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Using PTP for Synchronizing Legacy Networks

Martin Burnicki (martin.burnicki@meinberg.de)
Heiko Gerstung (heiko.gerstung@meinberg.de)
Udo Maltzahn (udo.maltzahn@meinberg.de)

Meinberg Funkuhren
Auf der Landwehr 22
31812 Bad Pyrmont
Germany

http://www.meinberg.de

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1. Introduction

This document summarizes the contents of the presentation at the IEEE 1588 conference 2005 in Winterthur, Switzerland and tries to reflect the contents of the presentation as complete as possible.

It contains some background information and describes the approach of two PTP/IEEE1588 applications Meinberg developed as a reaction to customer demands.

The authors would like to thank the hosts of the IEEE 1588 conference and plug-fest, namely the IEEE, NIST and the Zurich University of Applied Sciences (ZHW). It has been a very interesting and valuable experience for us and we congratulate the organization team for making this an outstanding event.

If you have any further questions regarding NTP, PTP or the Meinberg product range, please do not hesitate to contact the authors or info@meinberg.de.

2. Motivation

The Meinberg customer base is mostly interested in Network Time Protocol based synchronization, but recently a few customers started to show interest in PTP/IEEE 1588 compatible products. Most of those customers need to use both protocols, NTP and PTP, to synchronize their NTP/SNTP clients and their PTP clients. Therefore using a single time source for these two worlds seems to be a cost-effective way of meeting the demands of the end users.
A growing number of companies feel the need for time synchronization in their networks. As technical advancement goes on, growing demands for accuracy let customers ask for sub-millisecond performance, which cannot be guaranteed for NTP infrastructures.

The available solutions for high accuracy time synchronization are mainly based on the deployment of multiple hardware reference clocks in all systems with such a requirement for accurate time stamping data or time controlled processes. The possibility to use standard cabling systems for high-precision time synchronization instead of installing dedicated time sync cables (e.g. for IRIG signal distribution) is an interesting and cost saving approach for most end users.

For special applications like underground installations or other locations where the reception of a time signal like GPS or long-wave radio (e.g. the German DCF77 or the UK MSF signal) is simply not possible, the alternative of using a legacy Ethernet/IP based network for time synchronization is an interesting way of getting the time signals to the point where they are needed.

3. Today's Solutions

3.1) Network Time Synchronization

When it comes to time synchronization in legacy networks, the vast majority of systems go with NTP (Network Time Protocol) or SNTP (Simple Network Time Protocol), both sharing the same packet format. They mainly differ in how a client deals with the time synchronization information it receives from the server. While NTP clients calculate the current time with a weighted average over a set of servers and smoothly adjust their clock, SNTP clients often simply take the time received from one server and step their clock to be in sync.

While NTP is reported to achieve accuracy at the microsecond level, this is possible only in ideal environments where the NTP clients and servers are facing low workloads and no asymmetric network delays are experienced. The typical performance level of NTP time synchronization is in the 1 – 10 milliseconds range, which is sufficient for most of today's applications … but not for all.

3.2) Single Node Synchronization

Where the accuracy of NTP/SNTP is not sufficient enough or where no network is available at all (i.e. in standalone systems), the common way of getting time synchronization is to integrate some kind of hardware time reference into a system.

A number of different references can be chosen from, their individual availability is depending on the geographical location and the existence of other time sources.

A short and incomplete list could look like this:

- GPS based radio clocks (antenna location needs to have a free view to the sky, globally available)
- Long wave Radio Signals (regionally different, not available everywhere)
  Examples: DCF77 (Germany), MSF (UK), WWVB (USA), JJY (Japan).
  See http://www.npl.co.uk/time/time_trans.html for a comprehensive overview
- Frequency Standards / High Quality Oscillators (setting the start time manually and feed a PPS/10Mhz signal into the to-be-synchronized system which is generated by a highly accurate frequency standard, e.g. a cesium based system, or a high quality OCXO based system)
- IRIG (needs a dedicated cable and another time source capable of generating the IRIG signals)

4. Differences between NTP and PTP/IEEE1588

4.1)Network Infrastructure

While NTP was designed for operating in legacy networks including WAN links and Internet connections, PTP's favored network environments are small and dedicated networks used for specific applications, e.g. process automation networks.

NTP is mostly used in unicast mode, i.e. a client directly requests time synchronization from one or more servers and receives an appropriate reply. A roundtrip delay is then calculated by the client based on four timestamps (T1: Client sending the request, T2: Server receiving the request, T3: Server sending the reply, T4: Client receiving the reply). In environments where reduced network traffic is preferred and lower accuracy can be accepted, NTP can be used in broadcast or multicast mode where the server periodically sends out time synchronization packets as broadcast or multicast packets. Only at startup a client sends requests in order to measure the roundtrip delay, which is then applied to all incoming broadcast/multicast packets.

PTP is a multicast based protocol, where the Grandmaster Clock (this would be a "server" in NTP terminology) sends out its sync messages as multicast packets.

4.2)Time Sources / Redundancy

An NTP client is capable of receiving time from multiple upstream servers and calculates a weighted average based on measured quality (e.g. roundtrip delay, jitter, offset) and advertised information (e.g. stratum level) of each server. When one of the servers selected for synchronization fails or does not respond anymore, the client automatically removes it from its list of selected time sources. As soon as it comes back, it will be added (given the quality factors are sufficient).

The PTP approach is to select exactly one source of time (the Grandmaster clock) with a defined algorithm (the Best Master Clock selection algorithm) and all clients are ultimatively following this Grandmaster clock. The selection of the Best Master Clock is based on a comparison of clock descriptors, i.e. the "advertised" properties of each available clock. Redundancy is currently not implemented but a subcommittee is working on adding redundancy mechanisms to the standard.

4.3)Accuracy

Where NTP reaches a level of accuracy in the microseconds, PTP is capable of performing in the nanosecond range. The typical NTP accuracy within LAN infrastructures can be between 1 and 10 milliseconds. Over WAN/Internet connections it is usually better than 100 milliseconds.

PTP performance in LAN environments has been proven to reach a level of <10 nanoseconds with hardware implementations (hardware time stamping at the MAC/PHY level), pure software implementations can be in the microseconds range.

4.4)Security

Because NTP is used in legacy network structures and even over insecure Internet connections, security mechanisms have been introduced in the protocol at a very early stage. The current version 4 of NTP includes both symmetric and public key cryptography for signing NTP packets. The so-called autokey mechanism is used to exchange public keys without manual intervention. Because PTP/IEEE1588 was designed for separated and dedicated networks, no security features have been built into the first version of the standard. There are ongoing efforts to introduce security features in PTP, but this is still a work in progress.

4.5)Target Audiences

The two protocols were initially designed to cope with completely different demands. Where NTP is mainly used to synchronize legacy computer networks, PTP has been designed to deal with higher demands on accuracy in specific LAN-only environments, customers can be found e.g. in the process automation industry.

As other fields and markets start to demand a higher accuracy, more and more possible applications for IEEE1588 appear on the scene, all of them more or less requiring additions to the protocol standards. One example is the telecommunication industry, which is very interested in getting time synchronization over their packet networks when upgrading/changing their network infrastructures. In this field, security and redundancy are important factors and the next version of the IEEE1588 standard will have to address this.

5. Identified Applications

Two different applications were identified which could be of interest for operators of legacy networks. The first application is targeted at end users running NTP clients as well as PTP clients, the second application is using PTP to improve accuracy in a typical NTP infrastructure.

Both applications are based on an NTP Time Server with an internal GPS radio clock providing high accuracy time data received from the Satellites of the Global Positioning System (GPS), operated by the US Department of Defense. More info on GPS can be acquired here: http://tycho.usno.navy.mil/gpsinfo.html

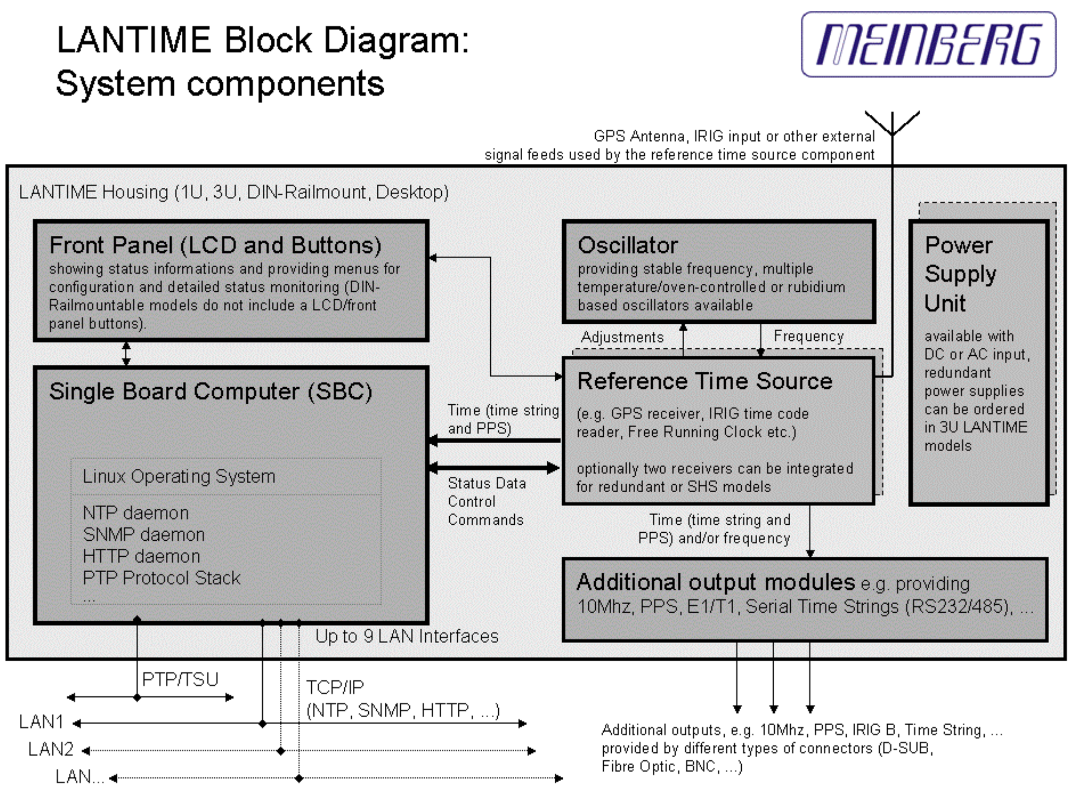
While GPS is used as a reference source for accurate time, any other time reference could be implemented to receive the current (absolute) time from any source that provides sufficient accuracy.

5.1) Application 1: Combined PTP Grandmaster Clock and NTP Time Server with GPS

In environments where both protocols are needed, a combined source of absolute and accurate time can offer several benefits:

- Both NTP and PTP client groups use the same time source (comparable time stamps)
- Equipment diversity can be reduced by integrating two related functions in one system, this means reducing costs for installation and maintenance

In order to be able to serve both NTP and PTP clients, an existing product design has been enhanced by adding an IEEE1588 compatible network port with an attached time stamping unit.



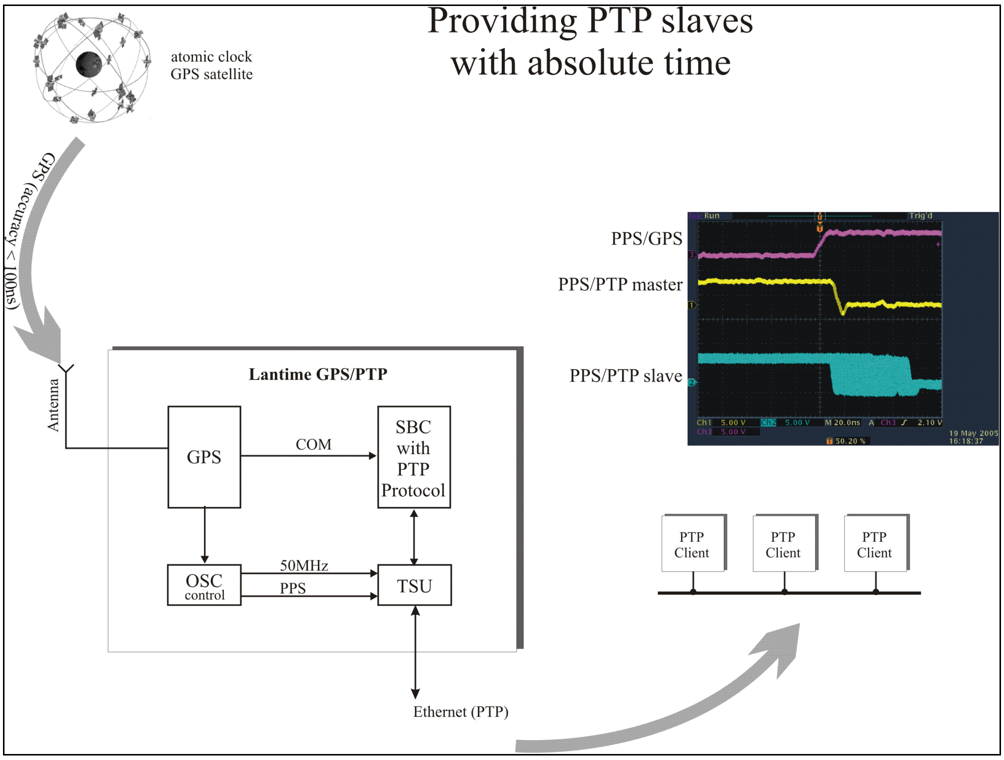
The basic system architecture of a LANTIME NTP Time Server consists mainly of a Single Board Computer (SBC), a high quality oscillator and a Reference Time Source, which is a GPS receiver in this project. After it has synchronized to the GPS signal, the receiver disciplines ("adjusts") the oscillator. This way the frequency provided by the oscillator is kept closely to the GPS frequency, which is important for having a good starting point as soon as synchronization is lost. When the GPS signal is unavailable or the receiver looses synchronization due to any other reason, it will start free running using the oscillator until GPS synchronization can be reestablished.

The NTP subsystem is reading the reference time from a serial time string and a PPS signal, both delivered by the GPS receiver.

The design of the PTP/IEEE1588 part of this solution can be described like this:

- The 50 MHz clock of the Time Stamping Unit (TSU) is derived from the high quality oscillator (OSC)
- At start-up the clock of the TSU is set to the GPS time (absolute time)
- The TSU has an additional input with which the nanosecond part can be zeroed. The PPS output of the GPS receiver is connected to this pin and is used to reset the ns part once the internal oscillator of the GPS receiver has warmed up (meaning necessary adjustment steps are under a certain limit)
- By using this mechanism, the TSU timestamp offset from the GPS PPS can be kept smaller than 20 ns

A short diagram showing the general concept of the GPS based Grandmaster clock:



5.2)Application 2: Using PTP to synchronize a „slave“ Time Server

In order to improve accuracy in pure NTP driven synchronization networks, PTP/IEEE1588 can be applied to bridge certain parts of the network maintaining a level of accuracy that could not be kept with NTP.

As a second application a LANTIME NTP Time Server was modified to additionally act as a PTP slave, using the IEEE1588 synchronization as the primary reference source for its NTP subsystem. The combined PTP Grandmaster clock/NTP Time Server with its GPS receiver (as described in Application 1) is used as the primary reference.

The benefits of this application are:

- NTP clients who are located at the other end of the network can be synchronized with a better accuracy, if a nearby NTP time server is synchronized with PTP
- Multiple output signals can be provided at the PTP slave location by using the internal high quality oscillator and discipline it based on PTP/IEEE1588 time synchronization, e.g. 10 MHz, PPS, E1/T1, IRIG B, serial time strings. This way equipment can be synchronized over the network that has no own capabilities for network time synchronization.

The basic system architecture of this solution is, identical to application 1, derived from a standard LANTIME NTP Time Server. In this case the internal GPS receiver has been replaced by a free running hardware clock and a high quality oscillator that is disciplined by using the PTP synchronization. All required frequencies and other signals can be provided based on the oscillator.

The specific software design looks like this:

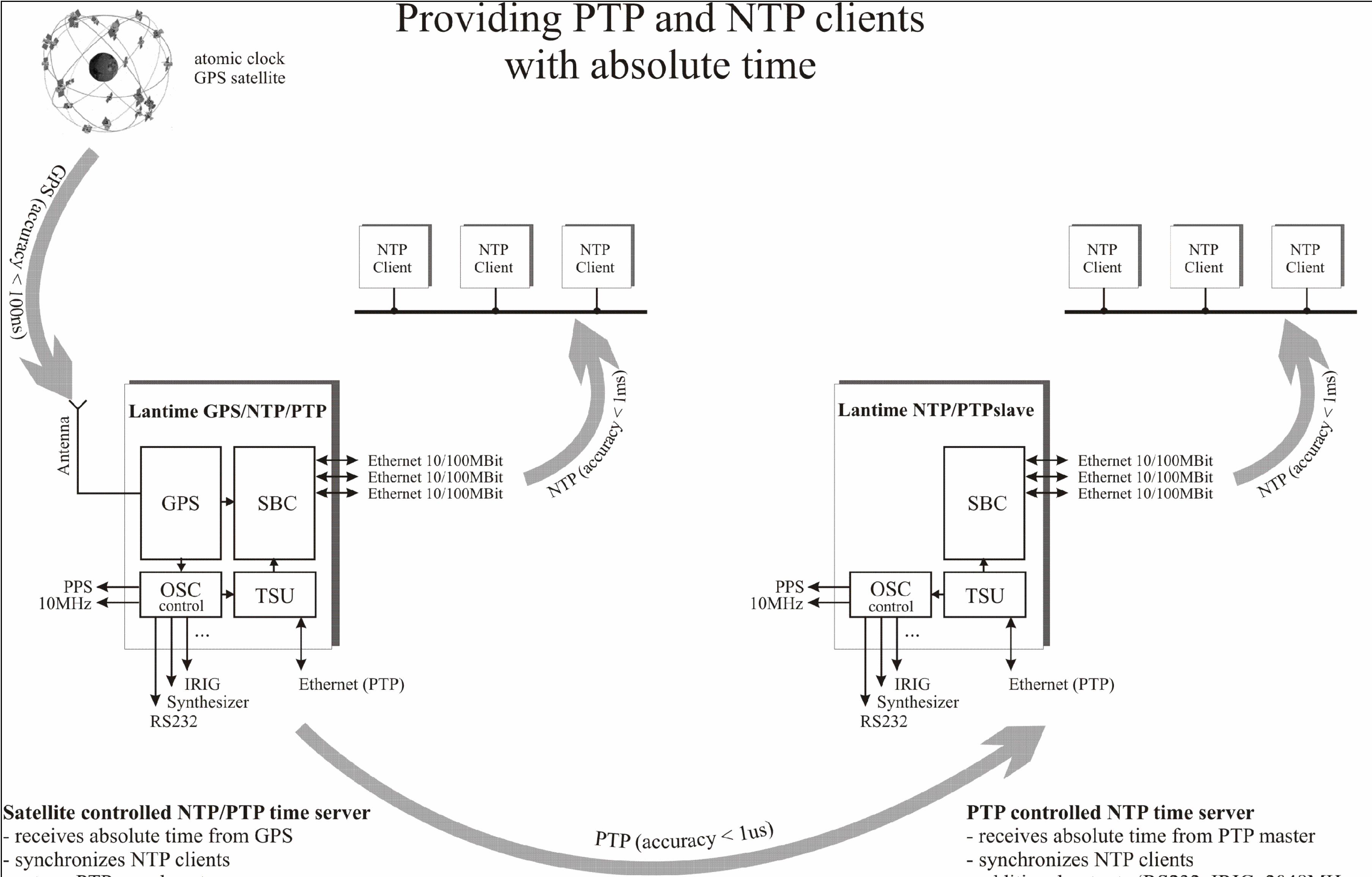
- At start-up the system waits until it is synchronized by PTP (PTP_SLAVE state has been reached)
- Now the system clock is set to the time of the TSU
- Afterwards, NTP is started. The NTP daemon has been modified with an additional refclock driver
- NTP reads the TSU‘s time by using a kernel device driver
- The TSU looks like a hardware reference clock to the NTP daemon

The NTP concept of “refclock” (=reference clock) drivers is used to feed PTP synchronized time into NTP. Per definition a reference clock has always a stratum of 0, which indicates that it is the most accurate source of time available.

For an SNTP or NTP client there is no difference in communication and handling, it simply sees that its NTP server is synchronized to a reference called “PTP” and that is has a stratum of 1 (which basically says that the server itself is getting the time from a stratum 0 source – the PTP/IEEE1588 Grandmaster clock).

In order to minimize accuracy degradation between the two LANTIME systems (the GMC and the PTP Slave system), all IEEE1588 measures like transparent or boundary clocks can be used on that part of the network.

Providing PTP and NTP clients with absolute time



Satellite controlled NTP/PTP time server
- receives absolute time from GPS
- synchronizes NTP clients
- acts as PTP grandmaster
- additional outputs (RS232, IRIG, 2048MHz ...)

PTP controlled NTP time server
- receives absolute time from PTP master
- synchronizes NTP clients
- additional outputs (RS232, IRIG, 2048MHz ...)