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PTB's Time and Frequency Services 2017

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BIOGRAPHIES

Dirk Piester received his diploma degree in physics and Dr.-Ing. degree from the Technische Universität Braunschweig. Since 2002, he has been with the Time Dissemination Group of PTB where he is in charge of PTB's time services. His main research interest is the comparison of remote atomic clocks and time scales via telecommunication and navigation satellites as well as optical fibers. In this framework two fellowships (in 2007 and 2010) were granted by the Japan Society for the Promotion of Science (JSPS). He chaired the Consultative Committee for Time and Frequency Working Group on Two-Way Satellite Time and Frequency Transfer from 2009 to 2015 and he is engaged in technical assessments for Germany's national accreditation body DAkkS.

Andreas Bauch grew up in Wiesbaden, Germany, and studied Physics at the Johannes-Gutenberg University Mainz. In 1983, he joined PTB as a PhD student, working on development and characterization of caesium atomic clocks. In 1991, he was nominated Head of the Time Unit Laboratory. In 2004, he became Head of the Time Dissemination Group. The Group operates a variety of time transfer equipment (GNSS receivers, two-way satellite time and frequency transfer ground stations) and realizes the reference time scale UTC(PTB). Involved in Galileo related work since 2001, he devoted much of his time in the Galileo Time and Geodetic Validation Facility project, coordinated by GMV, Spain, under contract of the European Space Agency, that came to an end with the dawn of 2018.

Jürgen Becker is technical staff member of the time unit section of Physikalisch-Technische Bundesanstalt. He got an in-firm training as physical laboratory assistant in PTB. Later he studied physics engineering at the Fachhochschule Ostfriesland/Emden and received a Diploma-engineer degree in 1996. He joined the Explosion-protection-of-electrical-equipment Section at the PTB in 1997 and changed to the time unit section in 1998. He is currently responsible for the operation and supervision of PTB's DCF77 time dissemination service, the distribution of time via the public telephone network and two-way satellite time and frequency transfer (TWSTFT) equipment.

Thomas Polewka (born 1968) is technical staff member of the Time and Frequency Department of Physikalisch-Technische Bundesanstalt. He got an in-firm training as physical laboratory assistant in PTB. Later he studied electrical engineering at the Fachhochschule Braunschweig-Wolfenbüttel/Wolfenbüttel and received a Diploma-engineer degree in 1994. He joined the Time and Frequency Department at PTB in 1995. He is currently responsible for the operation and supervision of PTB's GNSS equipment and for the distribution of PTB's standard frequency. He is also engaged in technical assessments for Germany's national accreditation body DAkkS.

Franziska Riedel received her diploma degree in physics at the Friedrich-Schiller-Universität in Jena. Since 2013, she has been employed at PTB as a member of the Time Dissemination Group. As a part of her dissertation, she is currently working on a European Metrology Research Programme project which includes frequency comparisons of optical clocks with broadband two-way frequency transfer via satellite.

Dieter Sibold received his diploma and Ph.D. degrees in physics from the Technische Universität Braunschweig. Since 1993, he has been working for PTB, where he is responsible for maintenance and development of PTB's various NTP time services. Since 2010 Dr. Sibold is working on the development of a new specification called Network Time Security, designed for securing time synchronization protocols. Since 2016 he is co-chair of the IETF's NTP working group. He joined the technical advisors' board of the Network Time Foundation in 2012.

Egle Staliuniene was born in Kaunas, in Lithuania in 1964. She received her Master degree in mathematical modeling and cybernetics from the Vilnius University, Lithuania with the thesis "Application of adaptive statistical models for short time range forecasting of economic data series". Since 2000 she is with the Physikalisch-Technische Bundesanstalt (PTB) Braunschweig as technical assistant and programmer. In 2003, she joined PTB's time dissemination group and is responsible for IT solutions of process automatization and control, data transfer, processing and visual representation.

Kristof Teichel received his M.Sc. degree in mathematics at Technische Universität Braunschweig. As part of his dissertation, he has been working at PTB on security measures for time synchronization protocols, in particular the development of the Network Time Security specification, and related research on security for time synchronization protocols on which he has authored and co-authored multiple peer-reviewed conference papers. Currently, he is involved in work on precise, secure and traceable timestamps for the finance industry with regard to ESMA's MiFID II regulation.

Wilfried Vajen (born in 1962) received his diploma degree in electrical engineering from the University of Applied Science in Hannover in 1992. Since 2014, he has been employed at Physikalisch-Technische Bundesanstalt (PTB) as member of the IP-based Time Dissemination Group. He is currently responsible for the operation and monitoring of PTB's various NTP time services and its internal PTP infrastructure.

ABSTRACT

PTB's time services accessible to the common public comprise the operation of Network Time Protocol (NTP) servers, a telephone time service and the standard frequency and time dissemination by the low frequency transmitter DCF77. New achievements in such services have been gained by improving the timing infrastructure for connecting external facilities to the local reference time scale, PTB's realization of Coordinated Universal Time, UTC(PTB). A new NTP server setup including smart meter-gateway administrator servers has been installed. Monitoring of signals from the long wave time service from the Europäische Funkrundsteuerung GmbH (EFR) and of Galileo timing signals has been included in the routine operations.

PTB, like other national metrology institutes (NMI), publishes regular reports on measurement results of GPS time derived from the satellite signals compared to the local reference time scale based on well calibrated receivers. These reports give confidence that the broadcast GPS signals provide a good approximation to UTC in both frequency and time. Accreditation bodies usually require accredited calibration laboratories to subscribe to the GPS monitoring reports from their NMI as part of the process of demonstrating traceability. The content and format of PTB's Time Service Bulletin has been revised and extended accordingly. It contains now not only the differences "GPS time – UTC(PTB)" but also "Galileo System Time (GST) – UTC(PTB)" and "GST – GPS time", as reported in Galileo navigation messages.

On initiative of Deutsche Telekom Technik (DTAG), PTB continues to support the operation of fiber optic time transfer of UTC(PTB) (one pulse-per-second) and frequency (10 MHz) signals to a test center of DTAG in Bremen. In early 2018, the link will be extended to the DTAG main timing facilities in Frankfurt am Main. All these activities result in a broader availability of German legal time. Furthermore, PTB organized and participated in GPS equipment calibration exercises, to support BIPM in the framework of the generation of Coordinated Universal Time (UTC).

INTRODUCTION

Coordinated Universal Time UTC is established at the Bureau International des Poids et Mesures (BIPM) by a post-processing computation based on the data of about 450 atomic frequency standards maintained in about 75 timing laboratories distributed worldwide. These laboratories are operated in many cases inside of National Metrology Institutes (NMI). They provide local realizations of the UTC time scale that is usually acknowledged as the national reference of time, and in addition they may also perform activities in the following fields:

- *development* of primary frequency standards and clocks,
- *participation* in international synchronization experiments,
- *dissemination* of time and frequency standard signals,
- *development* of accurate time and frequency transfer techniques,
- *research* on clock characterization and time scale algorithms,
- *calibration* of time and frequency equipment.

In fact, PTB's Time and Frequency Department is active in all these fields, and this report only covers a small part of the activities. PTB operates dedicated devices for the generation and monitoring of the standard time and frequency signals that are distributed locally and to remote users by different means, such as dedicated computer networks, telephone lines, and LF transmissions. The number of requests of the public NTP service approaches 6000 per second. The number of accesses to the telephone service remains in the range between 1700 and 1800 per day. The standard frequency and legal time transmitter DCF77 is still the most prominent part of PTB's time services. The number of operational receivers in Germany and Europe is estimated to be more than 100 Million. These features, together with the instrumentation suitable to calibrate time and frequency devices in terms of their specifications (time, frequency, frequency instability) complete the traceability chain foreseen in the Mutual Recognition Arrangement (MRA) put in force by the Comité International des Poids et Mesures (CIPM). PTB staff is also supplying their expertise to the German accreditation body DAkkS and are involved in the organization of national and international inter-laboratory comparisons which are instrumental in assessing the measurement capabilities of secondary calibration laboratories, that are the end level of the traceability chain devised by the CIPM MRA. The integration of the use of reception and processing of signals of the newer Global Navigation Satellite Systems (GNSS), such as the European Galileo and the Chinese BeiDou are discussed as well.

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PTB'S TIME SERVICES

PTB provides three services for the common public. These Network Time Protocol (NTP) servers, a telephone time service and the standard frequency and time dissemination by the low frequency transmitter DCF77. This PTTI Lab Report subsequently covers each of the services in some detail. Basic information about the respective service are repeated from previous laboratory reports [1, 2].

Network Time Protocol Servers

PTB is currently refurbishing and extending the architecture of its NTP-based internet time service. The purpose of these activities is to enhance the redundancy of the time service infrastructure, to facilitate its operational tasks, and improve its monitoring capabilities (see Figure 1). The new setup will comprise up-to-date hardware to continue the service of three publicly accessible NTP servers and, as a new service, two smart meter-gateway (SMGW) administrator servers for dedicated customers. Two NTP servers will be available for internal clients. Like the current system, the new setup will be distributed between PTB's datacenter and the time laboratory, but the two facilities will be connected internally by exploiting the superior performance of precise time protocol (PTP) capable servers and switches. Furthermore, the new setup will provide enhanced redundancy, monitor and control facilities for better availability and robustness of the services.

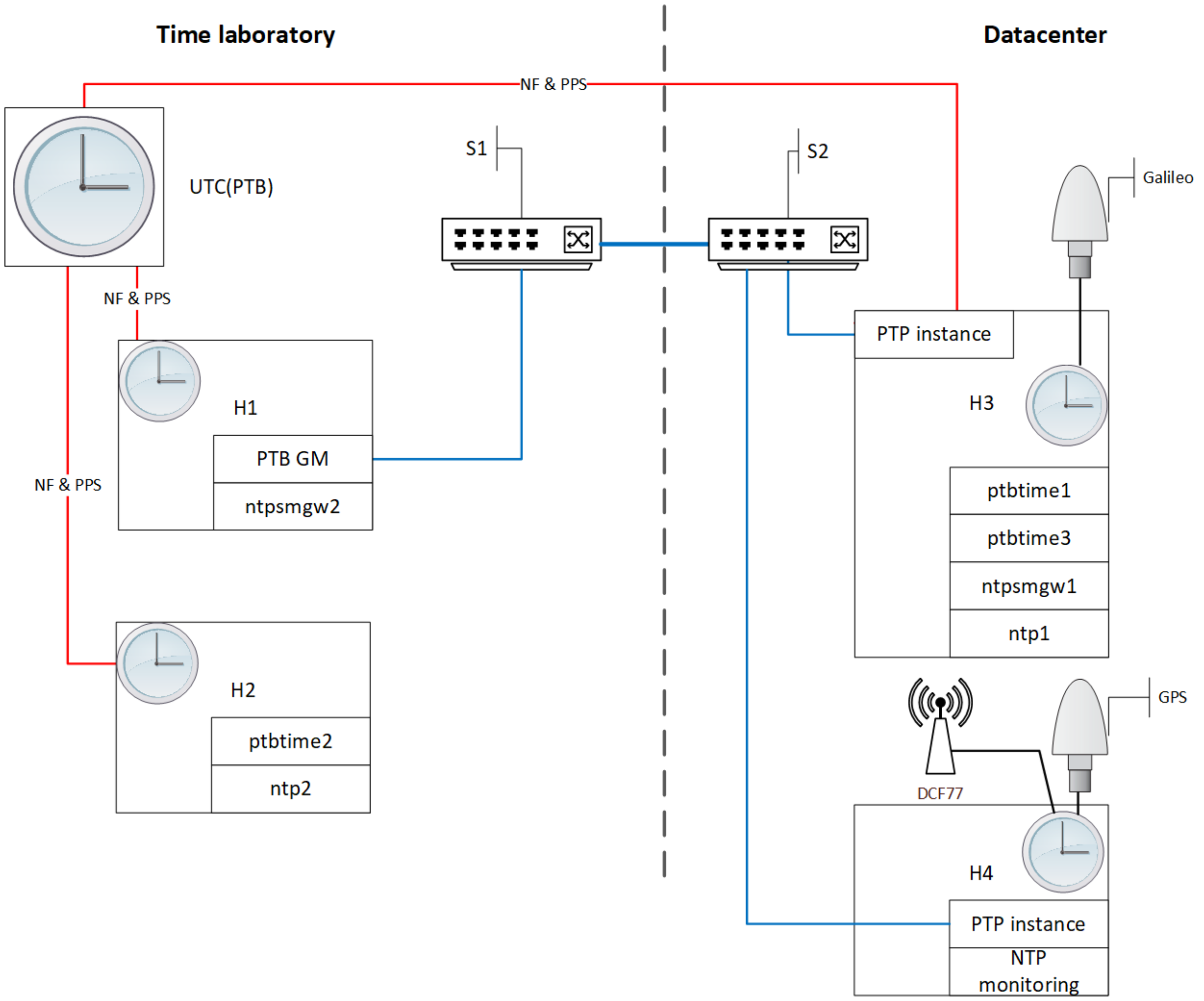

Figure 1. Schematic layout of PTB's new NTP time service infrastructure. The NTP server instances in the host systems H1 and H2 at the time laboratory are synchronized via PPS (pulse per second) and standard frequency (NF = 10 MHz) to UTC(PTB). The NTP time server instances in the host system H3 at the PTB's datacenter are synchronized to its internal clock which is disciplined by the PTP grand master located at the time laboratory. Red lines: PPS and NF signals, blue lines: PTP signals, black lines: GNSS and LF signals.

PTB's IP-based time service infrastructure comprises several groups of NTP server instances, each group intended for different purposes. The first group contains the NTP servers ptbtimeN.ptb.de, N = 1, 2, 3. These servers provide PTB's public and freely accessible NTP time service. The second group is formed from the NTP servers ntpsmgwN, N = 1, 2. They provide a fee-based authenticated NTP service based on NTP's pre-shared key approach defined in RFC 5905 [3]. This service was established because of PTB's duty to provide a secured NTP time service for the Smart Grid Initiative of the German Federal Ministry of Economic Affairs and Energy. The third group, comprised of the NTP servers ntpN, N = 1, 2, provides time service for PTB's internal infrastructure.

All NTP server instances are based on individual CPU modules hosted by commercial time server hardware (H1, …, H4). These instances are distributed between PTB's datacenter and the time laboratory as displayed in Figure 1. The time server distribution ensures that in case of a failure of a host system at least one NTP server instance from each group of NTP server instances remains accessible. The host system H1 at the time laboratory and H3 at the datacenter also provide each a PTP master clock, respectively. The NTP time servers and the PTP master clock within the host systems H1 und H2 at the time laboratory are synchronized to the PPS (pulse per second) and standard frequency representing UTC(PTB). During normal mode of operation, the PTP master clock in the host system H1 functions as PTP grandmaster (GM) clock. The NTP time servers in the host system H3 are synchronized via PTP to the PTP GM in the time laboratory. The PTP packets are routed over two PTP capable switches (S1 and S2) configured as transparent clocks and linked via an optical fiber. In case of a failure of the PTB GM at the time laboratory, the PTP instance in H3 at the datacenter will act as PTB GM. In this case either the PPS from the time laboratory or the Galileo signal will be used as primary reference to represent UTC(PTB). All utilized host systems are built from commercial equipment with high reliability reputation which (hopefully) simplifies the operational task compared to the current infrastructure.

The monitoring capabilities of the new setup are elaborated. To this end a separate host system (H4) is installed at the datacenter. This system hosts an NTP server and a PTP instance for monitoring all other NTP servers and PTP instances, respectively. The monitoring instance is also responsible to automatically shut down any NTP server or PTP instance which is in a faulty condition. To this end, the monitoring instance needs to have timing information which is independent of the timing sources from the monitored time server infrastructure. It therefore applies DCF77 as primary reference to synchronize to UTC(PTB). In order to avoid false positive actions due to disturbed DCF77 steering it also tracks GPS.

As displayed in Figure 2, the access rate of the public available NTP server instances has increased during the last four years from about 3000 to 6000 requests per second. These numbers include only the access to the NTP service. The access to Daytime and Time Ports are not monitored. The number of customers of the fee-based authenticated NTP time servers is small, hence the access rate remains very small (< 10 requests per second).

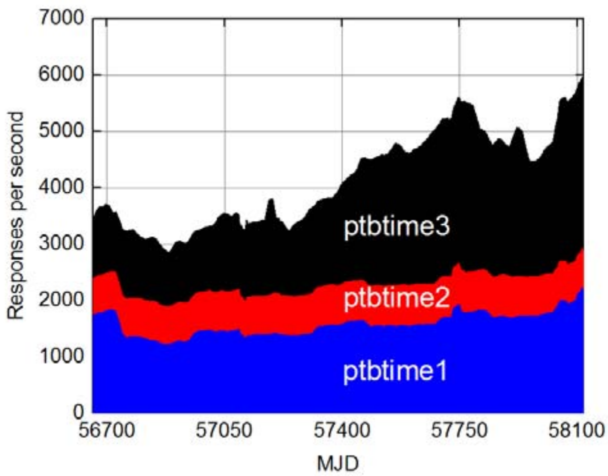

Figure 2. Accumulated number of requests/responses per second from 1st January 2014 (MJD 56658) until 31st December 2017 (MJD 58118) for the publicly available NTP servers ptbtimeN, N = 1, 2, 3.

Telephone Time Service

PTB's telephone time service provides accurate time to computers and data acquisition instruments via automatic access. Traceable time is delivered via a direct telephone line using the so-called "European Telephone Code" [4, 5]. Connection is performed under the phone number +49 (0)531 512038 via modems according to CCITT V.22: baud rate: 1200, full duplex, parity: none, data bits: 8, stop bits: 1, auto-line feed: no. The uncertainty is between 1 s and a few milliseconds, depending on whether the one-way delay is corrected for by measuring the round-loop delay or not. At present, PTB operates three Time Distribution Systems (TDS1, TDS2, and TDS3), designed and manufactured by the Technical University Graz many years ago. Each TDS is connected to a modem and two of them are connected via Eumex converters directly to the public telephone

ISDN network. Incoming calls are preferably routed to TDS2 working as the primary TDS. In case TDS2 is busy the call will be routed to TDS1. The facilities at the user's site consist of a switched-line modem and a computer on which suitable software must be installed to establish the connection, evaluate the time code received and synchronize the computer clock. Since 2013, about 1800 accesses per day have been processed with a slight decrease during the last two years (see Table 1).

Table 1. Number of calls per day, averaged over 1 year, processed by TDS1 and TDS2.

Year	Calls per day
2013	1809
2014	1804
2015	1764
2016	1775
2017	1727

Figure 3 depicts the number of calls per day averaged over one month and their division to TDS1 and TDS2 for the period January 2016 – December 2017. The service is mainly used in Germany by utility providers (gas transport sector), to get secure legal time information without the use of the Internet.

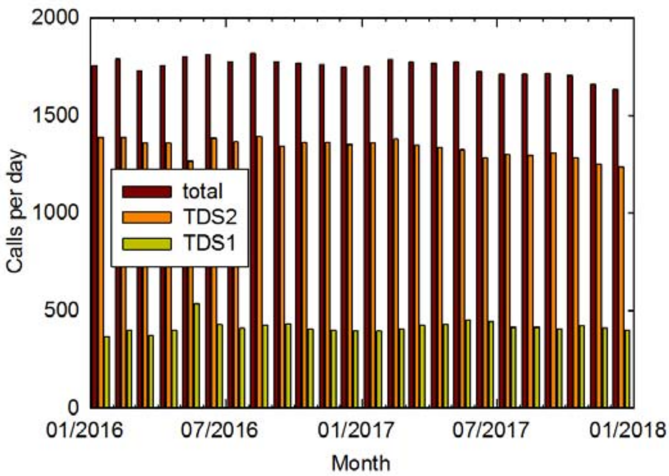

Figure 3. Number of Calls per day (averaged over one month) and their division to TDS1 and TDS2 for the period January 2016 – December 2017.

Comparable services are available in other countries, among them Japan and USA, but especially different European institutes offer similar services with a uniform time code [6]. The telephone services in other European countries are sometimes offered as services subject to charges and can be reached only from the respective country network.

The nearly constant and high number of about 1800 calls per day backed the decision to provide this service further on. However, the infrastructure of analogue and ISDN telephone lines is about to be dismantled in the not so distant future in Germany. Thus, for a further provision, tests are ongoing to verify that this service could be transferred to all-digital internet communication. Via a dedicated telephone-over-IP line with a so-called "digitization box" installed at PTB, TDS3 is accessible for external users. Test synchronizations with two industrial companies have been organized and have been performed regularly since July 2015 and are ongoing. After initial sporadic occasions of failure in operations, a "4-hour-service" has been agreed upon with the Deutsche Telekom. In summary, the feasibility of using the telephone time service in an all-digital environment has been demonstrated and will be ensured for the foreseeable future.

Low Frequency Transmitter DCF77

Still today, the low-frequency transmitter DCF77 represents the by far the best known service to disseminate legal time for Germany. Operated in Mainflingen (coordinates: 50°01' north, 09°00' east), approx. 25 km south-eastern of Frankfurt am Main, the DCF77 signal can be received not only in Germany but also in most of central Europe. Standard frequency of 77.5 kHz and coded time information are transmitted. Both are generated on the transmitter site from PTB equipment and broadcast via facilities operated by Media Broadcast GmbH under contract. The service and the technical installations have been described in detail elsewhere [7], here we only report on the availability of the service.

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DCF77 is in continuous operation (24/7) and the contractually agreed availability with the operator is 99.7 % per year, corresponding to a permitted down time of about 24 h per year. A backup transmitter and antenna secure this availability figures. Downtimes with durations longer than two minutes have been observed with a distribution as depicted in Figure 4 and the annual temporal availability of the DCF77 time service during the past 10 years is depicted in Figure 5. The most frequent cause for interruptions of longer duration was the electric detuning of the antenna resonance circuit by displacement of the antenna in heavy storm or freezing rain. When the mismatch becomes too large the transmission is interrupted. During 2016, major work on the antenna installations became urgent and resulted in unusually long downtimes.

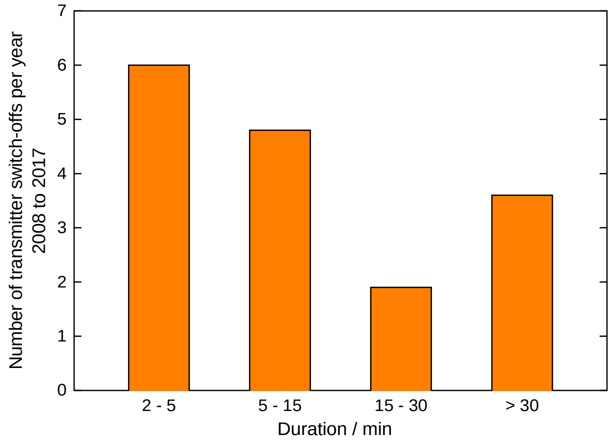

Figure 4. Distribution of transmission outage durations per year (averaged from 2008 to 2017).

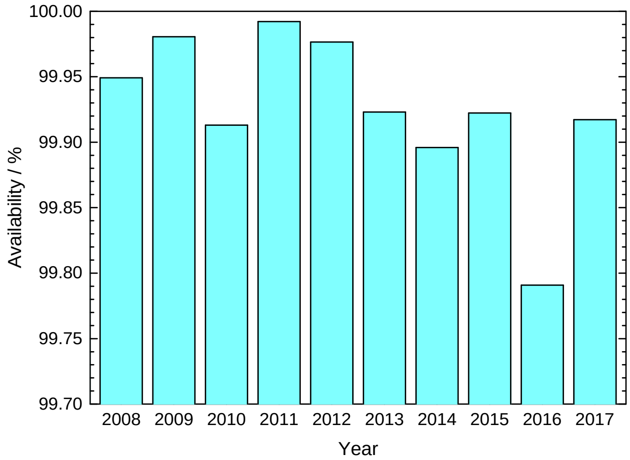

Figure 5. Annual availability of DCF77. Downtimes with durations of less than 2 minutes are not considered.

The availability of the DCF77 service is secured by a long-term contract with the operator of the transmitter facilities ensuring guaranteed service until 2021 and negotiations about the operation of DCF77 after 2021 will take place in due time.

MONITORING TIME SIGNALS BROADCAST BY EFR LONG WAVE TRANSMITTERS

PTB and the Europäische Funkrundsteuerung GmbH (EFR) agreed to install a monitoring system for EFR timing signals, which are part of a long-wave service for encrypted transmission of various data services, e.g. of control commands and tariff information in service of utilities to support tariff, load, and generation management in the electricity sector (see [8] for some details). EFR operates three transmitters, each with a range of about 500 km, which provide reliable coverage over a large part of Central Europe. The broadcast time-of-day information is derived locally and autonomously using GPS receivers at the transmitter sites. The monitoring system at PTB provides a comparison of the timing information obtained from the received EFR signals with UTC(PTB). It has furthermore been agreed that PTB provides the results of this monitoring in a dedicated bulletin which is publicly available via an ftp server (ftp://ftp.ptb.de/pub/time/bulletin/efr/). Making use of these signals and their documentation provided by PTB, users in Germany and neighboring countries have one more means to relate their local clocks to German legal time.

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GNSS-BASED CALIBRATION SERVICES

PTB continues to offer (in cooperation with BIPM and alike French and Spanish institutes) calibrations of GPS time links to other European NMIs as well as other research institutes. In 2017, PTB has organized and conducted three so-called G1G2 calibration trips to ESTEC (Noordwijk, the Netherlands), DTAG (Frankfurt am Main, Germany) and BKG (Wettzell, Germany). The latter campaign continues in early 2018. In addition, the future reference GNSS receiver of UFE (Prague, Czech Republic) got its GPS P1 and P2 internal delays calibrated by a common-clock exercise performed at PTB. Results of all campaigns are published on the BIPM web (https://www.bipm.org/jsp/en/TimeCalibrations.jsp) from where also the calibration reports can be downloaded.

GNSS TIME TRANSFER

Up to 8 GNSS time transfer receivers from four different manufacturers have been operated during recent years in PTB. Their observations are compared daily and checking for anomalies is done in an automated way. Standard daily observation files in the format CGGTTS V2E (or V2 for older receivers) [9] and in RINEX format are publicly available for the previous day and backwards at ftp://ftp.ptb.de/pub/time/GNSS/ in various folders. These files provide a direct reference to UTC(PTB) for the experienced user. For the public, the weekly PTB Time Service Bulletin (TSB) is published at ftp://ftp.ptb.de/pub/time/bulletin/. It is mainly intended for German users who seek to obtain traceability to German legal time. PTB has actively supported the development and operation of the timing system for the European GNSS Galileo. During 18 quarters PTB coordinated the contributions of five European timing laboratories to the mission of the Galileo Time Validation Facility, under industrial leadership of GMV, Spain [10]. Not surprisingly, PTB monitors Galileo signals with respect to UTC(PTB) using five calibrated receivers with the Galileo signal delays determined as described in [11, 12]. The TSB contains the offset between UTC(PTB), GPS time and Galileo System Time (GST), respectively, and also the offset between the two GNSS time scales as broadcast in the Galileo navigation message. GNSS common-view time transfer is routinely made between PTB Braunschweig and the DCF77 reference clock in Mainflingen, as shown in Figure 6. The large time offset is due to the equipment configuration on site and not relevant in the context.

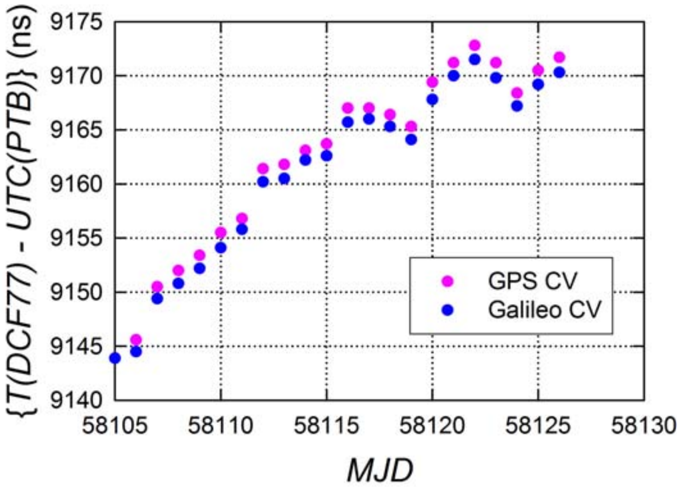

Figure 6. Time transfer results DCF77-UTC(PTB) using GPS CV (pink) and Galileo CV (blue). Modified Julian Day (MJD) 58130 corresponds to 12th January 2018. The Galileo internal delays had been determined in 2016, and offsets between GPS CV and Galileo CV were then at the 0.1-ns level. The current about 1-ns offset may be related to firmware updates on the receiver.

The development of the Chinese BeiDou satellite navigation system (BDS) was done in three steps. At the time of writing, BeiDou-2 consists of five satellites in a geo-stationary orbit (GEO), six in an inclined geo-synchronous orbit (IGSO) and three in a "more standard" GNSS-type orbit (MEO). Reception of signals from these satellites has been activated in two Septentrio PolaRx4 receivers in late 2017. In addition, a receiver assembled by the Chinese National Institute of Metrology (NIM) with BDS reception capability was given on loan to PTB. In fact, as a result of the orbit coverage of the BeiDou-2 satellites launched up to now the optimum observation area currently is East Asia and Australia. But we started to evaluate BDS reception and routinely perform BDS CV with NIM and the National Time Service Center of China (NTSC). The BeiDou system time (BDT) is related to UTC through UTC(NTSC). At PTB, and similar in other sites in Europe, the observation conditions for BDS signals are not optimum with regards to elevation and satellite distribution in the sky. In Figure 7 we illustrate the prevailing situation, showing the satellite traces in a polar plot (left) recorded during one day and the elevation of satellites during two days in late December 2017. The accumulation of traces with low elevation in the North-East is due to the satellites in an inclined geo-stationary orbit. Satellite C05 is the single satellite in a geo-stationary orbit visible in Europe. As a consequence of the reception conditions, and probably influenced also by the signal properties themselves, the recordings of REFSYS (measured time difference between the GNSS time and the local reference) for BDS is considerably noisier then the equivalent plot from reception of Galileo. Both recordings shown in Figure 8 are from the same GNSS receiver and taken simultaneously.

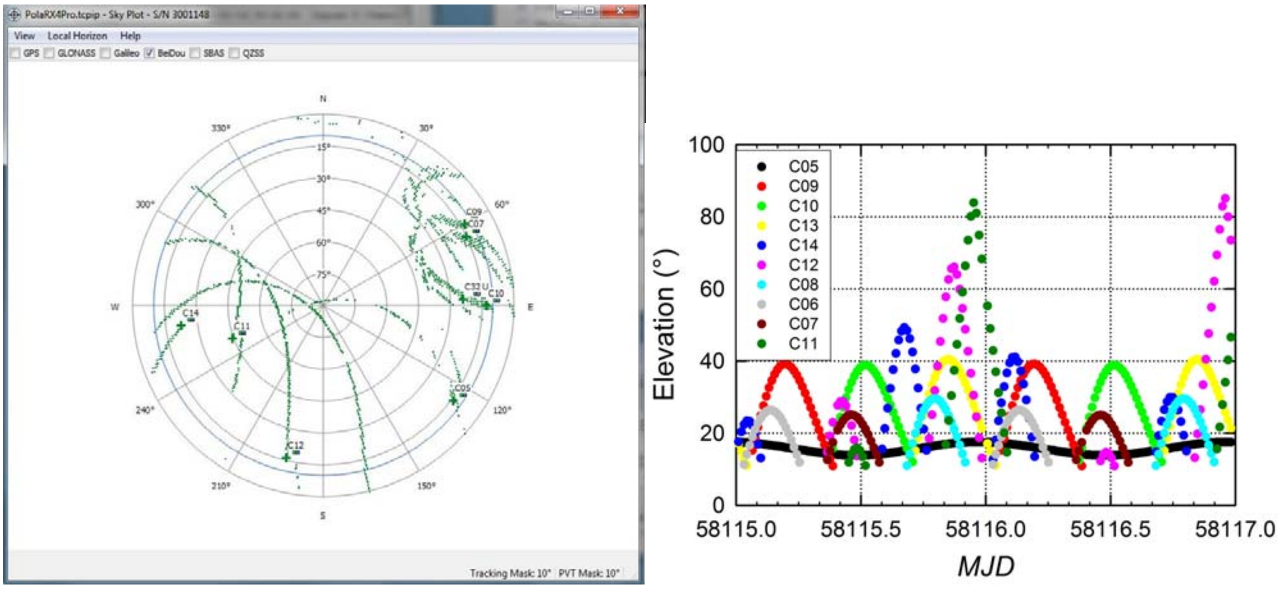

Figure 7. Observation of BDS signals in PTB, left: satellite traces recorded during about one day, screen shot 2018-01-15, right: Elevation of observations during two days in December 2017.

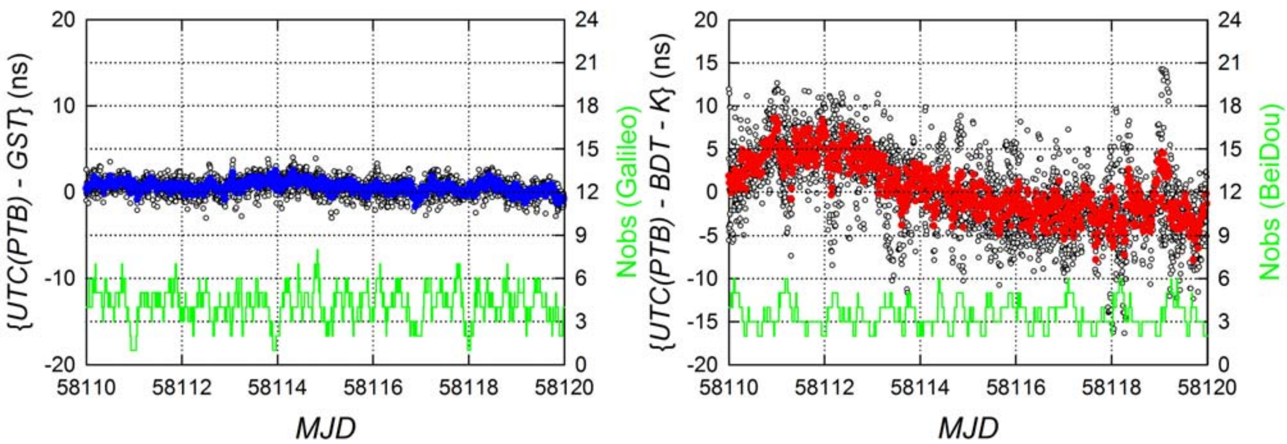

Figure 8. Galileo and BeiDou reception in PTB: Recording of UTC(PTB) minus system time and number of observed satellites in view (Nobs) during 10 days. The Galileo signal delays were calibrated as described in [11]. BDS signal delays are unknown and the plotshows the results after subtraction of the mean value K; MJD 58110 corresponds to 2017-12-10.

Results of common view time transfer with NIM and NTSC using GPS, BeiDou and Galileo are subject of other contributions in these proceedings.

FIBER OPTIC TIME TRANSFER

On initiative of Deutsche Telekom Technik GmbH (DTAG) a cooperation with AGH University of Science and Technology (Krakow, Poland) and PTB has been initiated to establish a fiber optic time transfer link connecting PTB with DTAG test center in Bremen for an experimental proof of concept (PoC) [13, 14]. The motivation is to provide reliable means for

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synchronization in a so-called “supervision level” of future 5G telecom networks with precision and accuracy superior to those using state-of-the art GNSS time transfer receivers. In this experiment 1PPSand standard frequency (10 MHz) derived from UTC(PTB) were delivered to DTAG in Bremen by using the ELSTAB system designed by AGH. The link was established as a loop having both ends at PTB. In Bremen, a special so-called tapping module was installed to enable access to UTC(PTB). In November 2016, the setup was changed to PoC phase 2, in which a hub at DTAG premises in Hannover has been installed. Time transfer between PTB in Braunschweig and DTAG in Bremen has been established in two steps via the hub in Hannover [15]. Parts of the old PoC phase 1 installation have been kept offering an independent monitoring setup as long as necessary. In December 2017, work has been started to connect the time laboratory of Deutsche Telekom in Frankfurt am Main with the Hannover hub (see Figure 9). As soon as this link is operational, the two realizations of Coordinated Universal Time UTC(DTAG) and UTC(PTB) can be compared with significantly enhanced precision and accuracy.

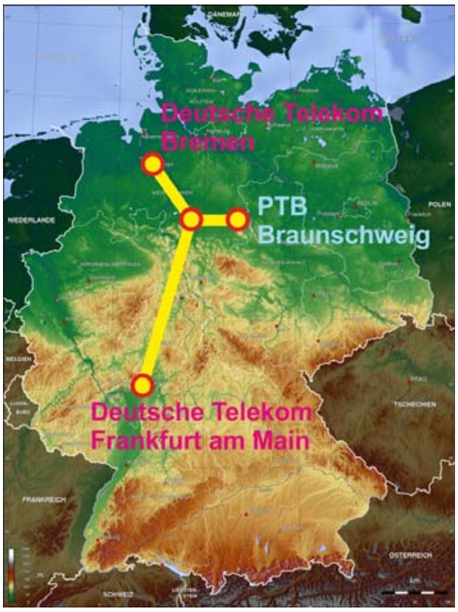

Figure 9. Scheme of the fiber optic time transfer network (proof of concept phase 3) between Deutsche Telekom and PTB.

ACKNOWLEDGMENTS

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REFERENCES

[1] D. Piester, A. Bauch, J. Becker, J. Leute, T. Polewka, F. Riedel, D. Sibold, E. Staliuniene, S. Weyers: **PTB’s Time and Frequency Services 2015 – 2016**; Proc. 2017 Precise Time and Time Interval Meeting – ION PTTI 2017, 30 Jan – 2 Feb 2017, Monterey, CA, USA, pp. 53-61, 2017.

[2] D. Piester, A. Bauch, J. Becker, T. Feldmann, J. Leute, T. Polewka, F. Riedel, D. Sibold, E. Staliuniene, K. Teichel, S. Weyers: **PTB’s Time and Frequency Services 2010 – 2014**; Proc. ION PTTI 2014 Precise Time and Time Interval Systems and Applications Meeting, 1-4 Dec 2014, Boston, MA, USA, pp. 26-32, 2014.

[3] J. Burbank, W. Kasch, D. L. Mills: **Network Time Protocol Version 4: Protocol and Algorithms Specification**. RFC 5905. doi:10.17487/rfc5905, 2010.

[4] P. Hetzel, T. Polewka, A. Söring, R. Metzger: **Time from European time keeping laboratories via telephone modem**; Proc. European Frequency and Time Forum (EFTF), 5-7 March 1996, Brighton, UK, pp. 540-547, 1996.

[5] P. Hetzel, T. Polewka, A. Söring, R. Metzger: **Zeitübertragung europäischer Zeitinstitute über Telefonmodem und das öffentliche Telefonnetz**; Kleinheubacher Berichte, vol. 40, pp. 343-350, 1997.

[6] Bureau International des Poids et Mesures: **BIPM Annual Report on Time Activities – Vol. 10 – 2015**; Pavillon de Breteuil, Sévres Cedex, France, 2016.

[7] D. Piester, A. Bauch, J. Becker, A. Hoppmann: **Time and frequency broadcast with DCF77**; Proc. 43rd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 14-17 Nov 2011, Long Beach, California, USA, pp. 185-196, 2012.
[8] B. Sbick, K. Katzmann, E. Staliuniene, D. Piester, A. Bauch: **Monitoring of Time Signals Broadcast by EFR Long-Wave Transmitters at PTB**; Proc. 2017 European Frequency and Time Forum & International Frequency Control Symposium, 10-13 Jul 2017, Besançon, France, pp. 703-704, 2017.
[9] P. Defraigne, G. Petit: **CGGTTS-Version 2E: an extended standard for GNSS Time Transfer**; Metrologia, vol. 49, G1, 2015.
[10] R. Piriz, D. Rodriguez, P. Roldan, A. Mudrak, A. Bauch, F. Riedel, E. Staliuniene, J. Galindo, H. Esteban, I. Sesia, G. Cerreto, K. Jaldehag, C. Rieck, P. Uhrich, D. Rovera: **The Time Validation Facility (TVF): An All-New Key Element of the Galileo Operational Phase**; Proc. 2015 Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum, 12-16 Apr 2015, Denver, Colorado, USA, pp. 320-325, 2015.
[11] P. Defraigne, W. Aerts, G. Cerretto, E. Cantoni, J.-M. Sleewaegen: Calibration of Galileo signals for time metrology; IEEE Trans. Ultrason. Ferroelect. Freq. Contr., vol. 61, no. 12, pp. 1967-1975, 2014.
[12] R. Piriz, D. Rodriguez, P. Roldan, A. Mudrak, A. Bauch, J. Leute, P. Pánek, A. Kuna: Relative Calibration of Galileo Receivers within the Time Validation Facility (TVF); Proc. 2015 Joint Conference of the IEEE International Frequency Control Symposium & European Frequency and Time Forum, 12-16 Apr 2015, Denver, Colorado, USA, pp. 245-249, 2015.
[13] L. Sliwczynski, P. Krehlik, H. Imlau, A. Bauch, D. Piester, H. Schnatz: **Towards sub-nanosecond synchronization of a telecom network by fiber optic distribution of UTC(k)**; Proc. 2016 European Frequency and Time Forum (EFTF), 4-7 Apr 2016, York, UK, pp. 1-4, 2016.
[14] L. Sliwczynski, P. Krehlik, J. Kolodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, A. Bauch: **Fiber-optic Time Transfer for UTC-Traceable Synchronization for Telecom Networks**; IEEE Communications Standards Magazine, vol. 1, no. 1, pp. 66-73, 2017.
[15] L. Sliwczynski, P. Krehlik, J. Kolodziej, H. Imlau, H. Ender, H. Schnatz, D. Piester, A. Bauch: **Fiber optic time transfer between PTB and Deutsche Telekom using multi-link redundant topology**; Proc. 2017 European Frequency and Time Forum & International Frequency Control Symposium, 10-13 Jul 2017, Besançon, France, pp. 681-682, 2017.