference server and the monitored server together with estimates of the uncertainty. The collected data is published in a various ways, including tables and graphs, on a colour coded webpage for a quick overview. Parameters are specified with certain alarm-levels and critical alarms and notifications are sent through e-mail or SMS. The method is presently in use for the NMI NTP-servers in Sweden as well as for the monitoring of NTP-servers in a telecommunication and Internet service provider company in Sweden [10].

7.3. Time scales

A development of the ensemble time scale algorithm, which will include all 28 clocks located in the different sites, is planned to be implemented 2016 [11]. It will compare all clocks to each other using, in addition to the local direct measurements, the GPS-links between the sites, and is expected to be more stable, accurate and robust than the present implementation. In addition, an in principle common time scale will be distributed to users independently from each of the four sites. Each site will use all presently available clocks, up to presently 28 clocks, but may vary dependent on data distribution and functionality of the sites.

7.4. GNSS software

Software for providing link data in the CGGTTS format is presently under development at SP. It will include data for the GPS, GLONASS and Galileo satellites and be used in commercial undertakings. It will include also the possibilities of alternating the position of the GNSS receiver antenna that may be calculated from the RINEX data, but still producing the same clock data. This could be useful in situations a costumer not wants to reveal its antenna position. Another feature of the software will be possibility to alter the clock reference in the RINEX files, which could be useful for referencing the RINEX underlying clock data directly to a national reference instead of to the reference clock of the receiver.

7.5. Time and Frequency Transfer

7.5.1. Fibre-optic techniques

The research on fibre-optic time and frequency transfer at SP have resulted in the development of novel techniques both on two-way transfer on active channels, one-way frequency transfer with real-time correction of delay variations and two-way coherent frequency transfer in a commercial DWDM communication network.

7.5.1.1. Two-way transfer on active channels

Two-way timing synchronization through the cadence of an SDH based data transmission is a technique that has been developed and prototyped during the last 10 years [12, 13]. The technique uses the repetitive signal of a synchronous transmission standard e.g. SDH, and time stamps the occurrence of the pre-determined sequence at both inputs and both outputs of a bi-directional link. Through the four time stamps achieved during the same epoch, the variation of one-way delay can be estimated. The system has been running continuously, comparing UTC(SP) with UTC(MIKE) for more than three years as a complementary system to GPS [14]. The distance between SP and MIKES is more than 1100 km, and shows the residual variation of the transfer, indicating a few ns in daily variation when the fibre is deployed in the ground, and less when the fibre is placed under water.

7.5.1.2. One-way frequency transfer with real-time correction

The technique using one-way broadcasting of frequency over two wavelengths, with real-time post-compensation of phase variations at the receiver, has been evaluated and improved since its first publication 2009 [15, 16, 17]. The technique has been awarded a Swedish patent in 2011, and approved for US and European patents in 2013 [18].

7.5.1.3. Two-way coherent frequency transfer in a commercial DWDM communication network

An experimental fibre link is established between SP in Borås and Chalmers University of Technology (Chalmers) in Gothenburg [19]. The one way fibre length is about 60 km and implemented in SUNET (Swedish University Network). The network connection is DWDM-based (Dense Wavelength Division Multiplexing) and connects the network routers in a central node with the client network, where each channel can be configured with terminal equipment based on user needs, such as Ethernet or POS (Packet-Over-SONET/SDH) technology at different bitrates. The aim of the method is to evaluate the signal quality when sending a stable optical frequency utilizing a wavelength in a DWDM system fibre pair. The technique uses a channel in the DWDM. This specific wavelength is within the C-band and is therefore compatible with common Erbium doped amplifiers in this network. Another aim of the system is to providing the ability to distribute monitored ultra-stable frequency with a future traceability to UTC(SP) to multiple users within the network. The time and frequency laboratory at SP is using an optical frequency comb and an ultra-stable laser as backbone for this method. The performance of the laser is unique in Sweden and several end-users would benefit from access to this type of equipment in their areas of research.

7.5.2. TW over Ethernet

Asynchronous communication is dominating todays Internet. SP has done research on using Ethernet as a carrier of time information [20]. The method uses TW as a principle and allows time information to be passively extracted at both ends of a point to point link. The work is ongoing and relates closely to the development of fast NTP servers. A typical application for this technique is to provide industrial end-users with traceable time and frequency.

7.5.3. GNSS Carrier phase

Research on the use of GNSS carrier phase observation (CP) for the use in time and frequency metrology is an ongoing project at SP. We mainly concentrate on the real-time aspect of carrier phase using differential methods [21]. CP-derived time delays have potential to be used in support of linking the national clock sites together, which helps to minimize the latencies in the group clock combination.

7.5.4. Very long baseline interferometry (VLBI)

SP time and frequency group cooperates with the geodesy group at the Onsala Space Observatory. A major space geodetic technique at the Onsala site is VLBI, which is among other things is used for research on rapid earth orientation parameter (EOP) resolution techniques. SP is involved using VLBI measurements for time and frequency transfer applications, which has so far resulted in a number of conference articles and a peer-review paper [22]. We are working towards real-time filtering of VLBI observations using state space filtering. This combines well with rapid EOP work done at OSO and the ambition of VLBI2010, which will be implemented at the site with two new telescopes.

7.6. Other GNSS applications: Positioning, Navigation, and Atmosphere

SP participates in the development of GNSS in geodesy, often together with the National Land Survey of Sweden and the Onsala Space Observatory. The quality of static positioning [23] as well as navigation applications [24] are investigated and amended. The atmospheric propagation delay is investigated at SP using GNSS data. Under contract with ESA, SP has studied variations in the ionospheric delay [25]. The tropospheric delay with applications in meteorology and climatology is also studied [26]. SP has also participated in an ESA study of the use of microwave radiometry for calibrating the delay due to atmospheric water vapour in communication links with deep space probes [27, 28].

The current road transport system has problems with safety, efficiency and size. Future ITS (Intelligent Transportation Systems), where vehicular communication systems, including GNSS data, play a key role, are envisioned to alleviate these problems and allow for a safer and more efficient coordination of vehicles. Especially in intersections which are among the most complex and accident-prone elements in the modern traffic system. SP research [29-31] focuses on reliability of packet transmissions in vehicular networks and the aim is to better understand the performance of vehicular communication system in different scenarios, and to understand what uncertainties a control system might have to deal with due to communication imperfections. This is done by using tools from stochastic geometry to derive analytical expressions for packet reception probabilities for a variety of scenarios of practical relevance.

8. References

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