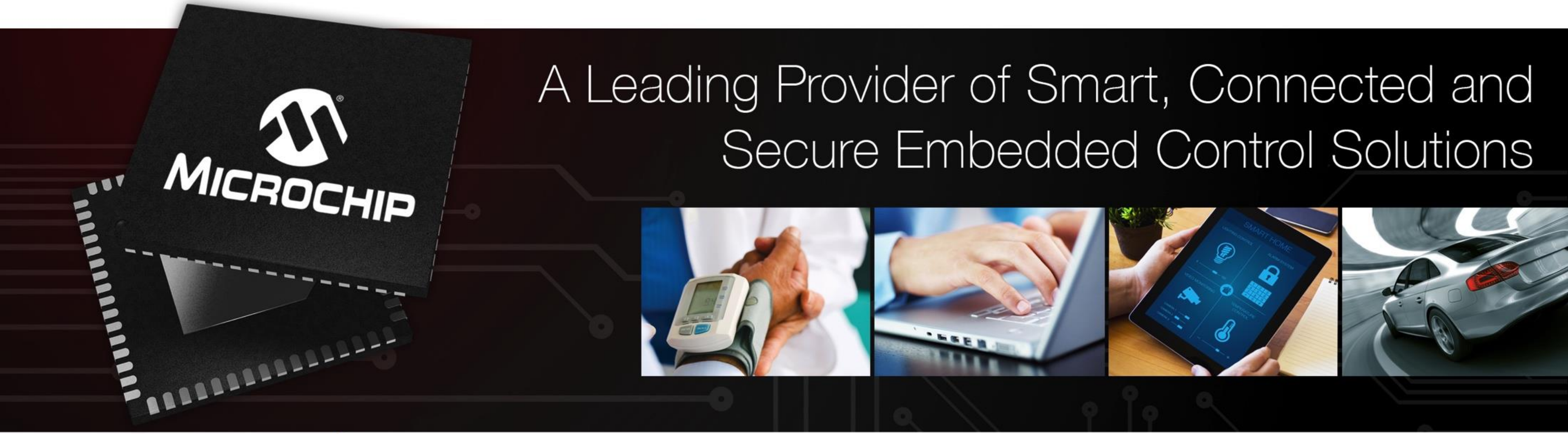

cnPRTC: Ensembling Primary Reference Clocks in a Network and the Associated Algorithms

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Introduction

Introduction

- cnPRTC “coherent network primary reference time clock”
- Evolution: PRC, ePRC, PRTC-A, PRTC-B, ePRTC
- Increased demands for accuracy and security

cnPRTC

- Network deployment and functional architecture
- Agreement algorithm, timescale algorithm, coordination function

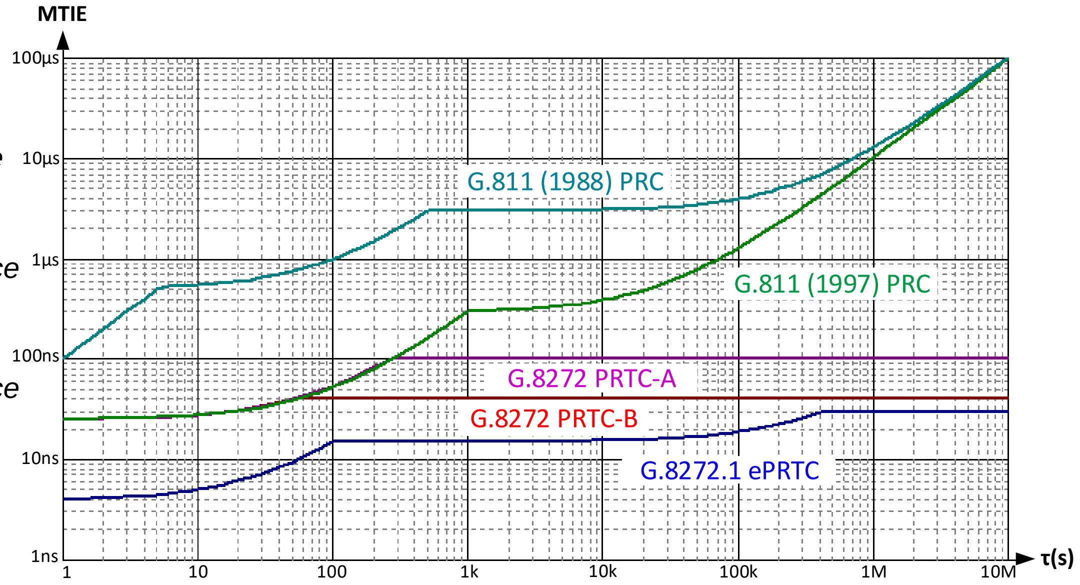
Ensembling Clocks

- Performance of ensemble vs. single clock
- Time scales

Summary

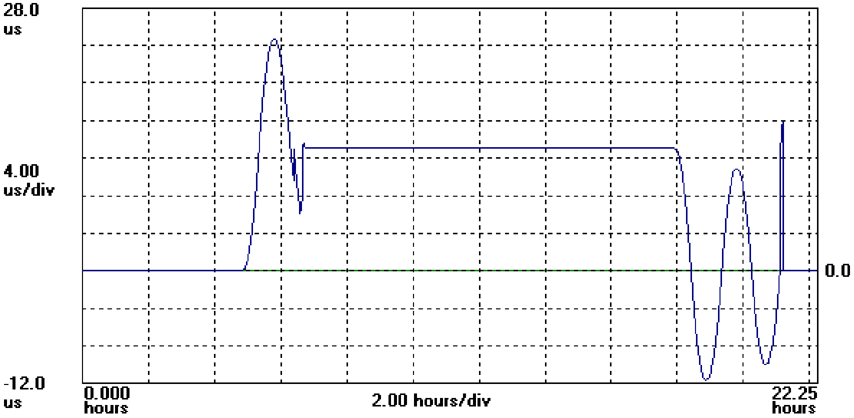
Accuracy Requirements Increasingly Stringent

- G.811 (1988) *Timing requirements at the outputs of primary reference clocks suitable for plesiochronous operation of international digital links*
  MTIE (1000s)= 3µs
- G.811 (1997) *Timing characteristics of primary reference clocks*
  MTIE (1000s)= 300ns
- G.8272 (2012) *Timing characteristics of primary reference time clocks*
  MTIE (1000s)= 100ns
- G.8272 (2018) *Timing characteristics of primary reference time clocks*
  MTIE (1000s)= 40ns
- G.8272.1 (2016) *Timing characteristics of enhanced primary reference time clocks*
  MTIE (1000s)= 15ns



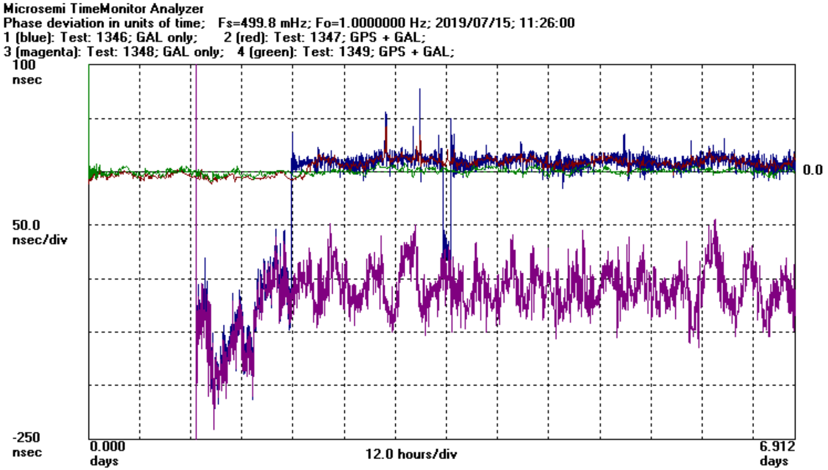
Security is an Important Issue for Timing

January 2016 GPS Segment Error:
13 µs UTC offset error

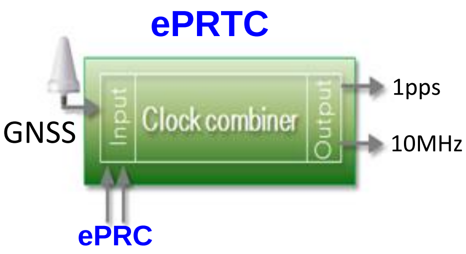


Plot showing how the anomaly event impacted one GPS timing receiver

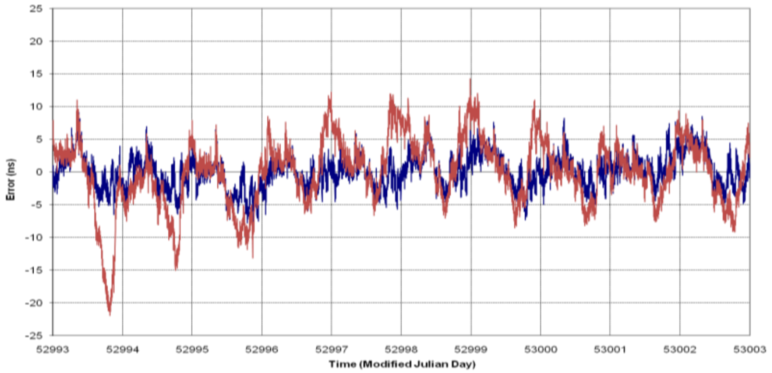
July 2019 Galileo Outage:
1-week duration



Newest PRTCs Address Accuracy and Security



ePRTC combines GNSS with an autonomous atomic clock for security (time holdover) and accuracy



Red: PRTC-A, Blue: PRTC-B

PRTC-B can make use of multiband for enhanced performance and immunity from space weather

cnPRTC builds on the ePRTC concepts of ensembling multiple sources for accuracy and security

cnPRTC in ITU G.8275 Appendix

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

G.8275/Y.1369
Amendment 1
(11/2018)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Packet over Transport aspects – Synchronization, quality and availability targets

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet protocol aspects – Transport

Architecture and requirements for packet-based time and phase distribution

Amendment 1

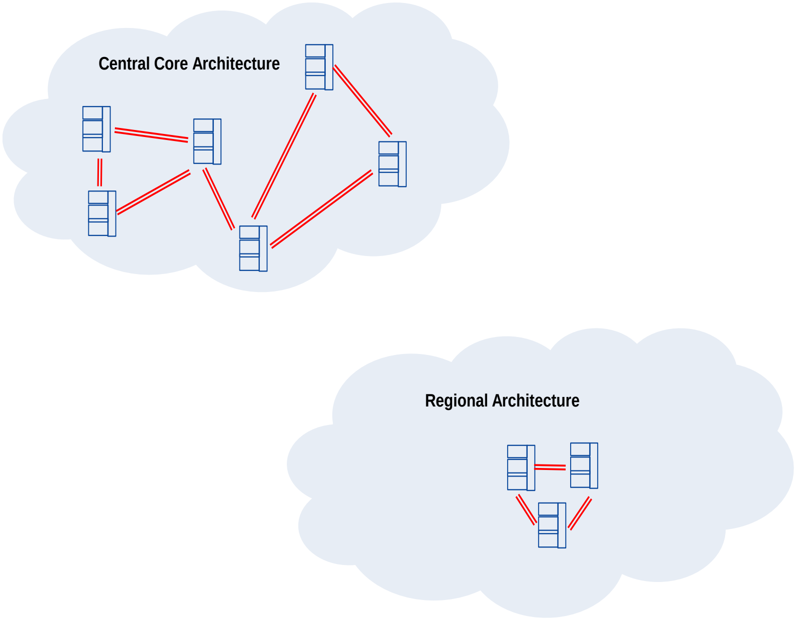
G.8275 “*Architecture and requirements for packet-based time and phase distribution*”

Amendment 1 was consented in October 2018 and contains a new appendix “*cnPRTC functional architecture*”

Amendment 2 was consented in July 2019 and adds a cnPRTC functional block diagram

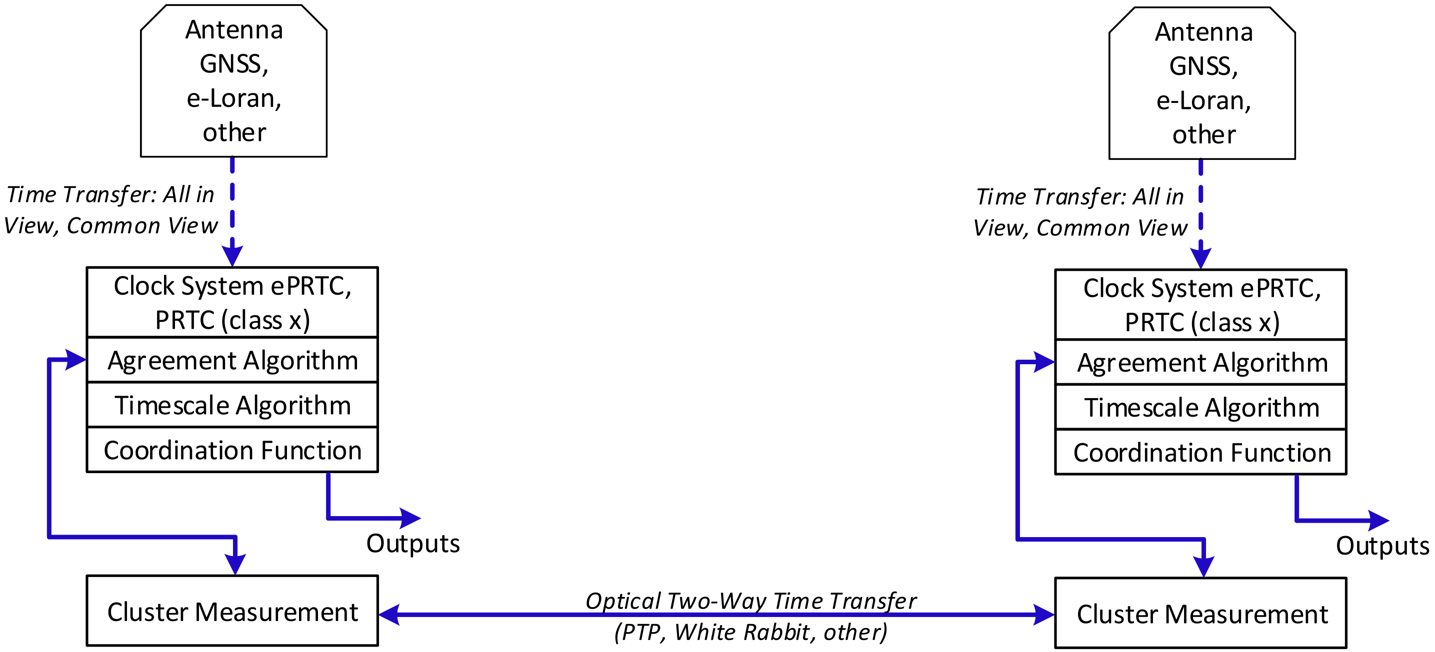
cnPRTC Network Architecture

cnPRTC Architecture Examples



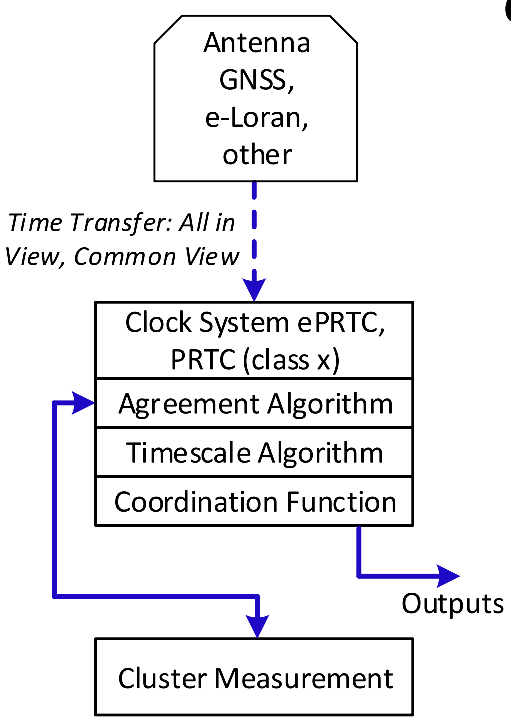
- The upper example with six clocks is applicable to a central core architecture.
- The lower example with three clocks is more applicable to a smaller, regional area.
- Note the clocks in the central core example are not fully meshed. Nevertheless, given the connections that are there, any clock can be compared to any other clock through a direct connection or indirectly through one or more intermediary connections.

cnPRTC Functional Architecture



cnPRTC Component Algorithms/Functions

cnPRTC Clock System



Agreement Algorithm

- Process both direct path and derived radio all-in-view clock measurement and remove and report faulty paths and degraded PRTC systems.

Timescale Algorithm

- Process output of agreement algorithm to determine clock state estimates of each PRTC.

Coordination Function

- Report required actions to each PRTC to support the required coherent operation.

Agreement Algorithm

- The “agreement algorithm” provides a mechanism for weighting, de-weighting or potentially eliminating clocks.
- It is important to determine the group of clocks considered worthy of including in the coherency.
- The agreement algorithm refers to a methodology for networking clocks which has been in use for a number of decades.
- It is of critical importance in a real-world application of distributed networks with distributed timescales.
- A prominent example of this is Network Time Protocol (NTP) intersection algorithm.

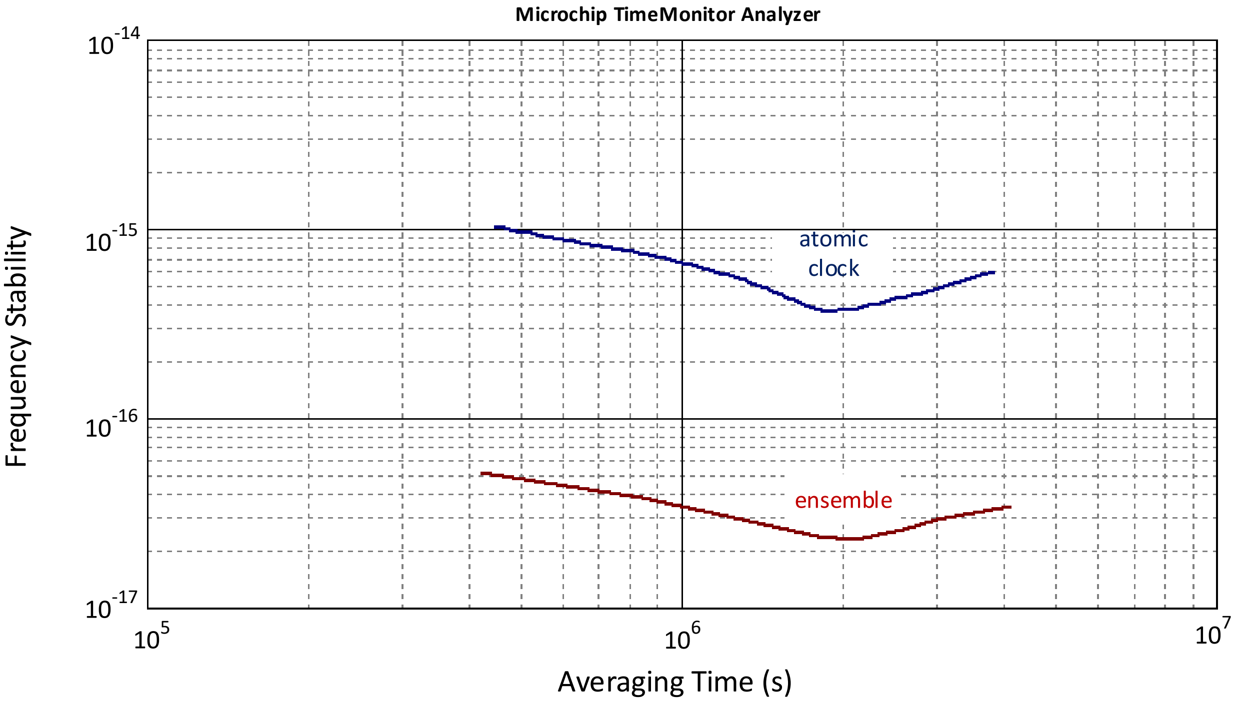
Timescale Algorithm

- The "timescale algorithm" is central to the ensembling function of the coherent network primary reference time clock.
- More generally it is central to the ensembling function of any group of clocks.
- Timescale algorithms are important to national labs and GNSS control segments, and indeed to the establishment of UTC at the BIPM.
- If the "agreement algorithm" has established a valid group of clocks, then pairwise measurements can be used to evolve the timescale.
- An example of a "timescale algorithm" among the many in use in time and frequency metrology is the International Atomic Time (TAI) algorithm.
- A timescale algorithm looks at the pairwise measurements and determines the state estimates for the phase, the frequency and the drift, that need to be applied to any of those clocks to put it on the ensemble average.

Coordination Function

- The “coordination function” applies the corrections determined by the “timescale algorithm.”
- It uses the knowledge gained from the timescale algorithm, the state estimates and goes out to all the distributed clocks with instructions for actions to take.
- It is important to note that the result of the action taken, because of errors in the system, does not perfectly match the desired action.
- Without further action there would be small accumulation of time error, with the clocks eventually drifting apart.
- Thus, continual measurements need also to be part of the coordination function, given coherency is the goal.
- The coordination function includes two things – it includes the instructions that are issued to the individual ePRTC or PRTC clocks to put them at the right time and the feedback to ensure that any errors are accounted for and corrected.

Time Scale Ensemble Performance



Time Scale Algorithms

- **Basic Time-Scale Equation:**

$$\sum_{i=1}^{N} a_i \hat{x}_i(t+\delta \mid t+\delta) = \sum_{i=1}^{N} a_i \hat{x}_i(t+\delta \mid t)$$

- Used by most time scale algorithms
- "The current estimates of the clock times with respect to the time scale are determined by the requirement that the weighted sum of the differences between the current time estimates and their predicted values is zero." (from *Advances in Time-Scale Algorithms*, Sam Stein)

- **Time Scales ("real-time" and "after-the-fact")**
  - Real-time algorithms [KAS-1(NRL), AT1(NIST)]
  - Post-processing algorithms [TA(NIST), A.1 (USNO), ALGOS(BIPM)]

- **ALGOS (BIPM) – 3 steps**
  1. Weighted average of ~350 free-running atomic clocks
  2. Steer frequency to SI second agreement
  3. Insert leap seconds to produce UTC to reconcile with Earth's rotation

Conclusions

- **The cnPRTC, “coherent network PRTC,” is driven by the need for a high level of accuracy coupled with the need for a robust, secure source of timing throughout the network.**
- **The cnPRTC is built on the ePRTC concepts of ensembling multiple sources for security and accuracy.**
- **A central component of the cnPRTC is the timescale algorithm, used in metrology to achieve the optimal time and frequency from a group of clocks.**
- **A properly designed timescale achieves a level of performance beyond that of the component clocks.**
- **Working hand in hand with the timescale algorithm are two other important components of the cnPRTC, the agreement algorithm which processes measurement information and the coordination function which conveys actions to the clocks to maintain the required coherent operation.**

Thank You

Thank You

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