RESEARCH REPORT

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Accurate time transfer to DGPS stations via communications networks

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Summary

The current DGPS system receives positioning and timing signals from GPS satellites and calculates corrections based on the reference data at each station. The correction data is sent via MF beacons to ships.

The objective of the project was to carry out an initial study of a backup system for GNSS at DGPS stations. One of the targets was to research the possibility to provide accurate time to DGPS stations over the telecom networks in stead of using GNSS. The research concentrated on packet switched networks and their ability to transfer real time services.

This report is an English summary of the Finnish research report that was one the outcomes of a project to develop radio navigation, commissioned by Finnish Transport Agency.

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1 Introduction

The Finnish Transport Agency is responsible for Aids to Navigation services to vessels in the Finnish territorial waters. The Agency maintains DGPS stations which provide DGNSS corrections and integrity information to maritime users.

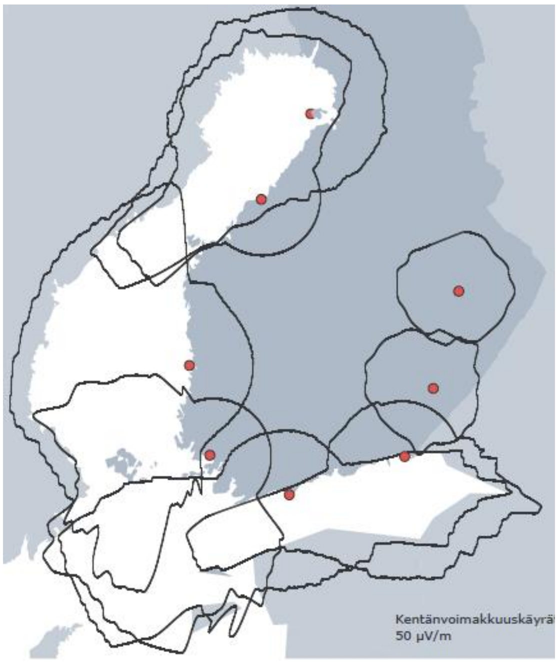

Figure 1.1 DGPS stations in Finland

The current DGPS system receives positioning and timing signals from GPS satellites and calculates corrections based on the reference data at each station. The correction data is sent via MF beacons to ships.

2 Objective

The objective of the project was to make an initial study of a backup system to the GNSS at DGPS stations. One of the targets was to research the ability to provide accurate time to DGPS stations over telecom networks in stead of using GNSS. The research concentrated on packet switched networks and their ability to transfer real time services.

3 Packet switched networks

Telecommunications networks can be divided into two main categories, namely circuit switched and packet switched networks. In the traditional circuit switched network the communication channel between the sender and the receiver is reserved for the whole duration of the call, and no other calls can use this channel.

This principle is used in conventional telephony networks and in GSM and 3G backhaul networks.

In the packet switched networks there are no reserved channels for the user connections. Data packets of different sessions use the same transfer channels and the packets reach the destinations based on the attached address information in the packet headers. In the Internet type of networks, packets of a session may take different routes through the network. Thus the packets may arrive to their final destination in a different order as they were sent. The receiving device has to re-order the packets using identifiers in the packet header as it is used in case of Internet Protocol (IP).

Today the common trend is to replace the conventional circuit switched networks with packet switched networks. The favour of the packet switched networks relies on the efficient use of network capacity. A major problem in circuit switched networks is that the capacity allocated for a call cannot be utilized by other calls. When all the channel capacity is occupied, no new calls can be established. In packet switched networks, the network capacity is available to all users, but at a lowered bit rate per session during periods of heavy network load.

The Ethernet MAC (Medium Access Protocol) protocol, originally developed for LAN (Local Area Networks) networks, together with IP is pushing their way to the core networks. In mobile networks the backhaul networks are also replaced by Ethernet based networks. The favour of packet switched networks relies on their scalability, cost efficiency and easy of maintenance compared to the traditional circuit switched networks.

In the packet switched networks, the data rate of a connection varies, because data is transported in bursts of packets during the call, whereas the conventional circuit switched networks guarantee constant transmission capacity. Routers and switches are the main causes for delays and delay variations, re-ordering of packets, traffic jams and even packet losses in the packet switched networks. In the Ethernet networks the receiver clock is synchronized to the preamble bit stream. So even a minor disturbance in the in coming bit stream may cause the loss of synchronization and failure in reception of the in coming packet.

3.1 Transfer of real time services

In traditional PDH- and SDH-networks, the clock signal is distributed in a hierarchical manner to every node. Thus all the nodes in the network are synchronized to the same clock and no synchronisation problems appear. This assures that the bit rate remains constant and no bit losses or delay variations occur. So the real time services, like transfer of video streams, can be provided with good quality.

In packet switched networks, each node runs using its own clock which is synchronized to the incoming bit stream. Thus the usual malfunctions in transferring packets are delay variations, changes in the packet order and even packet losses. Even though networks are converged into packet based networks, the network services have to be provided with the same quality and criteria as in the traditional circuit switched networks. To compensate the malfunction problems and to reach the required quality for real time services, different time distribution protocols have been developed for packet switched variable-latency networks. The oldest and most used protocol is ‘Network Time Protocol’ (NTP). This protocol provides 1 – 50 ms accuracy depending on the network topology and traffic load in the network. The IEEE1588 ‘Precision Time Protocol’ (PTP), promises even better than one microsecond accuracy.

4 Time transfer protocols

Several protocols have been developed for transferring time information over Internet. The target of these protocols is to synchronize the clocks of the computers over the network. In this chapter, we describe the most interesting protocols, namely NTP and PTP.

4.1 NTP protocol

The most common time distribution protocol is the Network Time Protocol (NTP) (http://www.ntp.org/). NTP is transferred in IP networks using User Datagram Protocol (UDP) protocol (port number 123). The newest version NTPv4 promises to maintain the time accuracy within 10 milliseconds over the public Internet. In local area networks the accuracy may even be within 200 microseconds under ideal conditions.

NTP uses hierarchical architecture for clock sources (clock strata). The structure may have up to 256 stratum levels, figure 4.1. Although the stratum level defines its distance from the reference clock, it does not tell the quality of the internal clock used in the stratum computer. In principle the lower the stratum level is the more inaccurate is the clock compared to the reference clock. Stratum 0 level devices are the reference clocks such as atomic clocks, GPS clocks or a radio clocks. The reference clocks are not attached to the network, but they are connected straight to the stratum 1 devices. The stratum 1 devices form the highest hierarchy level connected to the network. Usually these devices have GPS receivers, but there may be other reference sources such as 10 MHz, 1 PPS, IRIG or even national radio time services (e.g. DCF-77 in Germany). Stratum 1 computers (time servers) act as servers to stratum 2 computers, which then act as servers to next lower level, stratum 3 computers. The server sends a time information packet after the request from the client (lower stratum). The client can use more than one NTP servers to be able to check which of the servers give the best accuracy.

There are millions of NTP servers in use today and NTP software is included in almost all work stations and operation systems such as Unix, VMS, Windowshttp://www.pool.ntp.org/en/ .

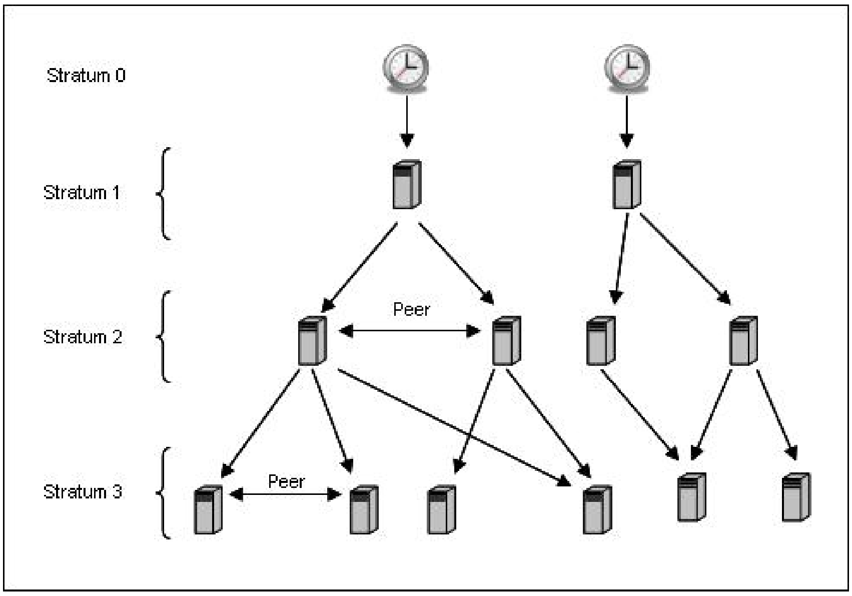

Figure 4.1 NTP hierarchical clock structure

The 'Transmitting Timing over IP Connections and transfer of Clock' (TICTOC) work group of IETF continues to develop NTP protocol furthermore. TICTOC will also consider the co-existence of PTP/1588v2 and NTP in the network to improve the transfer of time information.

4.2 PTP protocol

PTP was originally defined in the IEEE 1588-2002 standard (http://www.nist.gov/el/isd/ieee/ieee1588.cfm), officially entitled "Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems" and was designed for measurement and control systems residing on a local area network. Accuracy in the sub-microsecond range can be achieved with low-cost implementations.

In 2008 a revised standard, IEEE 1588-2008 was released. This new PTP Version 2 improves accuracy, precision and robustness.

IEEE 1588 is designed for local systems requiring accuracies beyond those attainable using NTP. It is also designed for applications that cannot bear the cost of a GPS receiver at each node, or for which GPS signals are inaccessible.

The IEEE 1588 standards describe hierarchical master-slave architecture for clock distribution. In the architecture, a time distribution system consists of one or more communication mediums (network segments), and one or more clocks. The ordinary clock is a device with a single network connection and is either the source of (master) or destination for (slave) the synchronization reference. The protocol specifies the 'Best Master Clock' (BMC) algorithm which elects the best candidate clock within the network to create a master/slave hierarchy. The boundary clock (BC) has multiple network connections and can accurately bridge from one network segment to another. A master is elected for each of the network segments in the system. The root timing reference is called the grandmaster. The grandmaster transmits synchronization information to the clocks residing on its network segment. The boundary clocks relay accurate time to next connected segments.

IEEE 1588-2008 version introduces a clock associated with network equipment used to carry PTP messages. The transparent clock (TC) modifies PTP messages as they pass through the device. Timestamps in the messages are corrected for time spent traversing the network equipment. This scheme improves distribution accuracy by compensating for delivery variability across the network. To improve the efficiency of the protocol, the new standard also specifies shorter PTP messages and allows sending several timing messages within one second. This enables the slaves to be better synchronized and to use cheaper crystal oscillators.

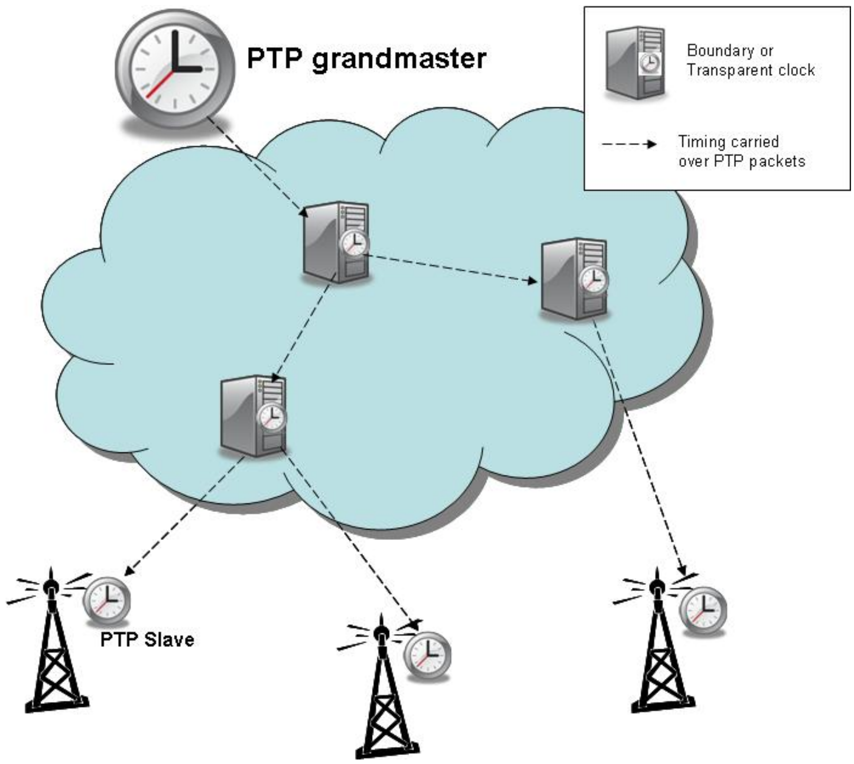

Figure 4.2 PTP clocks in the network

PTP can be implemented using either a pure software-based solution or a hardware-assisted solution. Software-based solutions are easy to deploy, but they introduce more inaccuracy in time-stamping caused by the jitter in the software stack. Hardware assisted solutions generate the time-stamps in hardware near the physical interface, figure 4.3. This improves considerably the accuracy of time-stamping.

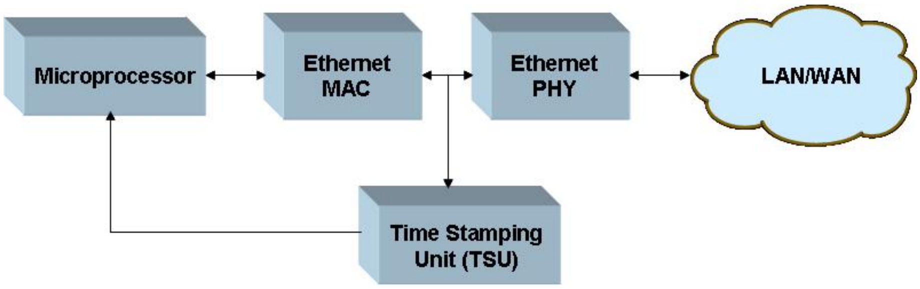

Figure 4.3 Hardware based implementation of time stamping

5 Recommended network and timing protocol for accurate time transfer

The public Internet consists of thousands of physical networks. There is no authorized institution, which controls the whole Internet, on the contrary, each operator takes care of its own network and connections to other networks. The Internet is all the time open to all users. This is the main reason to traffic jams especially during the rush hours. Also the network is vulnerable to malfunctions caused intentionally or unintentionally. The public network has serious security problems and every now and then you may hear opinions, which predict the Internet to be totally collapsed. On the other hand, it is too tedious and costly to replace the current network. Instead security systems and virtual private networks/connections have been deployed trying to compensate the problems in the Internet.

Mainly due to the security problems in the public Internet, some countries have implemented closed packet networks controlled by governmental authorities. These networks enable reliable and secure communication, and they are available only for closed user groups. Also the connections to the public Internet are restricted.

The available and realistic choices for time transfer protocols over packet based networks are NTP and PTP. The NTP promises 10 milliseconds accuracy while PTP may reach even within one microsecond accuracy.

The selection of a network and a time protocol for an accurate time transfer to DGPS stations is limited to the available networks and protocols. The best candidate is a closed packet network with a PTP service included. The included PTP service means, that there are boundary and transparent clocks deployed in the network so that the network delay can be calculated by the end users when receiving the time information from the master clock.

6 Abbreviations

BMC	Best Master Clock
DGPS	Differential Global Positioning System
GMDSS	Global Maritime Distress & Safety System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LAN	Local Area Network
MAC	Media Access Control
NTP	Network Time Protocol
MF	Medium Frequency
PDH	Plesiochronous Digital Hierarchy
PNT	Position, Navigation & Timing
PPS	Pulse Per Second
PTP	Precision Time Protocol
SDH	Synchronous Digital Hierarchy
UDP	User Datagram Protocol

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