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A new resilient time and frequency infrastructure for UTC(NPL)

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A new resilient time and frequency infrastructure for UTC(NPL)

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Abstract. The Resilient Enhanced Time Scale Infrastructure (RETSI) is an atomic clock network distributed geographically in secure locations, that is being developed as part of work in the National Timing Centre programme. It will become the source of UTC(NPL), the physical realisation of Coordinated Universal Time (UTC) maintained by the National Physical Laboratory (NPL) in the United Kingdom (UK). Dissemination points called User Access Nodes will link to RETSI via Orchestration Nodes, allowing users to access time and / or frequency references traceable to UTC(NPL). This will help to improve security and resilience in national time and frequency generation and distribution, enabling the UK to reduce its dependence on timing signals from Global Navigation Satellite Systems.

1 Introduction

The UK's critical national infrastructure (CNI) is heavily reliant on timing signals from Global Navigation Satellite Systems (GNSS), meaning that the use of GNSS could act as a single point of failure for many of the systems used by CNI. This risk was identified in the Blackett review [1], a study into the critical dependencies on GNSS in the UK, and was further highlighted in the 2023 update to the UK's national risk register [2].

The National Timing Centre (NTC) programme is enabling the UK to reduce its reliance on GNSS. A major part of this programme involves designing and implementing a new Resilient Enhanced Time Scale Infrastructure (RETSI), which will replace the UK's current UTC(NPL) infrastructure. Here we define the resilience of a time scale as its ability to withstand, adapt to and recover from challenges, and continue to generate its time and frequency signals. This is the key design objective for RETSI, which will have a distributed architecture at secure sites located across the UK. RETSI will form the generative core of the UK's timing system and produce GNSS-independent and UTC-traceable time and frequency signals that can be disseminated to UK CNI sectors.

In the following we present the design features of RETSI and then discuss its future applications as part of the wider NTC programme.



2 Design of the resilient national time and frequency infrastructure

RETSI is designed to be a mesh of four linked time scale laboratories (Core Nodes), that are separated geographically within the UK and located at secure sites. These Core Nodes comprise atomic clocks and other time and frequency distribution hardware, that generate several time scale realisations. At any given time, one of these realisations at one of the Core Nodes is identified as UTC(NPL), with the associated site called the ‘primary site’. The other Core Nodes in the network (at secondary sites) generate backups to UTC(NPL). The multi-site design and geographic separation of the Core Nodes improve the resilience of the overall system as it keeps them isolated from challenges local to a given site [3][4]. The high-level overview of the node structure of RETSI is shown in figure 1.

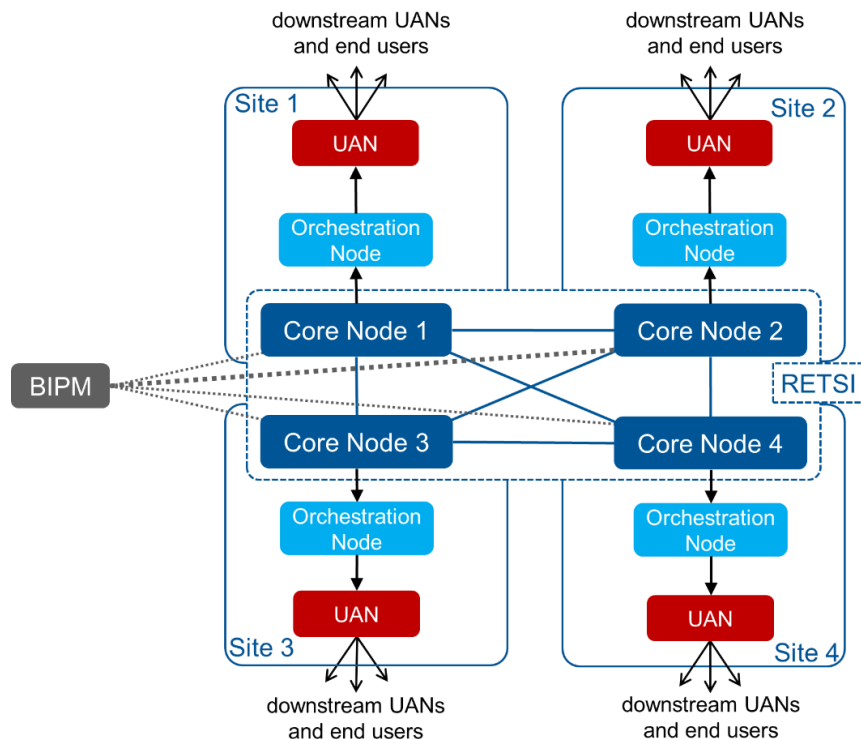


Figure 1. Concept for the design of RETSI, showing the four geographically distributed and interconnected sites, with their time scale laboratories (Core Nodes) and the interfaces to the BIPM. Solid lines indicate that both, physical time and frequency signals and data, are transferred, while dotted lines are used to indicate that only data is transferred. At any time, there is only one Core Node that generates UTC(NPL) and interfaces with the BIPM. In the example shown in this figure, this is Core Node 2 (indicated by the thicker dotted line to the BIPM), but the Core Node that generates UTC(NPL) may be changed from time to time. The Orchestration Nodes interface to RETSI and distribute its timing signals out to users via tier 1 User Access Nodes (UAN) located at RETSI sites. From the tier 1 UANs, timing signals may be distributed to end users either directly or via lower tier UANs beyond the RETSI sites.

Each Core Node produces four time scale realisations, each denoted UNR. These UNRs are outputs of frequency offset generators (FOG) that are fed from independent active hydrogen masers (figure 2). One of the UNRs at each site is designated as the reference time scale realisation for that site and is denoted UN_HUB. One of these UN_HUBs is selected to be the physical realisation of UTC(NPL). The unique aspect in the design of RETSI, compared to other national time scale infrastructures, is that the UN_HUB that defines the physical realisation of UTC(NPL) can be swiftly changed to a different physical realisation at a different site, in a process called “site selection”. This means the UTC(NPL)

time point can be relocated within the time scale network. Locally, at a given site, the UN_HUB can be switched to a different UNR at that site.

The Core Nodes are connected to each other by a network of time and frequency transfer links for comparisons of the outputs of UN_HUBs. Primarily, RETSI will use time and frequency transfer over optical fibres running between sites to facilitate such comparisons with low noise [5]. Additionally, Two-Way Satellite Time and Frequency Transfer (TWSTFT) links will be operated between sites. Operating these different modalities of time and frequency transfer increases resilience, since they have distinct failure modes, meaning they are unlikely to fail at the same time, and are both completely independent of GNSS. RETSI will continue to use GNSS time transfer methods, for cross-checking the measurements of the other transfer methods and calibration of link delays. However, RETSI is not operationally reliant on these GNSS links, hence a disruption of GNSS will not disrupt the RETSI output. RETSI will maintain traceability to UTC via the international TWSTFT links (along with calibrated GNSS measurements) between UTC(NPL) at the primary site and other UTC(*k*) labs.

A diagram in figure 2 shows the Core Node hardware including the independent maser clocks and FOGs forming the UNR chains, the time scale switches, and distribution and measurement hardware.

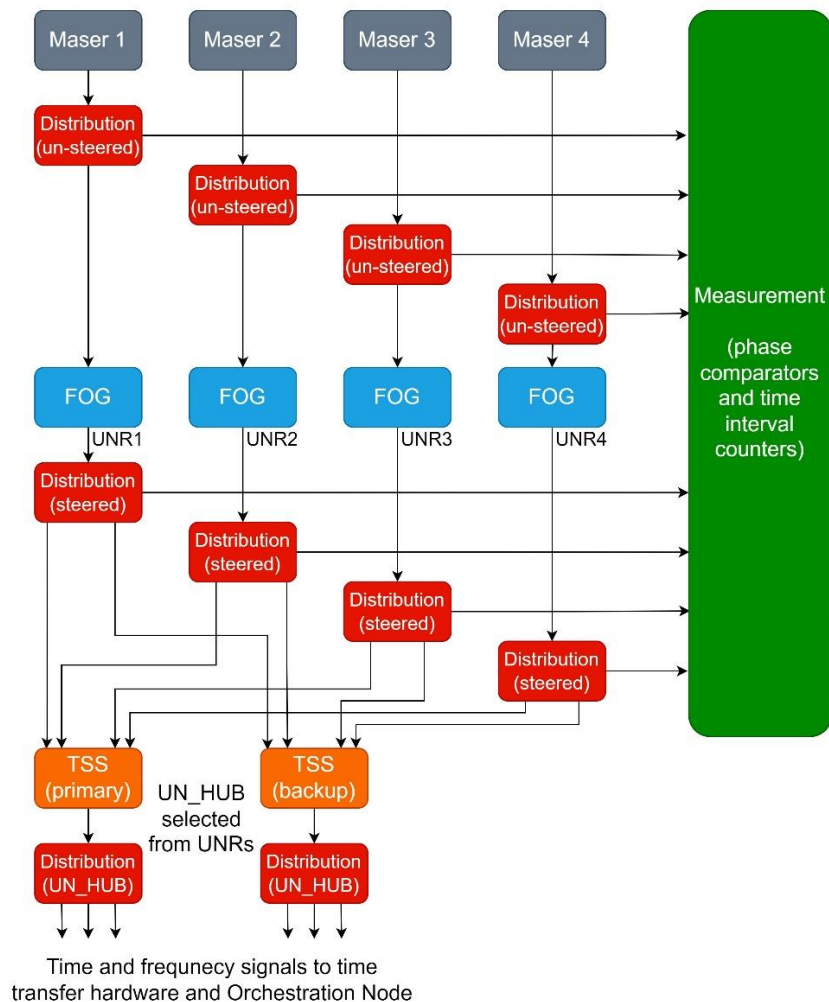


Figure 2. The concept for the generation, distribution and measurement of time and frequency signals in a single RETSI Core Node. The four maser chains allow for the generation of four independent time scale realisations (UNRs). Steers to the UNRs are applied with frequency offset generators (FOG). Time scale switches (TSS) facilitate the selection of which UNR is designated as the site reference time scale (UN_HUB). Arrows in the diagram represent the direction of time and frequency signal distribution.

Four free-running (un-steered) hydrogen masers produce 1 PPS, 10 MHz and 100 MHz signals that are multiplied in distribution amplifiers, and then measured with reference to the site's UN_HUB. Other signal copies are sent to FOGs that apply the frequency steers calculated in the RETSI steering algorithm to generate the UNR. The FOG UNR outputs are then, distributed for measurement against the site's UN_HUB. The time scale switches (TSS) implement the selection of UN_HUB from one of the UNRs. The TSS and the distribution amplifiers for UN_HUB output signals are duplicated in a separate hardware chain in order to eliminate a potential single point of failure. A timecode is also generated at each site from the local UN_HUB to provide adequate synchronisation for devices within RETSI that require it.

The UN_HUBs will be aligned to UTC(NPL) with a residual time offset of less than 3 ns, so that time steps are minimised when the UTC(NPL) realisation is changed in a site selection procedure. Similarly, the UNRs at a given site will be kept aligned to the local UN_HUB within 1 ns. The time offset of each UNR from the local UN_HUB is measured using a combination of time interval counters (for 1 PPS signals) and phase comparators (for standard 10 MHz and 100 MHz signals).

A steering algorithm will be implemented to keep all the UNRs, UN_HUBs and UTC(NPL) aligned with each other, and, importantly, to keep UTC(NPL) within a small offset from UTC (target: <5 ns; aspiration: <1 ns). The algorithm builds on the approaches of [6] and [7] and comprises both a frequency lock and a phase lock part. A stable frequency reference is derived from an ensemble of caesium (Cs) fountain primary frequency standards operated at different Core Nodes. In future, this ensemble could be expanded to include optical clocks. The frequency lock part of the algorithm steers every UNR independently using information from all available Cs fountains, including remotely located ones. The phase lock part combines time offset measurements made in real time with Cs fountain data and post-processed data on deviation from UTC published in Circular T by the BIPM. As the latter is only available with long latency, up to 40 days, the use of ultra-stable frequency standards to discipline UNRs is essential. Each month, RETSI will also submit the estimates of the average frequency of UTC(NPL) made by its primary frequency standards to the BIPM, and thereby contribute to the evaluation and steering of the UTC scale interval.

The status and performance of the Core Node output signals and time transfer functionality is continually assessed in RETSI in case of needing to change to a different physical realisation of UTC(NPL). Additionally, the primary site may need to be changed i.e., a new site selected as primary, for example when:

- the primary site is unresponsive,
- links from the primary site to other sites have failed,
- international TWSTFT links from the primary site to other NMIs have failed,
- major site maintenance is planned.

The design and implementation of RETSI respond to key needs for accurate, traceable, and highly available time reference signals across CNI sectors. As a result, its operational software adheres to the highest standards of security and reliability, to ensure its resilience to withstand, adapt and recover. The software is run on dedicated servers, and the outputs of the software are archived and stored securely. The computed outputs of the software are available to operators on a monitoring dashboard. Should problems occur during the operation, operators will be notified with monitoring alarms [8]. Hardware and software performance metrics and logs will be monitored and feed the alarms. A hierarchy of alarms, warnings and notifications will be established for the information that needs to be delivered to operators.

With the resilience of the entire system and security of the Core Nodes in mind, the distribution of RETSI output signals will be facilitated by an interface called an Orchestration Node (ON). The ON interfaces will be arranged on each site for the provision of RETSI timing signals to User Access Nodes (UAN), the nodes accessible by the users of RETSI (figure 3). ONs provide two services:

- Timing Signal Service: provision of physical signals (1 PPS and 10 MHz) from the co-located and remote UN_HUBs, 10 MHz outputs from co-located free-running masers, and timecode distribution.
- Status Signal Service: provision of information to RETSI users, that is updated every minute, indicating whether the distributed time and frequency signals are within specification. Additionally, information about pending leap seconds will be broadcast by this service. The status signal gives users confidence in the timing signals they are receiving, a unique feature and advantage of RETSI over GNSS services.

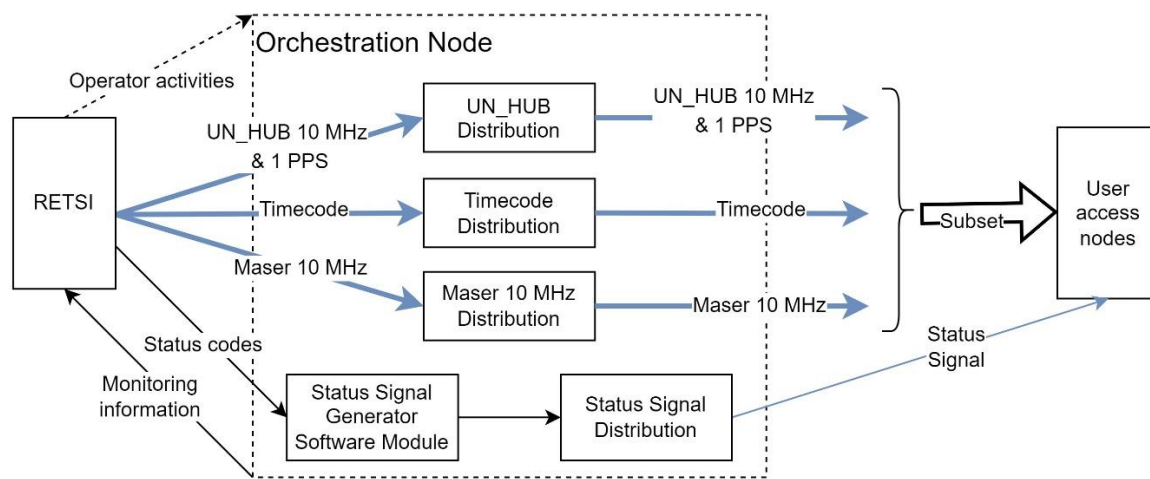


Figure 3. Orchestration Node high level design, showing interfaces with RETSI and User Access Nodes, and interfaces to the Orchestration Node. The dashed line represents the key operator management and configuration of the Orchestration Node. The subset of signals provided to an individual User Access Node is decided by its users and managed by RETSI operators.

3 Outlook

Implementation of RETSI and the Orchestration Nodes is underway. In the short-term, equipment is being installed site by site with links being formed between them. One of the RETSI Cs fountains is now operational, with the systematic effects being evaluated. Another Cs fountain is under construction. Once a robust programme of testing has been completed, a measurement campaign will be undertaken to relocate the UTC(NPL) timepoint from the legacy infrastructure at Teddington into the RETSI mesh.

The UK CNI sectors, which are dependent on time traceable to UTC, have expressed the need for dissemination of UTC(NPL) in resilient timing infrastructure. Precision time and frequency signals will be disseminated out of the RETSI time scale laboratory network via multiple UANs, which will supply industrial, academic and other specific users. UANs that interface directly to the ONs are termed ‘tier 1 UANs’. Lower tier UANs can stem out from the tier 1 nodes, thus distributing the precision time generated by RETSI to broader classes of users, especially those with critical applications for timing signals. This architecture will eventually reduce dependence on GNSS and strengthen the resilience of UK CNI sectors. Furthermore, distribution of these signals to users will drive innovation in the UK’s time and frequency sector and associated supply chain. The RETSI design allows for accommodation of the anticipated developments in optical frequency standards and the expected future redefinition of the SI second [9]. This work is strongly aligned with the UK’s Position Navigation and Timing policy framework to provide resilient, terrestrial, sovereign, and high-quality timing for the UK [10].

Acknowledgements

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