# DOES SYNCHRONIZATION ENSURE SIMULTANEITY?

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## Abstract

*The need of synchronization in complex systems is discussed. In some cases, this need is confirmed, simultaneity being one of this. Obstacles in synchronization are enlightened, and achievable accuracy is surveyed. Ways to avoid the need of clock synchronization for some tasks are mentioned.*

## 1. Introduction

Management of complex systems depends, among other things, upon a proper timing. When several systems or processes are to be kept in sync, some synchronizing measure is needed. Other time-related aspects of the task are in effect, too – for instance a duration of a sub-process, an age of a resource, a “time-to-live” of an agent... These other aspects are, in fact, pieces of information rendered by a sub-system to a higher level system, informing about sub-system's state. The control of these time-related parameters lies entirely upon the sub-systems; for these the sub-systems need to keep their own chronometers, appropriate for the sub-systems. A question of a comparison between such duration-related pieces of information and question of an aggregation of these will be discussed in section 4.

An orchestration of the sub-systems of the system is another question. We ask if, for orchestration of its composition level, the system of systems needs an “universal” clock. Next section discuses this. Available means of synchronization are surveyed in section 3. Other managerial aims concerning time management are given in section 4.

## 2. Orchestration of Systems

When sub-systems are to work in sync, one of following may be requisite:

A) Some actions should be carried out in a prescribed order.

B) Some delay should not be greater than a prescribed limit. This is a requirement of sort of simultaneity.

C) Some delay should be greater or equal to a prescribed limit. This is a requirement of “wait till”-type.

In case of fixed, predictable, limited-size system of systems, the task can be handled by Time-triggered protocol (architecture) (Kopetz, 1993, Kopetz, 2002), using circuit channel for periodic messaging between the sub-systems.

Let us discuss the general case. For A), if the should-be-precedent knows the should-be-successor, some passed token can serve for the should-be-successor as an allowance to start. If this is not possible or not appropriate, a controlling element can conduct the actions by waiting for the signal of the end of the should-be-precedent action to permit the start of the should-be-ensuing action. Still another way to manage this requirement is to create a time schedule to which sub-systems should act. This final way of management relies upon sufficiently precise time information of sub-systems' dispose. Either the subsystems have separate clocks, in this case these clocks should be sufficiently synchronized, or the sub-systems listen to time signals from some “universal” clock, in this case supposed transmission delay should be taken into account.

For B), a controlling element can command to start the actions; transmission delay should be taken in account. Another way is, again, to create a time schedule for the sub-systems; for this case, the same as in A) applies.

For C), a controlling element can command to start the actions; another measure is a time schedule for the sub-system, and the same as in A) applies.

## 3. Clock synchronization

The most accurate chronometers known today are *atomic clocks*. Precision of ground based atomic clock is within $1.4 \times 10^{-15}$, and the accuracy is less than a second per twenty million years (AIST, 2003). Combined input of many atomic clocks around the world makes up the International Time Standard, which is the primary international time standard. Atomic clocks are used also in Global Positioning System (GPS) satellites. The time precision in GPS satellites is kept using the correction of Einstein General relativity theory, because time difference between an on the ground clock and GPS satellite clock is $440*10^{-12}$ seconds (Ashby, 2003). If left uncorrected this would have resulted in timing errors of about 38,000 nanoseconds per day (Weis, 2005). Precision of atomic clock on GPS satellites is within $1 \times 10^{-12}$ (NASA, 2011). Although it was primarily designed as a navigation system, *GPS is the predominant means of disseminating precise time, time intervals and frequency today* (Dana, 1990). Most GPS receivers lose timing accuracy in the interpretation of signals; typical precision of a receiver is under $10^{-6}$ second. Some commercially available GPS receivers can reach precision $15*10^{-12}$ seconds (u-blox, 2012).

Time servers provide for time standard distribution *in computer networks*. While some time servers use atomic clocks, the most common “true time” source for time serves is a GPS receiver. Also another time server on the network or the Internet can be used as a time reference for a time server, and also a connected radio clock.

Other computers can utilize the service of time servers via *Network Time Protocol* (NTP) using UDP, utilize *Precision Time Protocol* on LANs, or *White Rabbit* Ethernet-based network, for instance. Any computer can adjust its clock by regulating its speed. Using “true time” information issuing from some source, offset of the two clocks, jitter and an observed delay of message transmission, the clock adjustment is calculated.

### 1.1. Time-triggered protocol (architecture)

Time triggered protocol serves for time synchronization and communication in networks consisting of simple devices (and maybe one or several master systems), when low latency and high dependability is critical. A typical use is in automotive vehicles and aviation. The main difference to the time synchronization dealt in 3.3 and 3.4 is that Time-triggered protocol is intended for limited system of systems, behavior of each is fixed and with no user application running on it. (For instance, ABS sensors in wheels offer no "user application".) The speed of TTP(A) channel today is 25Mb/s, and communication rate is inversely proportional to the number of nodes in the system.

### 1.2. Network Time Protocol

Following examples, repeated from (Palovská, 2011), illustrate time precision achievable by NTP; NTP uses Internet routes. The first are two outputs from fis2.vse.cz, a computer in local network of University of Economics, Prague.

The meaning of columns is:
*remote* – addresses of synchronizing peer (the mark before means: * synchronizing master, + potential master, - out layer, i.e. peer too different from good ones)
*refid* – synchronizing master of each peer
*st* – stratum, i.e. how far is peer from exact time (stratum 1 – directly connected to atomic or GPS clock, stratum 2 – synchronizing peer is stratum 1, etc.)
*t* – technical info about unicast broadcast communication
*when* – time since last received packet
*poll* – interval of synchronization packets (value 2^n where n is from 6 to 10) when time server starts, asks peer within short period (each 64 sec), later server reaches more precision of its clock and can ask with longer period (till 1024 sec)
*reach* – reach of last 8 packets in octal notation (Each reply on request of time is one bit in one byte for each pear. This byte is displayed in octal notation, i.e. 377 means all requests have replies, 376 means last request has not reply, 357 means it was 3 successful requests, 1 unsuccessful and 4 successful)
*delay* – delay of packets form peer
*offset* – offset in milliseconds of local and peer clock
*jitter* – jitter of peer clock

First output:

```
ntpq> pe
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
-ca65sb.net.vse. 131.188.3.220    2 u  390  512  377    0.762   -0.599   3.833
*ca65rb.net.vse. 192.93.2.20      2 u   99  512  377    0.716    0.159   1.037
+ipv6jm.vse.cz   195.113.144.204  2 u  346  512  377    0.296    0.152   0.188
-jmnt.vse.cz     91.189.94.4      3 u   95  512  377    0.606   -4.214   0.339
-ns.infonet.cz   145.238.203.10   3 u  163  512  377    2.360    0.862   1.210
+lx.ujf.cas.cz   195.113.144.201  2 u  471  512  377    1.443    0.461   0.362
-ntp.t-mobile.cz 192.53.103.104   2 u  345  512  377    3.167    2.007   0.521
```

A while later:

```
ntpq> pe
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
-ca65sb.net.vse. 195.113.144.201  2 u  409  512  377    0.762   -0.599   3.822
+ca65rb.net.vse. 192.93.2.20      2 u  121  512  377    0.716    0.159   1.032
*ipv6jm.vse.cz   195.113.144.204  2 u  362  512  377    0.309    0.130   0.128
-jmnt.vse.cz     91.189.94.4      3 u   99  512  377    0.606   -4.214   0.233
-ns.infonet.cz   145.238.203.10   3 u  181  512  377    2.545   -0.096   1.464
+lx.ujf.cas.cz   195.113.144.201  2 u  486  512  377    1.427   -0.039   0.372
-ntp.t-mobile.cz 192.53.103.104   2 u  356  512  377    3.167    2.007   0.415
```

In this case, the accuracy can be expected about $10^{-4}$ second. Following two outputs are from a notebook in an home network connected by a ADSL line. First:

```
ntpq> pe
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
*odine.cgi.cz    195.113.144.201  2 u 1003 1024  377   14.141    0.058   1.144
-bobek.sh.cvut.c 195.113.144.201  2 u  413 1024  177   42.048   11.834  33.414
+srv1.trusted.cz 195.113.144.201  2 u  602 1024  377   14.797   -1.232  35.018
+relay.qls.cz    147.231.19.43    2 u  987 1024  377   24.733    0.585   3.320
-ntp1.karneval.c 147.231.19.43    2 u  983 1024  373   12.835   -3.195   2.469
```

A while later:

```
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
-odine.cgi.cz    195.113.144.201  2 u  879 1024  377   17.587   -3.036   0.716
+bobek.sh.cvut.c 195.113.144.201  2 u  287 1024  377   11.919   -3.662   0.908
*srv1.trusted.cz 195.113.144.201  2 u  480 1024  377   13.608   -3.544   0.599
-relay.qls.cz    147.231.19.43    2 u  863 1024  377   14.643   -6.692   0.046
+ntp1.karneval.c 147.231.19.43    2 u  857 1024  337   13.988   -3.156   0.442
```

In this case, the expected accuracy is above one order worse, i.e. of $10^{-3}$ second. When load of the computer increases, this becomes even worse.

For a computer connected to the Internet via GSM, application of NTP makes no sense because this protocol is suitable only in a case of a long-lasting connection.

### 1.3. LAN protocols clock accuracy

Precision Type Protocol achieves clock accuracy in $10^{-6}$ second range (IEEE, 2010), (Weiss, 2005). White Rabbit aims at being able to synchronize about 1000 nodes with sub-$10^{-9}$ seconds accuracy over fiber and copper lengths of up to 10 km (Serrano, 2010).

### 1.4. The future

The time dissemination is constantly developing area. F. Narbonneau from LNE-SYRTE, Observatoire de Paris with his team designed system via optical fiber, with a capability of a relative frequency resolution of $10^{-14}$ at one second integration time and $10^{-17}$ for one day of measurement. (Dana, 1990).

## Comparability of durations

Durability is measured by a kind of chronometer. For this a commonly known and accessible type of process can be used as a yardstick, either by comparing the measured process to a state in which the “yardstick” process is, or by counting how many repetitions of the yardstick process passed. One type of the letter one chronometers is clocks. Usually we don't count the clock ticks, rather we subtract the final time from the start time.

Such measurement relies on the sameness of all occurrences or repetitions of the “yardstick” type of process. In case of clocks, it relies on the same rate of the clocks.

As explained the previous section, different clocks generally tick in different rate. So, durations derived from measurement by different clock can by of different accuracy. This is to be taken into account when comparing such data; more so, if aggregations are computed. In the aggregation case the deviation may grow significantly.

## Control and time management

In spite of ordering's being manageable by causality, simultaneity can be managed only by means of time measurement. As section 3 explained, no absolutely precise clock is available, so estimated error, offsets and deviations must be taken into account.

One another aspect is present in time management of systems, specifically that durations of sub-processes can be cost. Managing this cost comprises evidence of durations, and computation based on it. Surveillance of durations relies upon time measurement and estimation of signal transmissions delays.

## Conclusion

Some managerial and control needs require synchronization. No absolute synchronization is achievable, so precision and accuracy should be taken in account. From section 3 it follows that accuracy in a range of 10 milliseconds is achievable using NTP protocol when appropriate time servers are chosen as time standard. Such accuracy may possibly be sufficient in systems comprising human-computer interactions excluding concurrency.

Accuracy of one-to-ten microseconds is more difficult to achieve. When we work in a small geographical area, we can use the PTP protocol. On the global scale we need to use system with GPS modules.

Some managerial and control tasks relating time can successfully and safely be arranged by causal ordering.

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