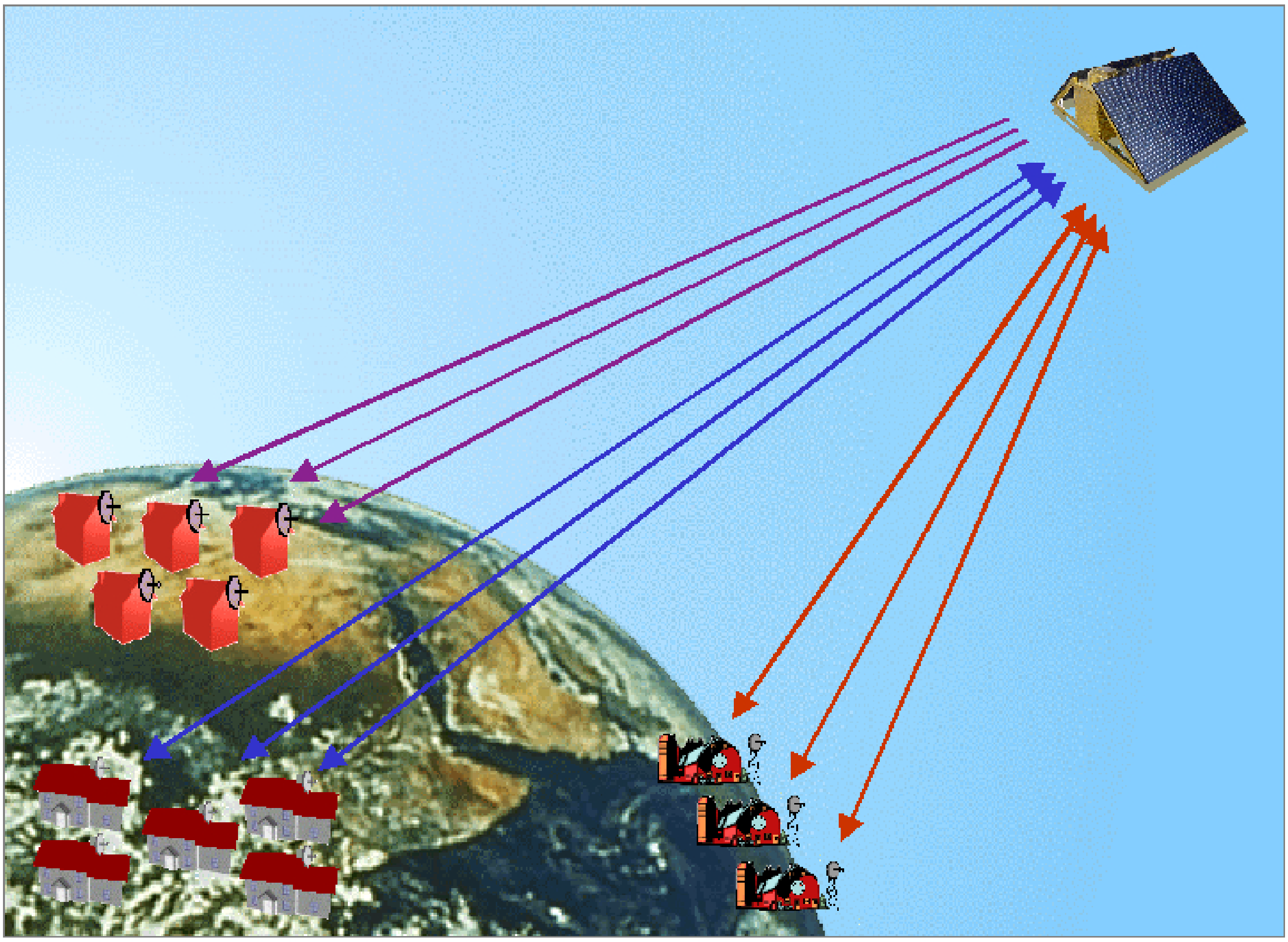
New Methods and Systems for Time and Frequency Distribution via Satellite



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NEW METHODS FOR TIME AND FREQUENCY DISTRIBUTION

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1. INTRODUCTION

The study presented in this document is intended to design an innovative clock dissemination system starting from the ESA patent 407. Nowadays a reliable and accurate clock distribution system is strongly needed both from scientific community and from business world. The today available solutions for the time and frequency reference distribution are mainly spin-off of the positioning systems and offer limited guarantees in terms of accuracy, stability and reliability.

2. UTC TIME REFERENCE

The Universal Time Coordinated (UTC) is established at the BIPM (Bureau International des Poids et Mesures) by a post-processing computation based on the data of about 200 atomic frequency standards. They are maintained in about 50 metrological or scientific institutions worldwide distributed. As a first step, the measurement data concerning clock comparisons are collected and a weighted average of clock readings is evaluated with the aim of optimising long-term stability. UTC is periodically corrected by the addition or subtraction of a second (leap second) to maintain a close agreement versus the Earth rotational time. The scale UTC was world-wide accepted and its use is recommended in many standards, starting from the “Conference General des Poids et Mesures” [1], later receipted by The International Telecommunication Union [2], [3], [4], the International Standardisation Organisation [5] and NATO [6].

3. CURRENT SOLUTIONS FOR TIME AND FREQUENCY DISTRIBUTION

The need that both scientific and industrial users have to synchronize the local references of time, or to trace the secondary frequency standards to an accepted national or international reference such as the Coordinated Universal Time (UTC), has always find satisfaction in the time and frequency dissemination services provided worldwide by diverse institutions. In this sense, any remote clock comparison technique can be seen also as a tool to disseminate a reference time scale versus a user. In this case one of the compared clocks is “the reference”, the other one is the ”slave”, that may be corrected in time and frequency to be aligned with the reference. Once the user has synchronized one of his clocks, this clock can serve as the master reference of a subsequent network of other clocks. When national or international primary standards are compared there is no more a reference and a slave distinction, but both clocks are of the same levels and often the same synchronization link is used as an intermediate mean to compare the remote clock, disregarding the disseminated time that such link may carry. In present days the time and frequency dissemination services still use terrestrial radio transmissions, when there is a need to cover a local area, but are surely of a far wider usage the satellite-based dissemination services that allow global coverage. These last can be based on satellite navigation systems (e.g. GPS, GLONASS) or on telecommunication satellites in geostationary orbits. Also the measurement techniques used are of course different as are the related accuracy obtainable by a user.
Apart from the services referred above, other means of accurate dissemination of the time and frequency information include the synchronized digital telecommunication networks and the optical fibers links. In this study, special focus is placed on the time synchronization techniques and the related capabilities for time and frequency transfer listed in the following [7]:

Terrestrial techniques:
- Network Time Protocol
- Dial-up telephone links
- Time signals from regular radio broadcasts
- Standard time and frequency transmissions
- Low Frequency navigation systems
- Television broadcasts
- SDH/ SONET digital communication systems

Satellite one-way techniques:

- Television satellite broadcasts
- GPS and GLONASS C/A code
- GLONASS P code
- GPS single channel "common view"
- GPS multichannel C/A code
- GPS P code carrier-phase

Satellite two-way techniques:

- pseudo random noise codes,
- pulsed laser.

The availability of a large variety of synchronization techniques does not necessarily mean that all the requirements coming from the users, both industrial and scientific ones, are satisfied. On the other hand, the development of primary frequency standards requires more precise and accurate means of time and frequency comparisons, especially in the short term, and the only two techniques available that could be used for this purpose, namely the Two-way Satellite Time and Frequency Transfer (TWSTFT) and the GPS/GLONASS Carrier Phase Time and Frequency Transfer (CPTFT), still need to be thoroughly experimented to fully exploit their accuracy and precision potential.

4. PROPOSED METHOD

At the current time, the most precise and accurate method for time and frequency comparisons between remote sites is the simultaneous, two-way exchange of timing signals through communication-satellite channels. The high accuracy achievable results from the use of a two-way exchange of signals which effectively eliminates the need for precise knowledge of the satellite position, the high degree of path reciprocity in the two directions, and the wide bandwidth of the satellite channel which permits -efficient signal design. One disadvantage of the technique is the need for each site to both transmit and receive signals and then to exchange the data for post-processing. The earth-station equipment at each site tends to be rather expensive, especially if the system is highly automated. Participants in the time transfers must coordinate with each other and with the satellite system operator. Because of the potential accuracy of near 1 ns and the precision of 0.1 - 0.5 ns, many timing laboratories in various parts of the world are developing a two-way time-transfer capability. Suitable satellite channels can be available throughout the world at reasonable costs. The proposed method offers, respect to techniques already available, comparable or even better performance along with the capability of supporting several ground-stations simultaneously. This capability constitutes a significant improvement respect to the traditional two-way systems, which support the synchronization of two stations only. This new feature is therefore obtained with the adoption of already existing communication techniques and with a little payload embarked on a geostationary telecommunication satellite. Furthermore the TFD network could be uninterruptedly available in real time without the necessity of post-processing. It could be envisaged that, with the launch of three TFD payloads in suitable positioned geostationary satellites, the system may broadcast a global real time reference.

5. SYSTEM DESCRIPTION

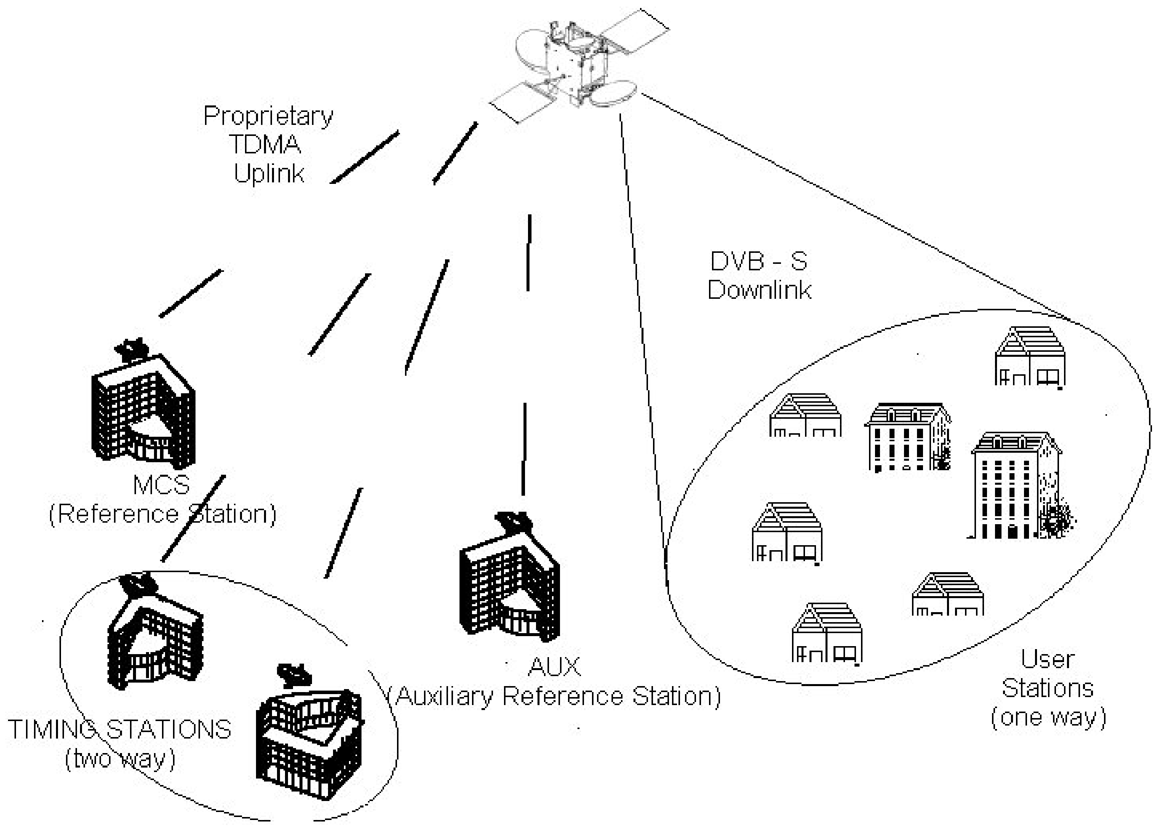

Figura 1 –System Overview

The system concept can be broadly summarized in the following points:

1. An ultra-stable state-of-the-art atomic clock located on ground is used as time reference (Master Clock Station, MCS). To ensure the system availability requirement a backup time reference will be provided in a different site (Auxiliary Station, AUX).

2. A less accurate clock is embarked on a geostationary regenerative telecommunication satellite as a piggyback, sharing with the telecommunication payloads the standard RF/IF front end.

3. The on board clock is synchronized to the ground-based time reference, using the two-way Doppler compensation technique to assure that the On Board Clock Module locks to the right frequency. In this manner the on board clock reaches the accuracy of the ground one and can be used as reference for the time and frequency dissemination.

4. The radio link connecting the ground stations and the space-based time reference is operated using a TDMA access scheme for the uplink. A suitable time slot is allocated for each two way stations accessing the network, allowing the measurement of the phase difference between the received clock and the on board reference.

5. The time/frequency reference available on the geostationary satellite after the synchronization envisaged in the point 3 is distributed using the DVB-S broadcasting system. The payload need a regenerative DVB-S processor, whose timing (i.e. the system clock) are derived from the on board clock. The results of the phase difference

measurements and related information are inserted in the MPEG-2 transport multiplex as for *private tables*. To accomplish this function, a connection shall be provided between the Time and Frequency Processor sub-system and the DVB-S sub-system.

6. The time/frequency reference will be available to users kited with DVB IRD (i.e. receive-only terminals) capable to extract and interpret the synchro information carried in the MPEG transport multiplex.

7. The time/frequency reference is also provided to "Clock Stations" and "Timing Stations". These are transmitting receiving stations, similar to the Master Control Station.

   - The Clock Stations will be state-of-the-art time reference located in scientific institutes for time and frequency standard maintenance. By accessing the TFD network, the clock stations could evaluate their error with respect to other time and frequency standards. This service will be always available and potentially suitable for a real time *official time* assessment.

   - The Timing Stations will be similar to the Clock Stations with the only difference that the time reference is not an international standard, but a simple accurate time reference, likely not atomic. These stations could access the network to improve their accuracy. A multiframe-based access could be envisaged to support a larger number of stations.

6. POSSIBLE USERS

In the following table the TFD system performance is compared with the requirements of the users:

	Telecom network	**Power distribution network**	**National metrological institute**	**Time tagging centre**	**Calibration laboratory**	**TFD**
Stability at 1 day	frequency at 10^{-11}	10^{-11}	10^{-15}	1 ms	10^{-12}	10^{-15}
Accuracy	frequency at 10^{-11}	time at 1 microsec	UTC at 10 ns synch at a few ns	time tagging at 1 s	UTC at 100 ns frequency 10^{-13}	~100ps wrt reference station
Liability	no	no	no	maybe	no	Possible

7. CONCLUSIONS

The proposed system, with respect to similar techniques already available, such as Two-way Satellite Time and Frequency Transfer offers comparable or even better performance along with the capability of supporting several ground-stations simultaneously. The TFD system could allow a real time reference distribution in a wide area (geostationary satellite footprint), even worldwide. The service is furthermore always available. The development time is expected to be short, being the system based on traditional TDMA techniques. A little payload embarked on a geostationary satellite is required. The simultaneous support of several ground stations could allow a real time calculation of an UTC-like time reference, obtained by averaging the signals provided by national or international primary standards.
The proposed solutions were tested and verified by means of a CGS developed breadboard, implementing the On-Board Clock module core functions.

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