Redundant Distributed Timescale Traceable to UTC(SP)

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***Abstract*—A variety of commerce needs or requires accurate time, such as air traffic control, bank transactions and computer log file comparisons. Whenever the used time needs to be compared with a timestamp generated by another system, both systems must be traceable to a common reference, such as a local UTC(k) realization.**

Within this paper a distributed timescale using five nodes across Sweden is presented. The foundation for time keeping at each node is two cesium clocks, which are connected to time analysis equipment and equipment for producing redundant timescales. Both timescales are used and distributed throughout the time node and then prioritized by the local NTP servers, PTP grand masters, and other time distribution services. The timescales are monitored by RISE Research Institute of Sweden to ensure traceability to UTC(SP).

To compare the timescales of each location with the other locations, GNSS common view is primarily used with an alternative fiber-based solution as back-up. All available time signals are measured relative to the master timescale, and that data is distributed to the other locations to be used as input in the steering of the local timescales.

The NTP servers of the time nodes are directly connected to Internet Exchange points, for central, highly available and fair connectivity to the Internet.

Keywords—time dissemination, traceable, robust, redundant, holdover

I. Introduction

Accurate time is essential and a requirement for the society and industries at presence. To meet the requirements for different kinds of applications, a common solution is to use a GNSS receiver. These are easy to use, cost efficient and accurate time sources. A major drawback is that these installations are susceptible for disturbances, since they can be intentionally or unintentionally jammed or even spoofed.

The Swedish Post and Telecom Authority (PTS) is the supervisory authority of the telecommunications in Sweden. They identified that telecom networks of today are dependent on time for correct operation. Implementation of robust and resilient time distribution in these networks can be prohibitively costly. PTS therefore decided to strengthen the national time source availability as a general national service [1]. As a result, the time dissemination system described within this paper was constructed, in a cooperation between Netnod Internet Exchange and RISE Research Institutes of Sweden.

Netnod operates different Internet services including NTP server system and RISE is designated national metrology institute (NMI) of Sweden and the organization responsible for the Swedish national time realization UTC(SP).

II. Robustness

A major incentive for the nationwide time distribution system is to assist other vital systems to run when infrastructure has failed or become unavailable, including the GNSS systems. The time nodes operate autonomously with high accuracy for extended periods of time if needed and are constructed with redundancy for critical parts and can continue to operate even after a component failure. Using the cesium clocks, they are expected to deliver a high accuracy time holdover, well within the Primary Reference Time Clock (PRTC) specification [2], even within specifications for a PRTC in non-holdover mode. They have also proven themselves to fulfill the Enhanced Primary Reference Time Clock (ePRTC) specification [3].

The time nodes are geographically distributed and placed in major cities, to be able to provide time in a region if it becomes isolated from the other regions. For physical security and resilience, the nodes are placed in secure and physically strong facilities, which are equipped with uninterruptible power supply such as battery and diesel generators. All time keeping components of a node, the cesium clocks, micro steppers, and PTP equipment has a dedicated 24 VDC battery with a capacity of about 3 days beyond the other backup power facilities (Fig. 1).

III. System overview

The system is constructed of five production time nodes, where four are presently operational and one under construction. There is also an extra time node for test and development.

The timescales of each node are generated by using cesium clocks connected to micro steppers for steering of frequency and phase. Each time node is constructed in a redundant fashion with all critical components duplicated into symmetric “node halves”, each generating its own timescale. All equipment which carry timescales are monitored for phase accuracy using multi-channel time interval counters, one per node half. The timescales are physically realized using 1 PPS, 5 MHz and 10 MHz, and any other formats are derived from these base signals. Time can be disseminated using a variety of distribution mechanisms, though mainly NTP over Internet or PTP over dedicated connections are used. The time node has equipment for time transfer from other nodes and other time sources as UTC(SP) using a fiber based PTP system and GNSS common view (Fig. 2 and Fig. 3).

Fig. 1. The time node sites have uninterruptible power supply (UPS) such as battery and diesel generators. In addition, the time keeping equipment in the node has 24 VDC battery for another three days.

A. NTP servers

Each time node has two NTP servers for distribution of time over public Internet. The servers are implemented using Field Programmable Gate Array (FPGA), each with 4 x 10 Gb/s ethernet interfaces and can handle full wire speed NTP traffic on all ports, IPv4 and IPv6, optionally cryptographically signed using static keys. The available capacity is largely excessive for normal load and is dimensioned for being able to handle and mitigate an overload attack until countermeasures can be put in place.

The resolution of the NTP servers timestamping is 15 ns, and measurements indicate that they have an accuracy well within +/- 100 ns. The NTP servers handles two clock inputs, each consisting of a 1 PPS and a 10 MHz signal, connected to the two timescales of the node, and falls over to the second clock input if the primary fails. They have 1 PPS and 10 MHz outputs connected to time interval counters for monitoring the internal clocks phase accuracy (Fig. 4).

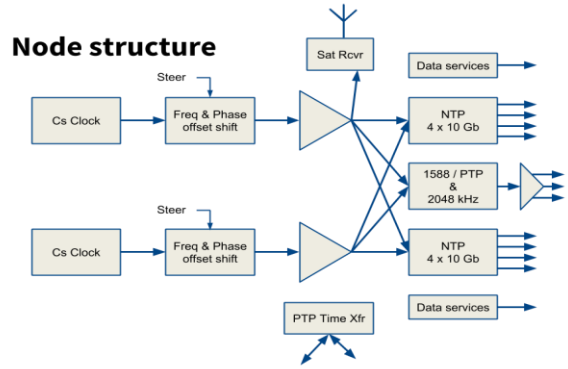

Fig. 2. Each time node generates two cesium clock-based timescales realized by a High-Resolution Offset Generator (HROG). The timescales are disseminated using NTP, PTP on dark fibers or alien wavelengths, and by using 1 PPS, 5MHz, 10 MHz, and 2048 kHz.

Fig. 3. A time node, with cesium clocks (red displays), phase and frequency steppers (blue-white displays), distribution amplifiers, multi-channel time interval counters for monitoring, GNSS receiver, PTP grandmasters, and computers. The taller computers close to the top are the NTP servers.

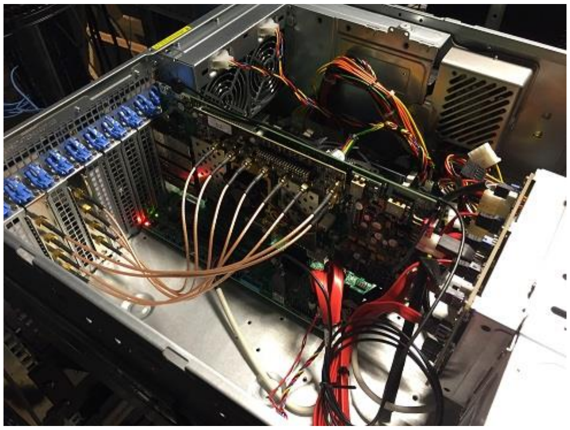

Fig. 4. The NTP servers are implemented in FPGA's, each with 4 x 10 Gb/s ethernet interfaces and can handle full wire speed NTP traffic on all ports, IPv4 and IPv6.

B. *PTP distribution*

For clients demanding accuracy higher than what can currently be achieved using NTP over public Internet or if a dedicated channel to the time source is required, generally PTP over dedicated connections is to prefer. The PTP signal, carried on 1 Gb/s synchronous ethernet, is delivered in dark fiber or in some cases using optical alien wavelength. The service is implemented using commercially available PTP grand masters with the time from the node timescales. The PTP grand masters are connected to both node timescales, with failover if the primary timescale fails. The grand master's internal phase accuracy is monitored using time interval counters. Users for these services are for instance telecommunications, power grid and financial market.

C. *Calibration*

Each time node must be calibrated in phase to compensate for site specific cable delays in connections to antennas and the fiber-based time comparison system. Calibration is performed by the national metrological institute RISE at least every second year, using a portable time calibration system designed by RISE.

The main components of the calibration system (Fig. 5) is an outdoor unit with a GNSS receiver, an indoor unit with time interval counters, and two White Rabbit links, one in each direction, to connect the outdoor and the indoor unit. Two optical fibers are required between the units for the White Rabbit links, normally previously installed fibers are used.

The clock signal from the node under calibration is connected to the indoor unit and sent using White Rabbit links to the outdoor unit and the GNSS receiver. It is also looped back using the other White Rabbit link to the indoor unit and a time interval counter to verify the integrity of the signal. The GNSS receiver uses the clock signal to timestamp the GNSS signals it receives, and common view time comparison against receivers at the RISE time lab is used to calculate the phase offset of the time node (Fig. 6).

The resulting calibration is a value of the phase offset, which is stored in node itself, and accounted for when calculations for steering of the time scales are performed.

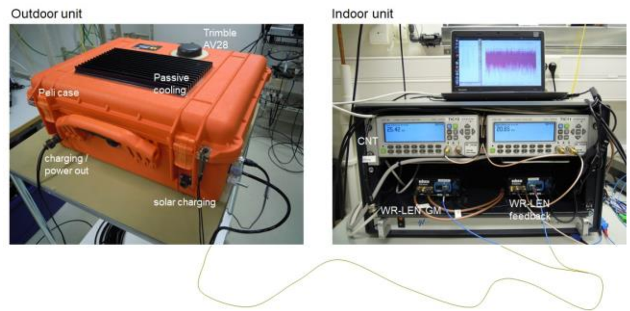

Fig. 5. Portable calibration equipment. Outdoor parts housing in a Pelican^{TM} case using passive cooling and solar charging as well as an GPS antenna. The indoor equipment is constructed of time interval counters, white rabbit equipment for time transfer and a computer for data collection.

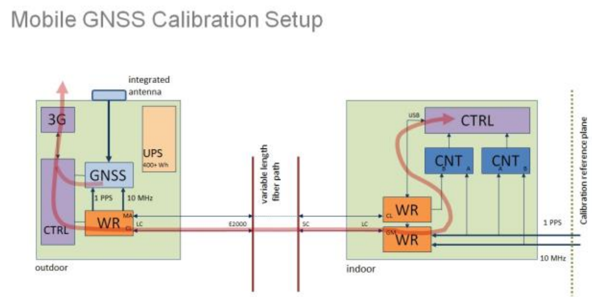

Fig. 6. The clock signal from the node under calibration is connected to the indoor unit and sent using White Rabbit links to the outdoor unit and the GNSS receiver. It is looped back using the other White Rabbit link to the indoor unit and a time interval counter to verify the integrity of the signal. The GNSS receiver uses the clock signal to timestamp the GNSS signals it receives, and common view time comparison against receivers at the RISE time lab is used to calculate the phase offset of the time node

D. *Distributed/local timescale calculation*

Work is ongoing to fully implement a distributed timescale calculation in each node. It will use all available clocks at the local node, other nodes, and other external clocks to calculate and predict the time to maximize stability during different holdover conditions. This work includes a method of continuously classifying all reachable clocks using all available time links and a method to weigh the ones currently available based on the previous classifying to produce a timescale.

IV. ROLES AND RESPONSIBILITIES

Netnod operates the time dissemination system and is responsible for keeping the nodes running and accessible.

RISE is the NMI having responsibility for the national time scale UTC(SP) and are constantly monitoring the time scales using the time comparison methods available, such as NTP service over the public Internet using high resolution NTP clients clocked by time scales traceable to UTC, and performs the biennial calibration as described.

V. CONCLUSION

A distributed, nationwide, robust, time dissemination system has been implemented and has been in operation for more than three years. The system works both as a primary time source and as a backup. At the time nodes the time scales are traceable to UTC(SP), and with calibrated time links traceability can be achieved also in the consuming equipment.

ACKNOWLEDGMENT

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[2] ITU-T G.8272/Y.1367.

[3] ITU-T G.8272.1/Y.1367.1.