Precise Time and Frequency Distribution over a Wireless Network for A-GNSS Users

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***Abstract*— Assisted-GNSS (A-GNSS) is an innovative technology intended to allow the use of GNSS (Global Navigation Satellite Systems) signals indoor or in environments in which the GNSS signal in space (SIS) is heavily attenuated or masked. Aiding is provided in the form of data that can be broadcast to the users via a variety of means, but primarily via the ubiquitous wireless telephone.**

ESA has tasked the DingPos project team to explore novel architectures to implement A-GNSS terminals using the SIS radiated by Galileo satellites to exploit the improved characteristics of the latter. In the framework of this project, ways are being explored to transfer precise time and frequency to the user terminal to aid in acquisition and tracking of Galileo signals. This is particularly important in the Galileo framework, where Local Elements have been sought as a way to improve the navigation system performance over limited areas.

I. INTRODUCTION

A-GNSS is a technology developed to allow GNSS receivers to operate indoor or in conditions in which the signal received is strongly attenuated. To recover the ranging signal longer integration times are necessary, which in turns requires accessing the navigation message content by other means, since this is no longer retrievable by the signal radiated by the GNSS satellites. Protocols, such as SUPL over cellular links, have evolved out of this necessity. Together with the navigation message data, differential corrections and time/frequency (T/F) information can be conveyed by A-GNSS to the user receiver to facilitate acquisition, tracking and navigation solution. Our task was to look into new possibilities to transfer time and frequency to the user receiver exploiting cellular/wireless links suitable for A-GNSS.

Cellular systems have evolved over the past 20 years from first generation (1G) analog, switched circuit-based networks to digital, packet-based networks. GSM, a second-generation (2G) cellular system, was conceived primarily as a voice communications system, with some additional features, such as SMS, which were added as additional bonus for the users.

Soon these features took over the voice messaging scheme traditional of classical telephony, and SMS messaging became extremely popular and a consistent source of revenues for cell phone operators. With it, the requirements for a higher data throughput started to arise, fueled by the extension of the SMS messaging scheme to convey pictures and, in general, multimedia information. The widespread availability of GSM networks access points started to attract data communications.

To cope with increasing needs for higher data rates and bandwidths, 2G systems evolved into GPRS services (General Packet Radio Services) for higher data rate communications and EDGE (Enhanced Data rates for GSM Evolution) services , in the so-called 2.5G systems evolution. However, the time- and frequency-related capabilities of GSM where limited by the intrinsic nature of the system (Table I).

	Case	PERFORMANCE	Comments
Synchronization	Nominal	3.69 µs	Limited by technique used
Syntonization	Nominal	$\frac{\Delta f}{f} \cong 1.1 \cdot 10^{-4}$	Maximum Likehood estimator, IS channel, E_b/N_0 = 20 dB, Normal Burst (midamble, 20 out of 26 bits)
Syntonization	Ideal	$\frac{\Delta f}{f} = \frac{1.1 \cdot 10^{-4}}{18.9} \cong 5.82 \cdot 10^{-6}$	Maximum Likehood estimator, IS channel, E_b/N_0 = 20 dB, Frequency Correction Burst (142 bits)

Table I - Summary of GSM time and frequency transfer capabilites

In the next generation cellular systems (such as UMTS) the transition to the digital communications world was completed and 3 G systems evolved as a packed-switched

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network. UMTS was intended to support data-intensive applications such as video conferencing via a mobile unit. However, the widespread diffusion of wireless connectivity for computers has threatened this position. Already VoIP applications (Voice Over IP) compete at lower cost with cellular communications services and the appearance of WiFi, and the near future of WiMAX, wireless links to computers may prove a substantial challenge to UMTS services and operators. Since 3G telephone already appears to the users as closed relatives to PDAs devices offering the same services in terms of connectivity, the future will be resolved by how much bandwidth the users will be able to access and through which technology.

The future (4G) generation of cellular phones will likely evolve to meet multimedia connectivity needs, whereas voice communications will become just one of the services offered to the users, in the form of VoIP (Voice over Internet Protocol) services. Actually most of the proposals, such as the IEEE 802.16m standard (also dubbed as WiMAX II), are oriented to provide Internet-type services with VoIP to support voice communications (ref. 6).

Table II - Intercomparison between various network protocols (IRIG, NTP, IEEE-1588, from ref. [4])

	IEEE-1588	NTP	IRIG
Peak time transfer error	> 100 ns	> 1 ms	10 µs
Network type	LAN[1]	LAN/WAN	Dedicated coaxial cables
Spatial extent	A few subnets	LAN/WAN	2 km over coax
Style	Master/slave	Peer ensemble & client/server	Master/slave
Protocols	UDP/IP – Multicast	UDP/IP – Unicast (mainly)	N.A.
Latency correction	Yes	Yes	Cable length to slave
Protocol specifies security	No	Yes – MD5 or Autokey	No
Administration	Self organizing	Configured	Configured
Dedicated hardware interface	Required for highest accuracy	No	Required
Update interval	≈2 seconds	Variable, nominally a few minutes	1 second

While in 2G and 3 G systems T/F dissemination was severely limited by the cellular networks capability and bandwidth , 4G will provide bandwidth and a network structure capable T/F dissemination to user terminals with unprecedented accuracy. Therefore, we are led to look into the existing T/F protocols for (wired) Internet/Ethernet such as NTP (Network Time Protocol) and PTP (Precise Time Protocol, IEEE-1588) to assess their capabilities to transfer time and frequency to remote users over a wireless network.

[1] Special switches are required

In the second half of the 1980's the Internet was developing from the Arpanet network into a truly worldwide data exchange service. Prof. David Mills, at the University of Delaware, started working on the development of a protocol (ref. 5) to transfer precise time via the Internet, where precise was to be intended in the level of a few ms, which was deemed excellent for worldwide distribution to a mass of users which did not require precise time. This effort was paralleled by other efforts, mainly led by national metrological institutes, to distribute time in a digital format suitable for computer use. These parallel efforts led to the development of a number of telephone time codes in Europe and in the U.S. that were soon superseded by the new Internet NTP (Network Time Protocol) standard. The NTP standard is now in widespread use and has effectively contributed to the disappearance of a number of standard time and frequency radio transmissions (broadcast) in the LF, MW and HF bands.

NTP resorts to statistics to achieve a reasonable result, by computing the estimated propagation delay over a large number of measurements, and achieves in a Wide LAN (WLAN) an estimated accuracy between 10 ms and 1 s with good reliability. Over a more restricted LAN, the accuracy of the time synchronization can improve up to 1 ms, the main limitation coming from regenerative nodes, such as network switches, which add unpredictable delays in the propagation of the messages.

However, the intrinsic wideband nature of the modern networks allows for far better synchronization accuracy than 1 ms if the delay uncertainties in networks switches and routing elements can be eliminated. From the experience of NTP a group of industrial electronics companies, headed by Hewlett Packard (now Agilent Technologies) recognized the advantages for industrial automation of distributing accurate time (and frequency) via LAN for SCADA applications and at the end of the 1990's a new standard started to form, which later became the IEEE-1588 standard (ref. 1), also known as PTP (Precise Time Protocol).

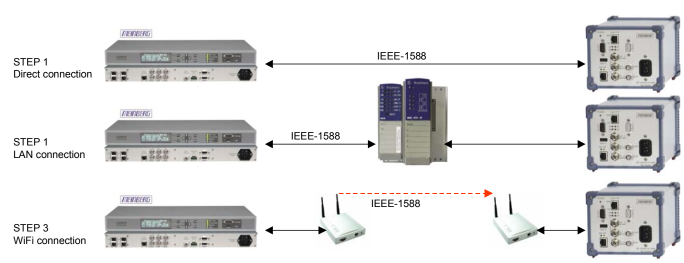

Figure 1 - Various connectivity configurations are tested sequentially to assess the T&F transfer capabilities of IEEE-1588 in different configurations

PTP reflects the LAN structure and reverts to a Master-Slave configuration, typical of a very accurate clock distributing time to less accurate clocks (ref. [3])This is in marked contrast with NTP, which is peer ensemble and client-server based, reflecting the open structure of the Internet as opposed to the hierarchical and fixed structure of an industrial LAN.

PTP is limited to LANs, does not specify statistical data processing to implement the synchronization (this is left to the user if he chooses to), but demonstrated microsecond and sub-microsecond synchronization accuracies over a LAN. This is certainly very attractive for A-GNSS applications. However, most of the PTP applications rely on wired networks. Therefore, in the course of the DingPos study, we have carried on a laboratory experimentation designed to assess the capability to distribute precise time and frequency over a wireless network and compare the results so obtained with parallel testing using wired connections.

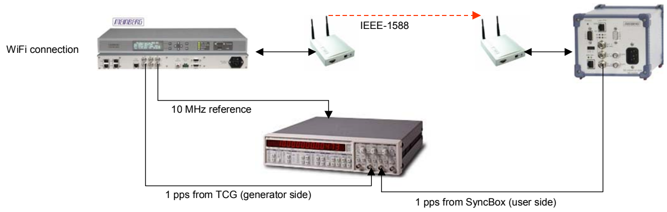

Figure 2- Test setup, synchronization error

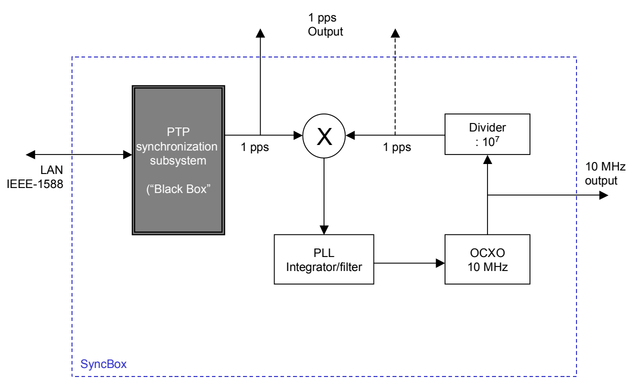

Figure 3 - 1 pps recovery in time transfer

II. Experimental Measurements

To demonstrate the capability to transfer time and frequency (T&F) to a remote terminal via a WiFi link and the IEEE-1588 protocol a demonstrator platform was developed and assembled in SEPA. The goals of the demonstrator are twofold:

- demonstrate the capability of the IEEE-1588 protocol to disseminate T&F information to remote terminals with sub-microsecond accuracy;
- demonstrate the capability of a WiFi connection to support IEEE-1588 T&F transfer to remote terminals.

To this end, we used commercially-available IEEE-1588 equipment from Meinberg to make a proof of the concept. With reference to Figure 2, a Meinberg M600 GPS-synchronized NTP/PTP server has been used to generate the PTP protocol messages sent via a wireless link to a Meinberg SyncBox that regenerenates T&F signals (10 MHz, 1 pps and IRIG-B). The inner working of the SyncBox is proprietary to Meinberg. However, it was apparent from the measurement data that the 1 pps output from the SyncBox was taken directly as the output of the PTP synchronization process (Figure 3) with no filtering on the 1 pps recovered. Meinberg was prompt to reply to our concerns, and they allowed us to test a new development, an M600 configured as a PTP slave to retrieve the 1 pps "filtered" by the integrating loop locking the internal 10 MHz oscillator to the external reference provided by the PTP (Figure 3). Therefore, we were able to test both units and compare the raw data from the SyncBox with a "filtered" 1 pps produced by the M600. In parallel, as a mean of assessing the performance of the equipment in a wired connection, we tested various configurations (Figure 1): a point-to-point link, a link via a switch (using different switches) and even a PC-board, developed for the IEEE-1588 by the Zurich University School of Engineering and provided to us by Meinberg as a part of their IEEE-1588 Evaluation Kit.

A direct connection to the SyncBox provided an assessment of the intrinsic capability of PTP to transfe r time (an arbitrary offset of about 88 ns has been added to the data to remove counter ambiguity around 1 s). The mean of 85.6 ns and standard deviation of 9.04 ns, so that both accuracy and precision are excellent. As you can see from the plot, the internal oscillator is apparently left to drift until it exceeds a predefined threshold (25-30 ns) that resets the 1 pps.

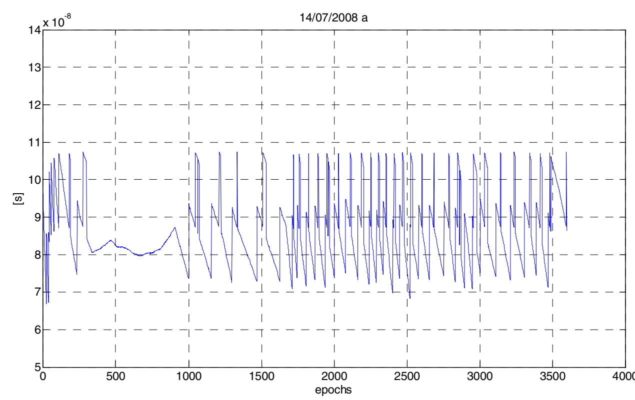

Figure 4 - 1 pps recovery, direct connection [arbitrary offset added (≈88 ns)]

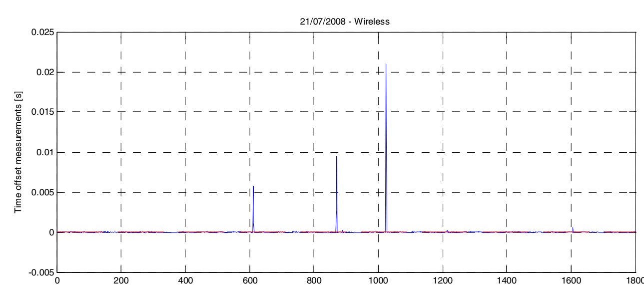

Figure 5 - Wireless connection, 1 pps behaviour

When interconnected via two access points, some outliers are apparent. Removing the outliers still results in noisy data, with mean and standard deviation of -2.94 µs and + 19.54 µs respectively[2]. The test with the M600 used as a receiver,

[2] We tested the wireless connection at 11 Mbps and 54 Mbps data rates, fixed (to constraint the latency and delays), with

filtering the 1 pps output, produced much better results shown in Figure 7: the mean is 233.24 ns and the standard deviation is 748.58 ns, a clear improvement with respect to the test with the SyncBox. No outliers are present. An additional run provides comparable results, with the mean being 186.11 ns and the standard deviation 567.90 ns.

Testing the frequency transfer capability, it appears that the algorithm corrects the frequency in relatively large steps (Figure 8), limiting the frequency accuracy in the transfer to a few parts in 10^{-8}.

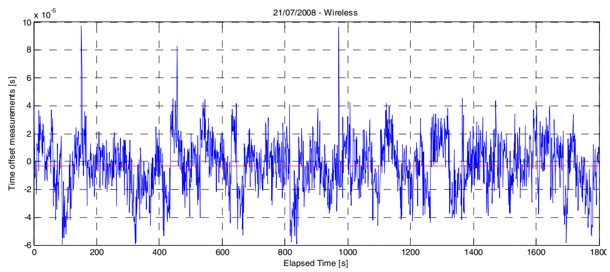

Figure 6 - Wireless connection, 1 pps behaviour, outliers rejected

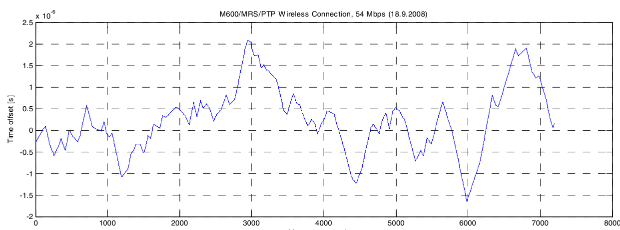

Figure 7 - M-600/MRS/PTP via WiFi link at 54 Mbps

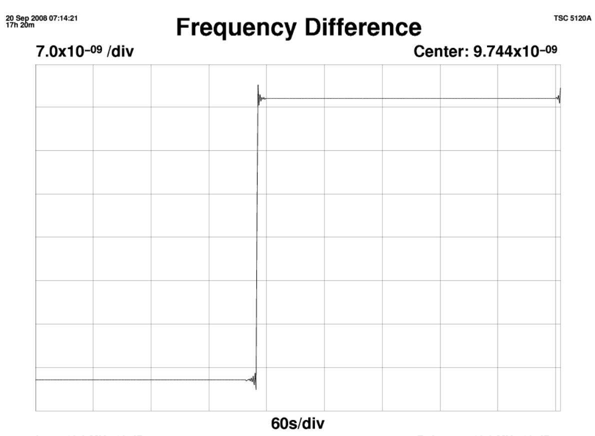

Figure 8 - Frequency correction applied to steer the frequency

It is no surprise that the Allan deviation peaks at around $3.5{\cdot}10^{-8}$ at τ = 1000 s. If this is the effect of the time constant of the loop under these conditions, having the free-running oscillator a stability in excess of $1{\cdot}10^{-9}$ at 1 s, the long time constant will result in a peak-to-peak time drift in the order or greater of 1 μs under these conditions, that is consistent with what has been observed on the 1 pps measurements.

Tests have been carried on to verify the effects of network loading on a wired network with two different types of LAN switches. The results seems to be dependent on the processing power of the switch. For a high-performance switch (HP, less noisy) we found a slight increase in time offset (error) when loading is removed and a significant increase in noise when loaded. A less-performing switch (Hirschman industrial switch) showed a marked increase in time offset (error) when loaded and a slight increase (not significant at this level) in noise.

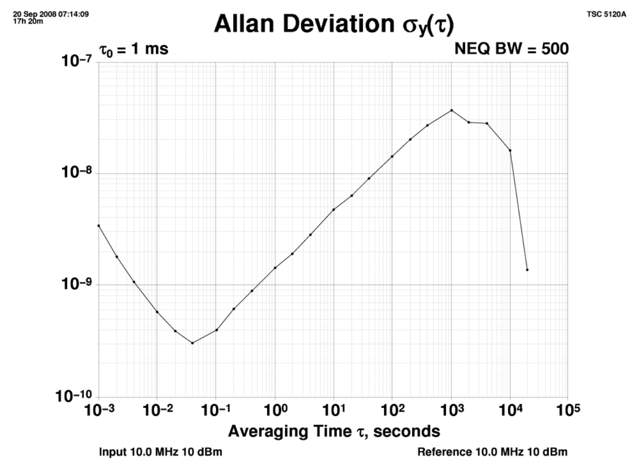

Figure 9 - Allan deviation after 17 hrs 20 min

It is clear from various tests performed with additional Meinberg equipment and different recovery algorithms that:

- the Meinberg equipment provides an excellent tool to test and exercise the PTP T&F transfer capabilities, but some work needs still to be done to optimize the performances; since PTP does not specify data processing as part of the standard (as is the case of NTP), the particular implementation of PTP recovery at the receiving end affects significantly the results;
- the equipment architecture, components (local oscillators) and algorithms should be optimized for the particular noise introduced by the link, link asymmetries and local oscillator stability to achieve the best performance in PTP time and frequency transfer
- some work is certainly needed to improve the wireless link access points in supporting time transfer, work that has been certainly carried on wired switches;

Nevertheless, it is the opinion of the authors that better results can be achieved by the use of PTP than those demonstrated by these tests, but additional work must be done both to understand how the various network latencies affect the time transfer and to optimize the algorithms and equipment with respect to the particular operating conditions.

no significant improvement at 54 Mbps over the 11 Mbps connection.

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