



Designing of Method for Improving Synchronization Accuracy in Packet Networks

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Abstract: This article deals with the possibilities of improving the synchronization accuracy over packet networks. The first part is focused on the analysis and measurements of synchronization accuracy in the real packet network. Measurements were performed using the precision time protocol. The transmission parameters of a network were changed using a network emulator and the resulting accuracy was measured again. The second part deals with methods for improving the accuracy of synchronization. Additional source of a local clock is used at the client's side to improve the synchronization accuracy. Proposed methods were simulated under the same conditions as the previous measurements. The resulting synchronization accuracy was better during the simulation than during the real measurements of a network.

Keywords: Synchronization, Packet network, Precision Time Protocol, Ethernet, styles

I. Introduction to Synchronization Protocols

The process of synchronization of individual network devices is one of the most discussed topics since the early development of the communication protocols. Time synchronization in packet networks is only a part of the global synchronization topic. The reliable distribution of accurate time synchronization is critical in almost all types of telecommunication networks and equipment. Today, specific synchronization networks and protocols are used to synchronize the devices in backbone networks, e.g. OTH, but it is also necessary to deliver the synchronization into other types of networks, such as the Ethernet.

In general, packet networks such as the Ethernet are the fastest expanding networks today. Time synchronization is therefore becoming more important and more necessary. Several protocols have been already established for obtaining accurate time over packet networks. Precision Time Protocol which is described in the standard IEEE 1588 is the latest. This protocol is able to cooperate with the network card and to improve the synchronization accuracy. The first standard, which describes PTP, was issued in 2002, but in 2008 a new revision of this document was published [1]. Another protocol is Network Time Protocol (NTP) [2], which is already used for a long time in real networks. NTP is one of the most popular protocols used for computer time synchronization across the Internet. The main difference between NTP and PTP protocol is the method of their implementation [3]. PTP allows software and hardware implementation while NTP allows only software implementation. The PTP is the most accurate protocol today for packet-based networks, but its hardware support is necessary. Its accuracy is usually better than hundred of nanoseconds. Ensuring a perfect synchronization is a necessary precondition for transmitting the data streams in real time [4].

The basic principle of all synchronization protocols is the process of exchanging the timestamps between the server and the client. Timestamp contains either delivery time or sending time. Using these timestamps, the client tries to calculate the delay between the server and the client to determine the exact time.

The client sends request message that contains an originate timestamp T_1 . Upon receiving the request message, server generates a receive timestamp T_2 . After processing the request, server sends back reply with originate timestamp T_3 . Then the client receives the reply and generates a receive timestamp T_4 . From these four timestamps, a network delay d (1) and a clock offset o (2) can be calculated.

$$d = \frac{(T_4 - T_1) - (T_3 - T_2)}{2} \quad (1)$$

$$o = T_3 + d - T_4 \quad (2)$$

The clock offset o represents client and server time difference. The calculation of network delay assumes that client to server delay is approximately equal to server to client delay. We are not able to measure the delay in one direction and this potentially causes synchronization inaccuracy.

Variable delay in packet networks has fundamental impact on synchronization accuracy. Packets delay dispersion depends on network configuration and load. PTP protocol solves this problem by implementing a clock into a network card and by synchronizing the network components themselves. However, when standard network device is inserted between PTP devices, the synchronization accuracy decreases [5]. The improvements

of the accuracy can be achieved by using statistical method and algorithms on the client side, which is also discussed in this work.

II. Simulation – Current State

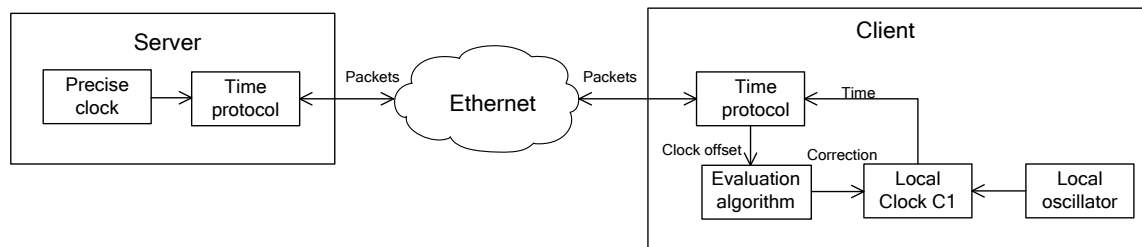
Time synchronization protocols were explained in the first chapter. Different delays in different directions and variability of these delays are a major problem for determining the precise synchronization.

Several basic methods for time synchronization are used today. Either synchronous Ethernet or Precision Time Protocol is usually used to achieve high accuracy of synchronization in local networks. The resulting synchronization accuracy is primarily determined by the value of delay in a packet network. The first part of this work deals with simulation of the real network behaviour and with the measurement of synchronization accuracy depending on network delays.

A. Model of Synchronization

Synchronization in packet network works according to the following block diagram. Ethernet network adds a variable delay between the server and the client.

Figure 1 Block diagram of time synchronization.



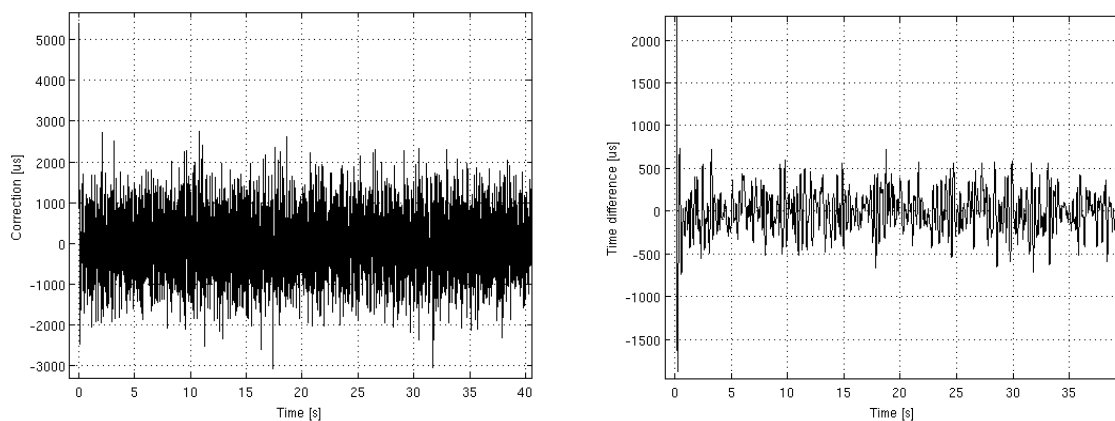
Time Protocol provides the exchange of messages between the client and the server as described in first chapter. The resulting clock offsets are processed by the evaluation algorithm. A statistical methods or filtering algorithms can be used as evaluation algorithms. The FIR (Finite Impulse Response) filter was used as a regular filter.

The application of a low pass filter is optimal. Filter with higher order is not very suitable for this application, because its latency is too high. FIR filter with order 20 and limit frequency 0.03Hz was used in simulation. The resulting correction is used to adjust the time. This time is then used again by time protocol.

B. Simulation Results

The main task in this article was to simulate the effect of different delay dispersions on the accuracy of time synchronization. The simulations were performed under the same conditions as the real measurement, which is described in the following section. The mean delay and maximum deviation of transmitted packets between server and client were changed to achieve the same value as during the real measurement.

Figure 2 Clock offset determined from packets (L) and the server and the client time difference (R)



First simulation was created with 3ms mean delay value of packets and with maximum deviation of 1ms. The time difference between the server and the client was set to 4ms at the beginning of the simulation. Figure 2 on the left shows server and client time difference calculated from incoming packets (figure 2 on the right). The synchronization accuracy determined from clock offsets is low, approximately ± 2 ms.

Clock offsets are processed by FIR filter. The corrections of results coming from the FIR filter are much smaller and therefore the resulting synchronization accuracy is better.

Simulations were performed under different input conditions. Table I contains results for all simulations. The calculations of statistical values were performed after time stabilization on client side.

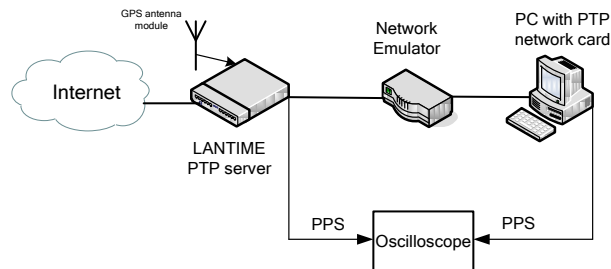
Table I The simulation results under different conditions.

Delay setting in simulator		Synchronization accuracy results				
Mean [s]	Max variance [s]	Local Clock	Mean [s]	Var.	Min[s]	Max [s]
3E-03	1E-03	C1	3.8E-06	6.1E-08	-7.3E-04	1.0E-03
3E-03	2E-03	C1	7.8E-06	2.2E-07	-1.5E-03	1.5E-03
1E-02	1E-03	C1	-1.3E-05	5.9E-08	-7.3E-04	6.2E-04
1E-02	3E-03	C1	-7.3E-05	5.6E-07	-2.3E-03	2.1E-03

III. Synchronization Measurement

The devices supporting Precision Time Protocol were used to measure the accuracy of synchronization over packet networks. The LANTIME (Local Area Network Timeserver) M600/GPS server from the Meinberg - Radio Clocks co. was used as the synchronization server for the entire network [6]. The network card PTP270PEX from the Meinberg - Radio Clocks co. was used as a slave device in a synchronization network. Simena Network Emulator [7] was used as another network device.

Figure 3 The Network topology for synchronization measuring.



This device has been connected between the server and client and was used to emulate the network delays (Fig. 3). Network Emulator allows setting bandwidth, network delay and other options. Network delay can be set from 1ms and was used for measuring accuracy of synchronization.

Time synchronization is performed between the client network interface card and server over the network emulator that adds a delay of individual packets. Time synchronization is performed using the PTP protocol. Pulse per Second (PPS) output from server and network card was used to determine the accuracy of the resulting synchronization measured by the oscilloscope. Time difference between the server and client (synchronization accuracy) is determined using an oscilloscope every second, and this value is recorded.

A. The Results of Measurement

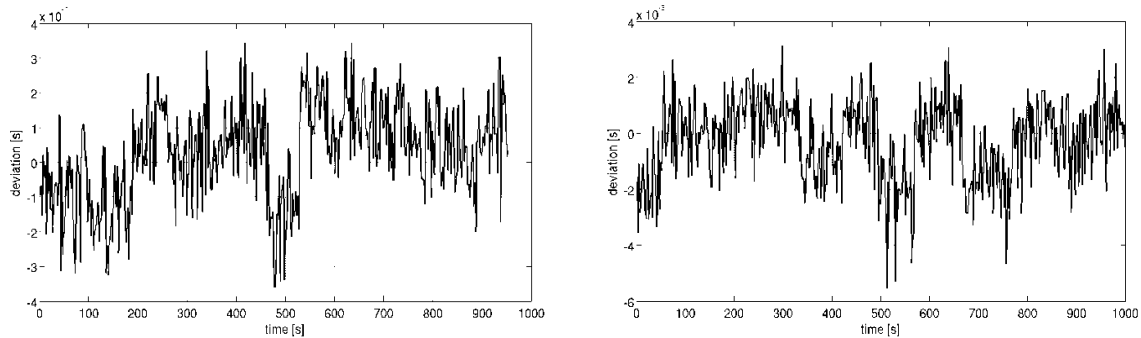
The network emulator was used to alter several transmission parameters of a real network during the measurement of the synchronization accuracy. We performed measurements for various network delays and variance. The network emulator used a normal distribution, the mean value of packet delay has been adjusted in the range from 0 to 10 ms and variance was adjusted in the order of milliseconds. The results are shown in Table II.

Table II The simulation results under different conditions.

Delay setting in network emulator		Synchronization accuracy results			
Mean [s]	Max variance [s]	Mean [s]	Var.	Min[s]	Max [s]
0	0	9.9E-05	1.4E-08	-1.6E-04	3.5E-04
3E-03	1E-03	2.3E-04	1.8E-06	-3.6E-03	3.4E-03
3E-03	2E-03	2.6E-04	6.1E-06	-8.0E-03	6.7E-03
1E-02	1E-03	-3.1E-04	1.9E-06	-5.5E-03	3.2E-03
1E-02	3E-03	1.3E-03	1.4E-05	-1.0E-02	1.0E-02

The results show that the accuracy of synchronization does not depend on the mean delay, but rather depends on the packet delay variance.

Figure 4 Results of synchronization accuracy for 3ms mean delay and 1ms variable delay (L) and for 10ms mean delay and 1ms variable delay (R)



The result of precision synchronization with 1ms deviation provided by network emulator is similar for mean value with 3ms or 10ms. Figure 4 represents the time difference between the server and client, which is indicated as a deviation.

The resulting synchronization accuracy is quite poor. Synchronization accuracy is approximately equal to the variance of packet delay. The precision time protocol is designed for precise synchronization and was probably not designed for dealing with a large network delay generated by the emulator. The second part of this article deals with the simulation, where we will try to improve the final accuracy of synchronization.

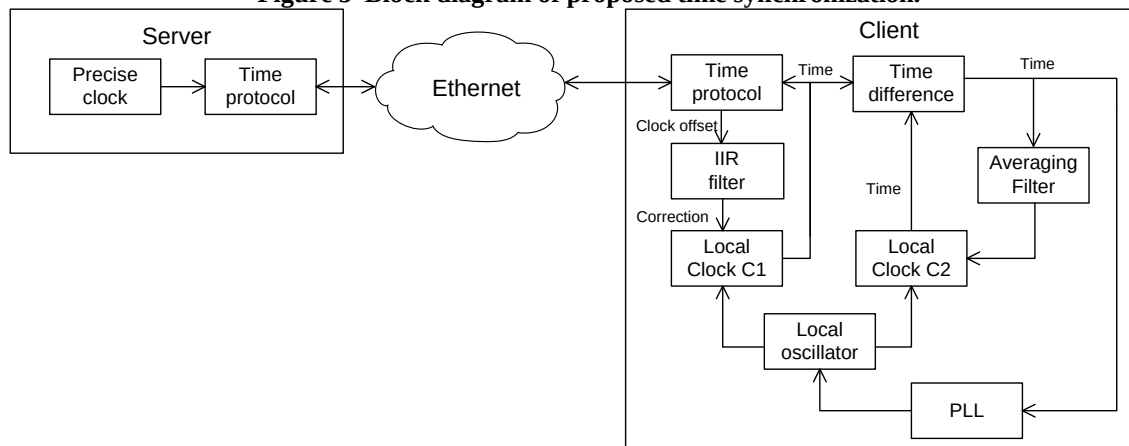
IV. Simulation - Improved Method

In the second and third chapter, the simulations and the measurements were performed in real network. This chapter is focused on improving the synchronization accuracy on the client side. Additional local clock source C2 was connected to the client side (Fig. 5).

A. Model of Synchronization

Our goal is to design and simulate an algorithm that will achieve better accuracy of synchronization. The purpose of the algorithm is to eliminate the influence of a variable delay, which is a major problem for all synchronization protocols. Two local clocks (C1 and C2) are used to increase the synchronization accuracy on the client side. These clocks are driven by local oscillator and are controlled by corrections which are determined from the packets using filtering algorithms. Determination of the proper resulting clock correction has a major impact on the resulting accuracy. Local clock source C1 acts as a main clock and is synchronized from the packets that carry time information. Of course, the resulting correction (clock offset) is determined by calculating (2) and is subsequently processed by the filter.

Figure 5 Block diagram of proposed time synchronization.



Different types of filters with different orders were tested. Better filter than standard filter used in Chapter 2 was searched. We propose a low pass filter with limit frequency of 0.01 Hz. IIR (infinite impulse response) filter with order 4 achieved good results.

Local clock C2 is designed to refine the resulting time. It is controlled by timing signal from the clock C1. Time difference module and the filter are also used. Averaging filter calculates mean value from specific number

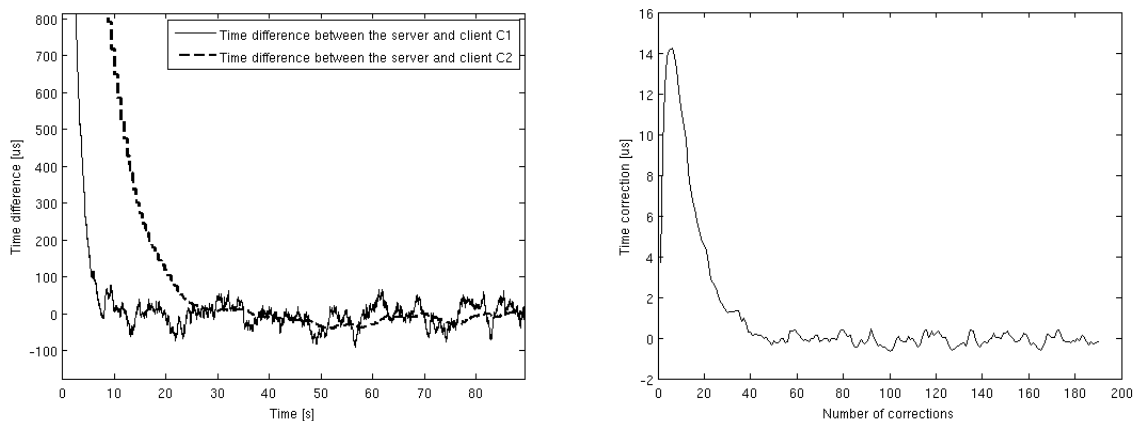
of samples. In this case, 100 of samples is collected and then the resulting correction is determined for the local clock C2. Various numbers of samples were tested but the resulting effect on accuracy was not very significant. Local clock C2 has slower response to change input values of the time correction. This results increased clock stability and accuracy.

The last block, which is used to increase the stability, is a phase lock loop. This block provides local oscillator frequency adjustment depending on the results of time corrections. Correction of the local oscillator must be very gentle to avoid undesirable oscillations of the oscillator. The correction results from time difference module are evaluated by local phase loop module and then this module regulates the frequency of the local oscillator.

B. Simulation Results

The simulations were performed under the same conditions as the real measurement and the simulation in second chapter. The second simulation should achieve better results by using client side extension (Clock C2). Next figure 6 (left side) shows server and client time difference on the local clock C1 and C2. The solid curve represents time difference between the server and client C1 and dashed curve between server and client C2. Local clock C1 is driven directly from the time packets (from time protocol module and IIR filter) and this causes higher inaccuracy compared to the local clock C2. The local clock C2 is controlled by time difference between C1 and C2. Averaging filter reduces the influence of individual correction to avoid rapid changes of time in clock C2.

Figure 6 The server and the client time difference (L) and time correction on the local clock C2 (R).



The figure 6 (right side) represents time corrections that were made on the local clock C2. Time corrections were calculated using the averaging filter for a longer time period (filter averages the constant number of input values). These corrections are in the order of microseconds.

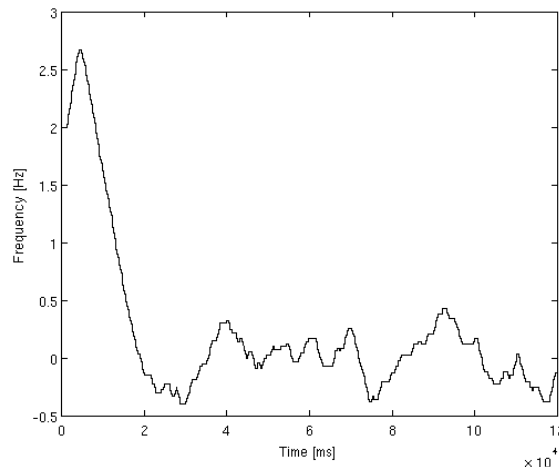
The results are much better than during the measurement and simulation in the second chapter. The calculations of statistical values were performed after time stabilization on client side.

Table III The simulation results under different conditions.

Delay setting in simulator		Synchronization accuracy results				
Mean [s]	Max variance [s]	Local clock	Mean [s]	Var.	Min[s]	Max [s]
3E-03	1E-03	C1	6.5E-06	8.5E-10	-6.9E-05	1.1E-04
3E-03	1E-03	C2	3.7E-06	3.7E-10	-2.8E-05	7.5E-05
3E-03	2E-03	C1	-3.2E-06	2.8E-09	-1.9E-04	1.5E-04
3E-03	2E-03	C2	-1.1E-06	1.0E-09	-8.5E-05	9.7E-05
1E-02	1E-03	C1	-1.1E-05	1.0E-09	-1.0E-04	6.6E-05
1E-02	1E-03	C2	2.0E-06	1.1E-09	-3.9E-05	8.0E-05
1E-02	3E-03	C1	-2.5E-05	9.9E-09	-2.8E-04	2.3E-04
1E-02	3E-03	C2	-1.5E-05	1.0E-09	-8.8E-05	3.7E-05

The additional process of tuning the local oscillator further improved the resulting accuracy. Simulations with different local oscillator settings were made. At the beginning of the simulation, the oscillator frequency is set to 2 Hz difference compared with precise oscillator. The figure 7 shows the ability to tune the local oscillator frequency.

Figure 7 Difference frequency of the local oscillator.



V. Ideas for further improvements

Packets variations have significant impact on synchronization accuracy as mentioned in this article. The synchronization accuracy is improved by using algorithms on the client side. IIR filter and averaging filter were used in our case. One possible extension is to design both filters with different type. Averaging filter should be replaced by some better adaptive filter. However, it would be necessary to simulate its resulting effect on the synchronization accuracy.

VI. Conclusion

Time synchronization process is very important in many network devices. The goal of this work was to design and simulate a possible method for increasing the synchronization accuracy in packets networks. Client design was made to be very versatile, so it can be used either for NTP or PTP protocol.

We also performed several measurements and compared it with simulation results. Measurement results are comparable with the current state simulation in the second chapter. When IIR filter is used (simulation in the fourth chapter) the local clock C1 precision is better than measurement results. When we compare the results of the local clock C1 a C2 (the fourth chapter) we find that the variation of C2 is always smaller than C1 with the same input conditions (Tab. III). This behavior is correct and it was our goal. Graphical comparison is shown in Figure 6.

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