Network and Software Architecture Improvements for a Highly Automated, Robust and Efficient Realization of the Italian National Time Scale

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***Abstract*— Recently, the informatics infrastructure of INRiM Time and Frequency Laboratory has been completely renewed with particular attention to network security and software architecture aspects, with the aims to improve the reliability, robustness and automation of the overall set-up. This upgraded infrastructure has allowed, since January 2020, a fully automated generation and monitoring of the Italian time scale UTC(IT), based on dedicated software developed in-house [1]. We focus in this work on the network and software aspects of our set-up, which enable a robust and reliable automatic time scale generation with continuous monitoring and minimal human intervention.**

Keywords*— *informatics architecture; cybersecurity; redundancy; robustness; virtual machine; monitoring; maintenance; timing; time scale generation, time and frequency laboratory

I. INTRODUCTION

Time is the only measurement unit continuously available, therefore the generation of a real-time time reference is strictly connected with robustness and redundancy concepts.
UTC(IT), the Italian reference time scale, is based on a robust and redundant hardware architecture [2], put in place at INRiM premises to allow a continuous and efficient timing service. This is achieved by steering independently two Active Hydrogen Masers (AHM) towards Rapid UTC (available from the Bureau International des Poids et Mesures – BIPM) in an automatic way, generating a “master” time scale and a “backup” time scale (Fig. 1). The backup time scale is aligned to the master time scale at sub-nanosecond level in order to allow a seamless switch in case of anomalies. Such possibility is automatically ensured by a prototype unit for switching signal developed by SKK Electronics [3]. At the same time two additional test time scales are generated (highlighted in blue in Fig. 1, based on the same atomic clocks of the official ones. The test chain relies on totally independent hardware and it is used as validation platform for alternative algorithms performance and robustness tests.

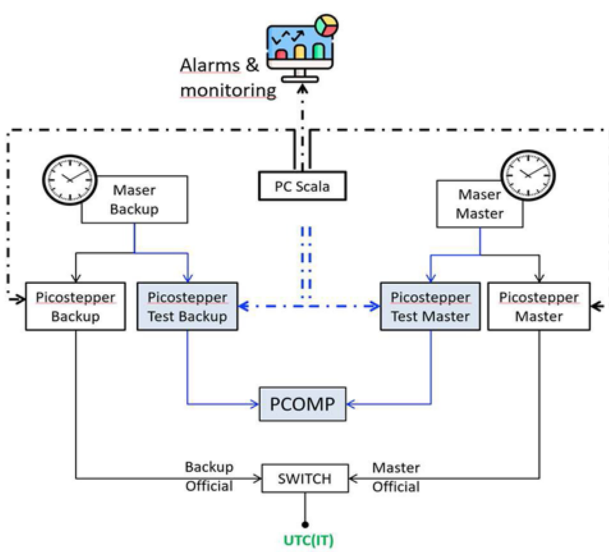


Fig. 1. The generation of UTC(IT)

In order to facilitate the management of all the equipment involved in the generation of the national time scale UTC(IT), the laboratory’s informatics infrastructure, in both terms of hardware and software, and the underlying network architecture are redesigned. Particular interests include the need to better access and control these devices remotely without compromising cybersecurity aspects, and to reduce the effort needed for monitoring and maintenance activities.

II. NEW EQUIPMENT AND THE VIRTUAL MACHINE ARCHITECTURE

Throughout years of operation, the laboratory has accumulated a variety of informatics equipment, such as desktops, laptops and industrial computers, all in different configurations and performance. While they were appropriately selected for each particular intended usage, e.g. time scale steering or data archiving, the management and maintenance activities of these devices are fairly complicated.

By identifying common elements amongst these important computers and their services, we have upgraded the computers architecture to a set of four servers (Fig. 2). These machines are of the latest generation, which covers optimal performance for a reasonable amount of time. Two servers are responsible for running hypervisors, on which virtual machines are used to replace most single physical computers. New services are also added, thanks to the powerful new hardware. The other two servers are used as Network Attached Storages (NAS) and hosts the data archive of the laboratory, which is centrally managed by the File Management System (FMS). This two-by-two approach is an implementation of our need for redundancy: the virtual machines will always have a hot/cold backup in case of failure, and the data archive is mirrored on each server, preventing both data loss and allowing minimal time to restart a failed service, while allowing reasonable time to replace faulty components. This helps ensuring INRiM services continuity, a crucial aspect for the provision of timing services to the users.

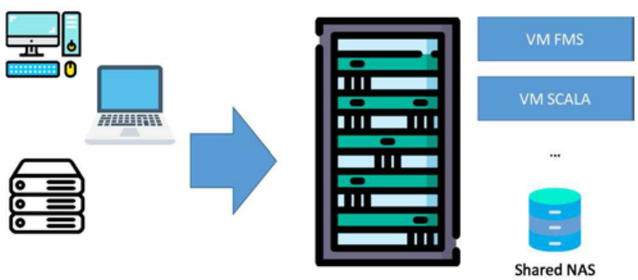


Fig. 2. Migration of services to new centralised servers

III. SOFTWARE ARCHITECTURE FOR THE GENERATION OF UTC(IT)

The new hardware architecture discussed above is backed by an efficient and reliable modular software architecture (Fig. 3). We differentiate various tasks in different scripts or executables, which allows rapid development and deployment with flexible configurations, minimal maintenance, and easy intervention.

Our various time scale generation algorithms are implemented in MATLAB®. This programming language is selected for its widely validated scientific computing capability, which allows us to not only precisely compute steering corrections, but also generate textual and graphical products for the aid of scientific analysis. Parallel Python scripts are also used for monitoring purposes, which aid in collecting output and debug data and perform some simple mathematics calculations without loading the full MATLAB® computing library.

The execution of these algorithms is orchestrated by a series of scheduled shell scripts in Linux. The popular Crond is the preferred scheduler, which has a straightforward syntax and predictable behaviour for what concerns the operations.

Input data files such as the reference data of Rapid UTC (UTCr-UTC(IT)) from the BIPM FTP server or, more recently, HTTP/HTTPS API (https://webtai.bipm.org/database), measurements of the clock time offsets and other time transfer data are available thanks to our continuous effort in digitalizing and automating the data acquisition processes [4].

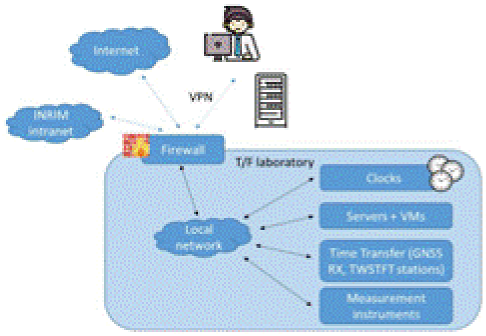


Fig. 3. New network architecture at INRiM Time and Frequency Laboratory

Upon detection of anomalies in any process, alarms are raised prompting human intervention where needed. Our technical team is equipped with detailed written procedures for recovery and maintenance purposes. The monitoring program also automatically generates daily emails on the status and performances of algorithms and UTC(IT) time scale.

IV. NETWORK ARCHITECTURE

Our new set-up is supported by a network infrastructure with an advanced level of cyber-security in order to protect the timing services provided by INRiM from possible threats coming from both inside and outside the institutional perimeter.

Another added value has been done by the improvement of the networks perimeters in terms of security aspects. Fig. 4 describes the relationship of our instruments on the networking level. We defined a local network, separated from the Internet and the current INRiM intranet by a dedicated firewall. Well- defined IP rules are put in place to manage data flows from both inside the local network and between the local network and beyond the firewall.

Remote access is granted through the use of VPN technology. The firewall is also capable of providing separate VPN accounts and defining access to only specific instruments. Naturally, the credentials are provided to staff that has specific needs for remote access.

A demilitarized zone (DMZ) has been created in order to expose external-facing services to untrusted networks and this adds an extra layer of security to protect the sensitive data stored on internal networks, using firewall to filter traffic.

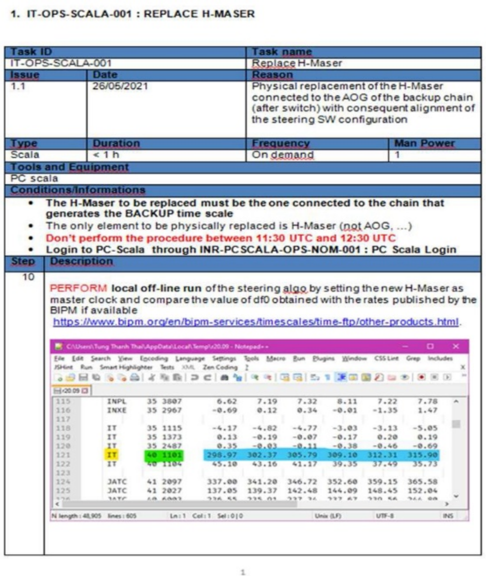
The network is also designed with a modular approach. This allows for connecting future off-site infrastructures, represented by the server rack icon in Fig. 4. This is also achieved thanks to the use of various functions of VPN technology, which connects the off-site instruments to the “main” network, allowing seamless data flows between sites and facilitate our scientific work. We have been testing this approach both locally and remotely with great success for example on a travelling station for the distribution of UTC(IT) via optical fibre over long distances.

Fig. 4. Modular software architecture for the generation of UTC(IT)

V. AUTOMATIC MONITORING - MAINTENANCE

The new overall architecture has led to greatly reduced managing and maintenance complexity with respected to the previous configuration.

On the generation of UTC(IT), a daily monitoring report is automatically generated and sent to staff via email. This includes internal parameters of the steering algorithms that are currently both in use as principal steering option and also algorithms under testing; for example, Fig. 5 shows the estimation of the AHM frequencies versus Rapid UTC and INRiM's Cesium Fountain and also the expected steering corrections. These debug quantities are useful for preliminary investigations from remote, in the case of unexpected events. In addition, the email also contains near real-time time transfer results so our staff can easily check the behaviour of the generated time scales at INRiM with respect to UTC, UTCrapid, and the best local realizations of UTC, namely UTC(k)s.



1. IT-OPS-SCALA-001 : REPLACE H-MASER

Task ID		Task name	
IT-OPS-SCALA-001		Replace H-Maser	
Issue	**Date**	**Reason**	
1.1	26/05/2021	Physical replacement of the H-Maser connected to the AOG of the backup chain (after switch) with consequent alignment of the steering SW configuration	
Type	**Duration**	**Frequency**	**Man Power**
Scala	< 1 h	On demand	1
Tools and Equipment			
PC scala			
Conditions/Informations			

- **The H-Maser to be replaced must be the one connected to the chain that generates the BACKUP time scale**
- The only element to be physically replaced is H-Maser (not AOG, ...)
- **Don't perform the procedure between 11:30 UTC and 12:30 UTC**
- **Login to PC-Scala through INR-PCSCALA-OPS-NOM-001 : PC Scala Login**

Step	Description
10	PERFORM **local off-line run** of the steering algo by setting the new H-Maser as master clock and compare the value of df0 obtained with the rates published by the BIPM if available https://www.bipm.org/en/bipm-services/timescales/time-ftp/other-products.html.

115	INPL	35 3807	6.62	7.19	7.32	8.11	7.22	7.78
116	INXE	35 2967	-0.69	0.12	0.34	-0.01	-1.35	1.47
117								
118	IT	35 1115	-4.17	-4.82	-4.77	-3.03	-3.13	-5.05
119	IT	35 1373	0.13	-0.19	-0.07	-0.17	0.20	0.19
120	IT	35 2487	0.35	-0.03	-0.11	-0.38	-0.46	-0.69
121	IT	40 1101	298.97	302.37	305.79	309.10	312.31	315.90
122	IT	40 1104	45.10	43.16	41.17	39.35	37.49	35.73
123								
124	JATC	41 2097	337.00	341.20	346.72	352.60	359.15	365.58
125	JATC	41 2027	137.05	139.37	142.48	144.09	148.45	152.04

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Fig. 5. Example of written procedure for replacing an AHM involved in the time scale generation chain

Such monitoring described above is an example of a specific service that was recently implemented. In a more generic term, a new monitoring web page (https://www.tfmonitoring.inrim.it) is available for all staff to check easily, and in every moment, the behaviour of the UTC(IT) time scale and all the other parameters of interest, including, but not limited to, internal atomic clocks parameters, environmental parameters, computer status, NTP status and overall system health. Relevant information about our time dissemination services are also made available to public access (Fig. 6).

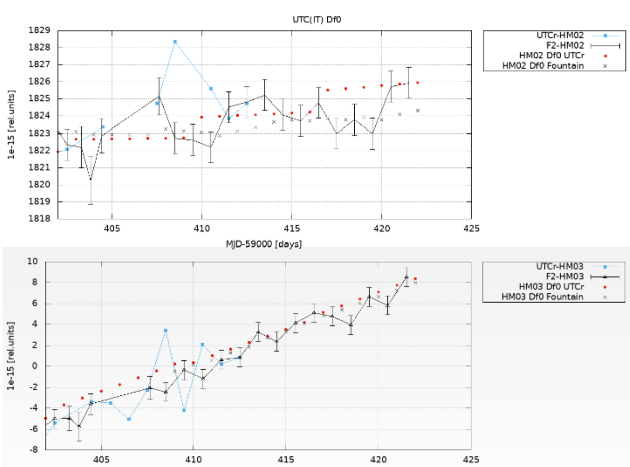

Fig. 6. UTC(IT) monitoring email: Steering corrections

Last but not least maintenance and troubleshooting procedures are defined and made available for staff; for example, see Fig. 7. Such procedures can be triggered by specific automatic alarms, maintenance needs or anomalies detected by skilled operators' observation of monitored parameters. All the maintenance, both preventive and corrective, and contingency procedures are detailed in different steps, in order to allow the proper and easily execution even in the cases in which a quickly and immediately intervention is needed.

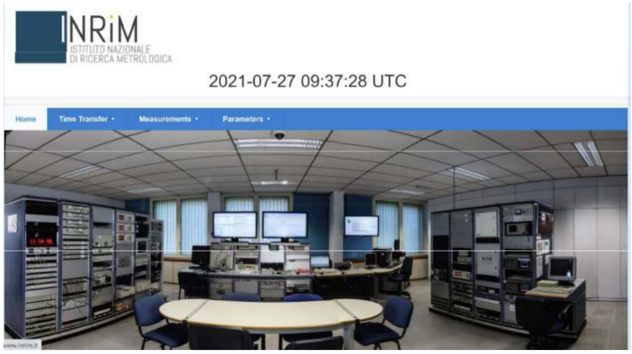

Fig. 7. INRiM Time and Frequency laboratory web page

An efficient monitoring platform is an important value since INRiM has been involving, for many years, in various projects aimed to the control of timing services provided by GNSS systems and augmentation systems, such as Galileo and EGNOS, with European Union Agency for the Space Programme (EUSPA) and the European Space Agency (ESA), alongside many other scientific and industrial partners.

VI. CONCLUSIONS

This approach to automation has proven to be efficient, shown by the state-of-the-art performance of UTC(IT) [5]. The continuous automatic monitoring allows to promptly recognize any possible issue. The modular software architecture guarantees the possibility to continuously improve the algorithms with limited coding workload. Last but not least, the informatics architecture allows a complete remote control of software as well as measuring instruments, which results to be essential during the current pandemic period.

ACKNOWLEDGMENT

Icons were taken from https://www.flaticon.com and https://webtai.bipm.org/database

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