IoT Lecture 7

1

Time (1)

Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
- Network Time Protocol
- Precision Time Protocol

- Time is well defined and measurable at each location.
- Measurement precision required in various applications
  - Navigation
    - Chronometer to GPS
  - Legal
    - at what time precisely did Herr Schmitt hand in his dissertation / allegedly murder his wife
    - (US 200ms , ETSI (see oneM2M) 10ms)
  - Technical
    - as a reference to determine the order of events
    - to determine the age of data items (data correlation; data base replication)
    - to measure time intervals (and to calculate derived quantities)
    - to coordinate measurement instants (sampling, triggering)
    - as a basis for the execution of coordinated actions (time based behaviour)
    - to generate frequencies
    - to decouple communication from execution

LEARNING AIM: The students will be able to explain why time-synchronisation is necessary.

2

Time (2)

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LEARNING AIM: The students will be able to define the relevant terminology

Session 1: Time Synchronisation
- Time basics
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Terminology

- Resolution: increment value
  - Increment once per second, resolution is one second
- Precision:
  - Smallest value of time measurable
  - *Precision is the random uncertainty of a measured value, expressed by the standard deviation or by a multiple of the standard deviation*
- Accuracy
  - How close to an official reference second derivative)
  - *Accuracy is the closeness of the agreement between the result of a measurement and a true value of the measurand.*
- Jitter
  - Difference of differences
  - *Jitter is defined as the short-term variations of a digital signal's significant instants from their ideal positions in time.*

https://github.com/osgi/design/blob/master/rfps/rfp-0174-IoT-Requirements.pdf

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Time (3)

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LEARNING AIM: The students will be able to list the three standard time systems

Session 1: Time Synchronisation
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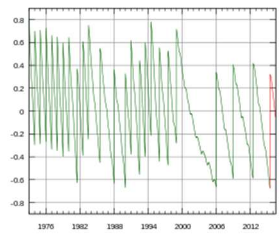
Sources

- UT1 – Universal Time 1
  - *Based on astronomical observations of Earth's rotations*
  - *Modern continuation of Greenwich Mean Time*
    - ► *Mean solar day*
- TIA – Temps Atomique International
  - *Weighted average of over 400 atomic clocks*
  - *Averaging -> stability*
  - *The SI definition is defined in terms of caesium clocks*
- UTC – Coordinated Universal Time (ITU-R TF.460-6)
  - *Based on TIA with leap seconds included*
  - *Spans from UTC-12 to UTC+12*



http://www.zeitkultur.com/ruth-belville-die-zeitverkauferin/
https://en.wikipedia.org/wiki/Leap_second

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Time (4)

Session 1: Time Synchronisation
- Time basics
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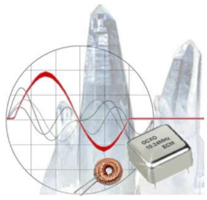
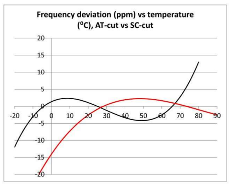
Distributed Time

- The relationship between time at different locations is unclear
- Why?
  - Each distributed device ticks to a different clock
  - Microcontrollers generally clocked by quartz oscillator
  - Time noted by counting clocks
    - ►PC clocks include a Real Time Clock
      - » Usually using a quartz of 32.768 kHz.
        - » This delivers a pulse per second on the 15th bit of a shift register
  - Quartz drifts
    - ►50 ppm -> 4.32 seconds a day
  - Drift dependent on temperature, humidity and pressure





LEARNING AIM: The students will be able to explain why clocks need to be controlled

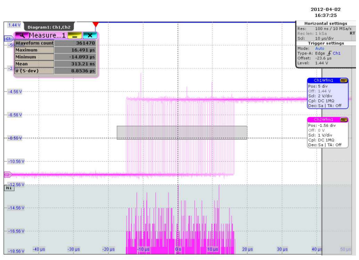
http://www.ecmelectronics.co.uk/images/ECM_Quartzwave.jpg
http://www.simonsdialogs.com/wp-content/uploads/2014/09/r820t-quartz-ref-osc-temp-dependence.jpg

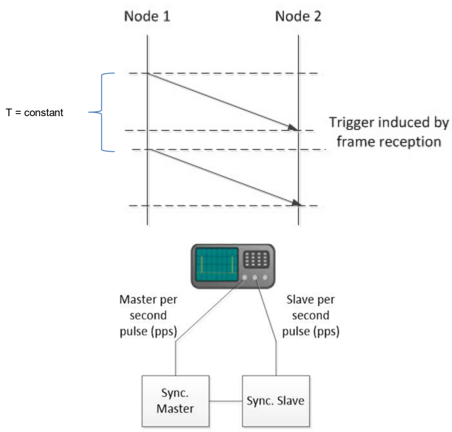
Relative Synchronisation

Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
- Network Time Protocol
- Precision Time Protocol

There are several ways to control the time on a distributed device

- On a trigger increments the clock of Node 2 by T
- Jitter = 32 us
- Only suitable in protected environments





LEARNING AIM: The students will be able to explain relative, open and closed loop synchronisation

Open Loop Synchronisation

Session 1: Time Synchronisation
- Time basics
- **Simple Time Synchronisation**
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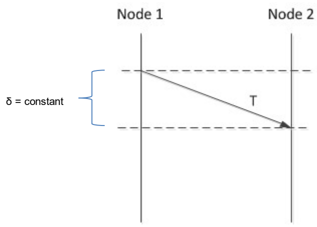
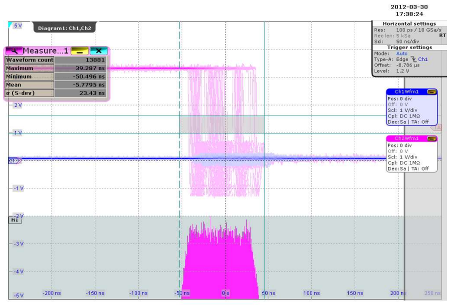
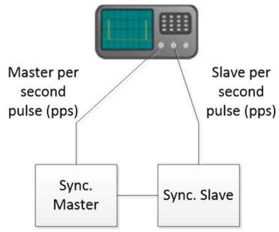
- Effectively clock replacement
  - Node 2 clock replaced by T in frame + δ
  - Update rate 1 ms Jitter = 80 ns
  - Only suitable in protected environments







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Open Loop Synchronisation: Cristian

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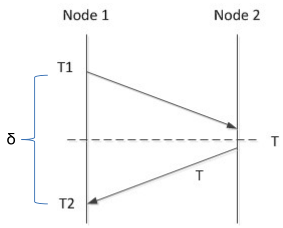
- Cristian's Algorithm
  - In this case Node 1 requests the time from Node 2.
  - t = T + δ/2



LEARNING AIM: The students will be able to state Cristians algorithm

http://cs.ucsb.edu/~hatem/cs271/ChristiansAlgorithm.pdf

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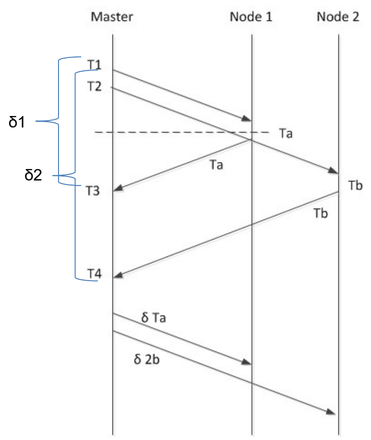
Open Loop Synchronisation: Berkeley

- Berkeley Algorithm
- Use Cristian's algorithm to get time from all nodes
- Master observes round trip time
- Estimates its and the nodes time
- Averages this time to get a system time
- Calculates the delta of this system time to the time of each individual node
- Transmits this delta time to the individual nodes

Accuracy under test conditions 20-25ms



LEARNING AIM: The students will be able to state the Berkeley algorithm

Gusella, R.; Zatti, S., "The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3BSD," in *Software Engineering, IEEE Transactions on* , vol.15, no.7, pp.847-853, Jul 1989

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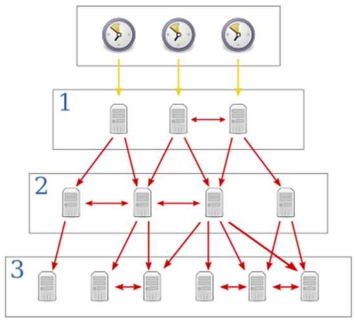
Closed Loop Synchronisation: Network Time Protocol

- NTPV4 – RFC 5905
- Based on UDP/IP port 123
- Reference implementation available
- Features a hierarchy of clocks
- High precision clock sources – expected to be atomic or GPS
- Stratum 1 – server clocks associated with the high precision clock sources
- Stratum 2 – network synchronised with stratum 1, act as servers for lower strata (stratum 3 .. 15)



LEARNING AIM: The students will be able to explain NTP

https://en.wikipedia.org/wiki/Network_Time_Protocol

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Fundamental Operation

Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
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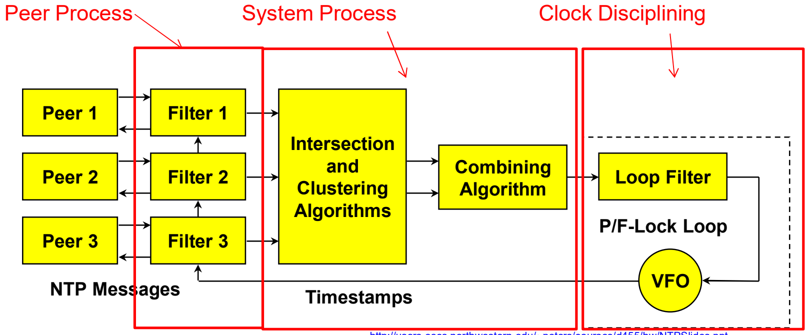
- Expects multiple sources (peers)
  - Signal averaging, redundancy
  - Can be decomposed into peer processes, system process and clock adjustment processing or clock disciplining
  - In essence a voting system to get the best possible clock value

LEARNING AIM: The students will be able to explain the voting procedure of NTP



http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt

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Time Sources (1)

Session 1: Time Synchronisation
- Time basics
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- Client needs time from multiple sources
  - Broadcast/multicast server generates messages at (default) 64 seconds and time to live (default) 127
  - Broadcast client responds and the pair build up synchronisation and cryptographic protocols.
  - Manycast originates from the client at minimum feasible rate and minimum TTL
  - Server pool scheme
    - Some NTP servers on DNS queries return a randomized list of NTP servers
- Once servers have been «collected» they are evaluated in the System Process Block

LEARNING AIM: The students will be able to state the discovery mechanisms behind NTP

http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt

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Time Sources (2)

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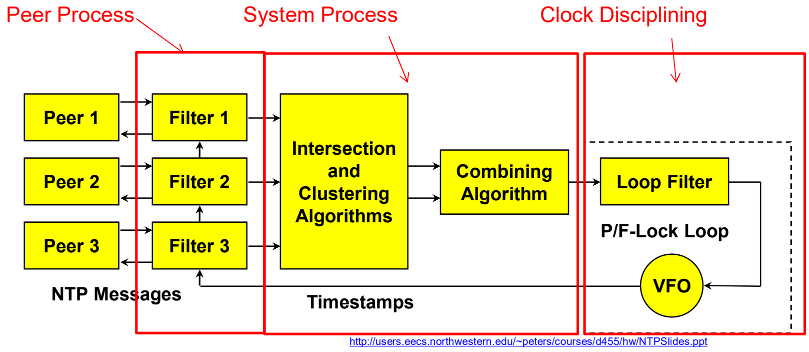
Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
- **Network Time Protocol**
- Precision Time Protocol

- Client polls servers
  - The faster the polling and the lighter the network load the better the accuracy
    - 100 us with update rates of one minute
    - 10 ms with update rates of 15 minutes
    - 100 ms with update rates > 30 minutes+

LEARNING AIM: The students will be able to state NTP key performance indicators



http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt

Frame (1)

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- The client sends frames to the server

Leap Indicator (2-bits)
0x00 no leap adjustment
0x01 minute has 61 seconds
0x02 minute has 59 seconds
0x03 clk unsynchronised

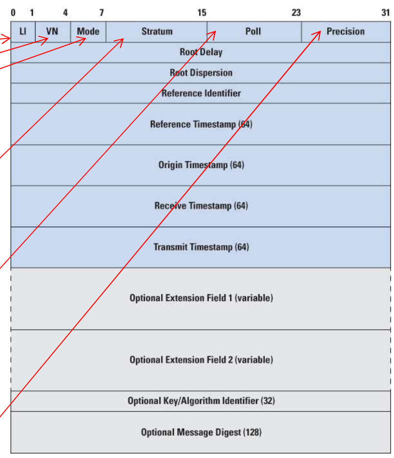
NTP version number (3 bits)

NTP packet mode (3 bits)
The values of the Mode field follow:
0: Reserved
1: Symmetric active
2: Symmetric passive
3: Client
4: Server
5: Broadcast
6: NTP control message
7: Reserved for private use

Stratum level of the time source (8 bits)
0: Unspecified or invalid
1: Primary server
2–15: Secondary server
16: Unsynchronized
17–255: Reserved

Poll interval (8-bit signed integer) value of the maximum interval between successive NTP messages, in seconds.

Clock precision (8-bit signed integer) The precision of the system clock, in $\log_2$ seconds.



LEARNING AIM: The students will be able to explain a NTP frame

http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt
http://www.cisco.com/web/about/ac123/ac147/images/ipj/ipj_15-4/154_ntp_fig01_lg.jpg

Frame (2)

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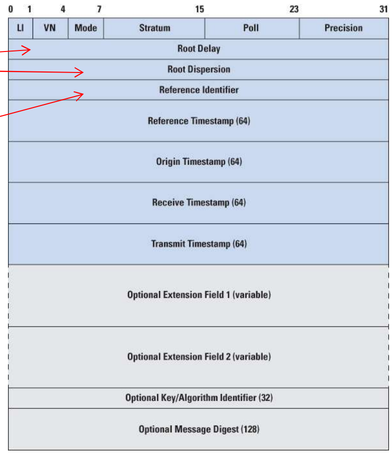
The total round-trip delay from the server to the primary reference sourced. The value is a 32-bit signed fixed-point number in units of seconds, with the fraction point between bits 15 and 16. This field is significant only in server messages.

The maximum error due to clock frequency tolerance. The value is a 32-bit signed fixed-point number in units of seconds, with the fraction point between bits 15 and 16. This field is significant only in server messages.

For stratum 1 servers this value is a four-character ASCII code that describes the external reference source (refer to Figure 2). For secondary servers this value is the 32-bit IPv4 address of the synchronization source, or the first 32 bits of the *Message Digest Algorithm 5* (MD5) hash of the IPv6 address of the synchronization source



Code External Reference Source
LOCL uncalibrated local clock
CESM calibrated Cesium clock
RBDM calibrated Rubidium clock
PPS calibrated quartz clock or other pulse-per-second source
IRIG Inter-Range Instrumentation Group ACTS NIST telephone modem service
USNO USNO telephone modem service
PTB PTB (Germany) telephone modem service
TDF Allouis (France) Radio 164 kHz
DCF Mainflingen (Germany) Radio 77.5 kHz
MSF Rugby (UK) Radio 60 kHz
WWV Ft. Collins (US) Radio 2.5, 5, 10, 15, 20 MHz
WWVB Boulder (US) Radio 60 kHz
WWVH Kauai Hawaii (US) Radio 2.5, 5, 10, 15 MHz
CHU Ottawa (Canada) Radio 3330, 7335, 14670 kHz
LORC LORAN-C radionavigation system
OMEG OMEGA radionavigation system
GPS Global Positioning Service

https://labs.apnic.net/?p=462

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Timestamping (1)

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Session 1: Time Synchronisation
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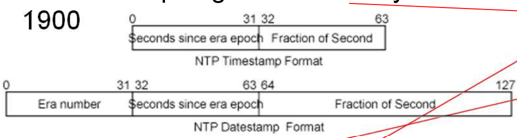
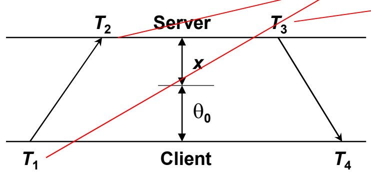
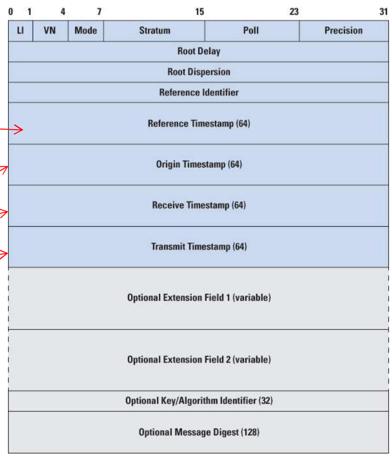
- Reference timestamp is the time the client last corrected the clock
- Teststamp begins 1st January 1900







$$\theta = \tfrac{1}{2}[(T_2 - T_1) + (T_3 - T_4)]$$
$$\delta = (T_4 - T_1) - (T_3 - T_2)$$

LEARNING AIM: The students will be able to explain the NTP timestamps

https://www.eecis.udel.edu/~mills/pic/time1.gif
http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt
http://www.cisco.com/web/about/ac123/ac147/images/ipj/ipj_15-4/154_ntp_fig01_lg.jpg

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Exercise 1 NTP

Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
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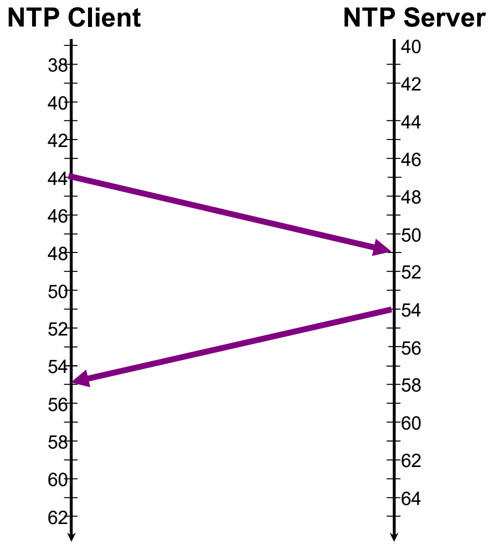
- Precision Time Protocol



Calculate the Offset and Delay

Exercise 2 NTP

Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
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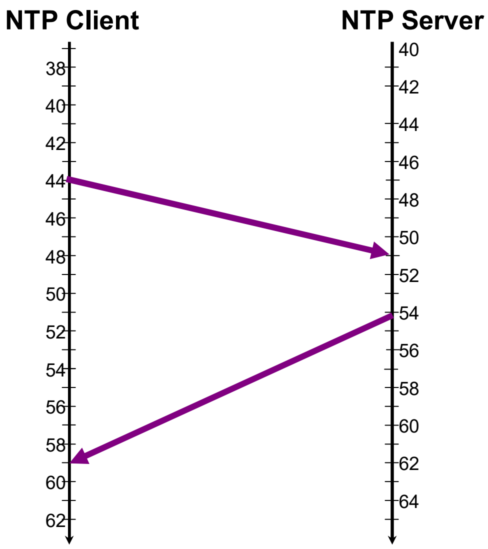

Calculate the Offset and Delay

Time Sources (3)

Session 1: Time Synchronisation
- Time basics
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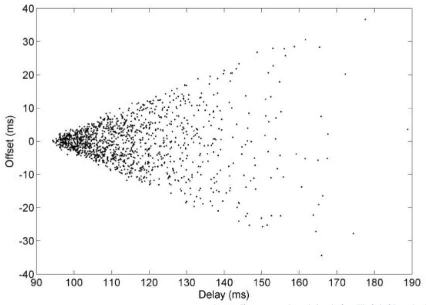
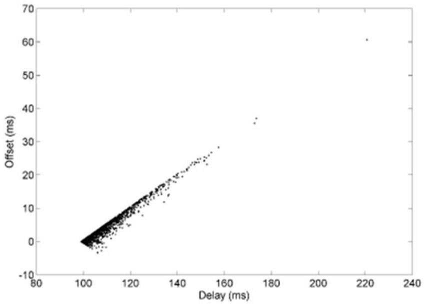
- For each server the client maintains the state.
- Using a sliding window it gets the smallest of last 8 delay measurements
- Based on the scattergram this is the most accurate





https://www.eecis.udel.edu/~mills/pic/time1.gif
http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt
http://www.cisco.com/web/about/ac123/ac147/images/ipj/ipj_15-4/154_ntp_fig01_lg.jpg

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Time Sources (4)

Session 1: Time Synchronisation
- Time basics
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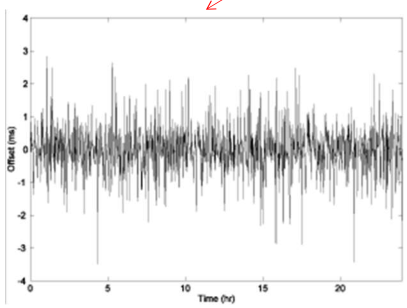
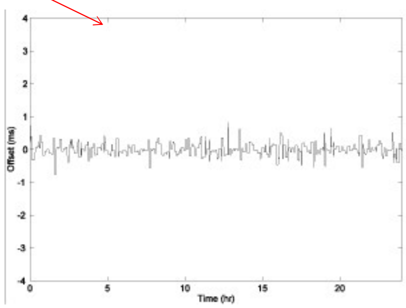
- **Network Time Protocol**
- Precision Time Protocol

- Algorithm produces this from that





https://www.eecis.udel.edu/~mills/ntp/html/filter.html

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Voting (1)

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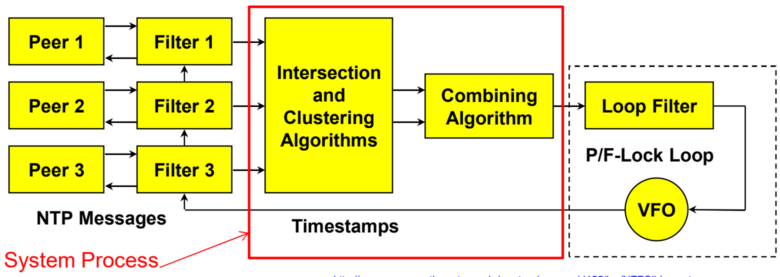
- From the peer process we have a collection of best possible time values – how do we get the truechimers and dump the falsetickers?
  - Eliminate the obvious errors
    - Stratum error (never been synch or below an acceptable level)
    - Distance error
    - Loop error (source synchronised with the client)
    - Unreachable error (source is unreachable)



http://users.eecs.northwestern.edu/~peters/courses/d455/hw/NTPSlides.ppt

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Voting (2)

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Session 1: Time Synchronisation
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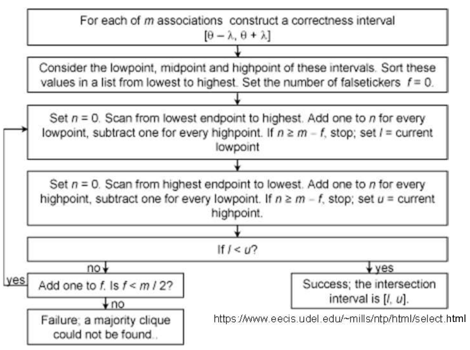
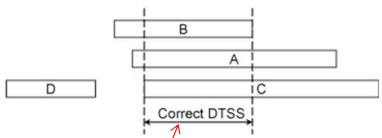
- The filter stage found us the best local sources, here we are looking for the best absolute sources.
  - We find it by considering the distance of the server from the primary clock. Distance means effectively delay
- Using this criteria we find the best set of truechimers



https://www.eecis.udel.edu/~mills/ntp/html/select.html



From survivor list produce weighted average of offset

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Voting (3)

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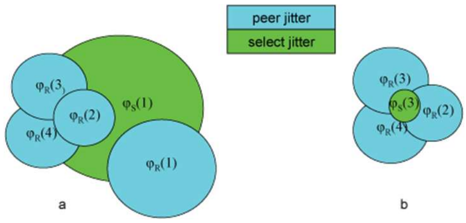
- The final result should be a weighted average. To increase the quality of the average (tightness) we eliminate as many of the jittery sources as possible
- The selection jitter (green) on the left is largely due to source 1 (blue) by eliminating source 1, the selection jitter is reduced to that on the right (green)
- The list of survivors consists of source 2..4
- From this list of survivors the weighted average is calculated. The weights can include (personal?) preferences



https://www.eecis.udel.edu/~mills/ntp/html/select.html

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Clock Control

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Session 1: Time Synchronisation
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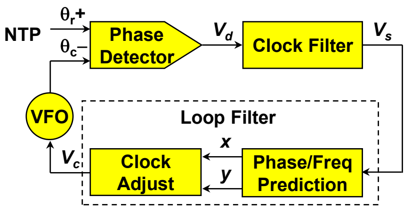
- At long last we have from n peers a single offset and delay value which we can use to discipline our clock
- The system clock is the Variable Frequency oscillator
- The controller is a Proportional Integral controller (PI)
  - The P reacts to the absolute changes
  - The I component allows the offset to go to 0



https://www.eecis.udel.edu/~mills/ntp/html/select.html

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NTP Issues (1)

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Session 1: Time Synchronisation
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- U Wisconsin operates a number of time servers for campus access.
- A home router came on the market that
  - had the address of one of these servers hard-coded in firmware and could not be changed,
  - could send packets continuously at one-second intervals under conditions when the path or server was unavailable..
- This would not be a problem if only a small numbers of these routers were sold.
  - However, eventually 750,000 routers were sold and most could not be recalled, updated or even reliably found.
  - The resulting traffic overwhelmed the server, university network and service provider.
- There has been no wholly satisfactory solution to this problem other than to insure continuous service and to educate the manufacturer about socially responsible product design.

https://www.eecis.udel.edu/~mills/.../**distlec/distlec.ppt**

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NTP Issues (2)

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Session 1: Time Synchronisation
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- NIST operates about a dozen NTP public time servers in the US.
  - Three of the busiest servers are in Boulder, CO
  - They share an aggregate load similar to USNO, but the NIST network infrastructure is far more resilient than USNO.
- An experiment collected statistics in a nine-second window on each machine using a sampling technique which captured about 13 percent of the arrivals.
  - The results revealed over 500 clients with polling intervals of 5 seconds or less and 15 with poll intervals less than one second. Well behaved NTP clients send at rates usually at intervals of fifteen minutes or more.
  - Most incidences involved packet bursts lasting from a few seconds to several days and separated by minutes, hours or days.
  - One particularly offensive elephant was sending continuously at two packets per second.

https://www.eecis.udel.edu/~mills/.../**distlec/distlec.ppt**

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Network Time Protocol Summary

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Session 1: Time Synchronisation
- Time basics
- Simple Time Synchronisation
- **Network Time Protocol**
- Precision Time Protocol

- Fundamental assumption:

  The one-way transmission delay
  is estimated being half of the round trip time

- Accuracy depends on two major factors

  → Symmetry of the transmission path

  → Accuracy of timestamps

- NTP OK for a large range of tasks – not that good for precision time applications as found in control systems
  - There is a market for a protocol with better precision
    - Precision Time Protocol (PTP) IEEE 1588

https://www.eecis.udel.edu/~mills/.../**distlec/distlec.ppt**

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Precision Time Protocol: Introduction

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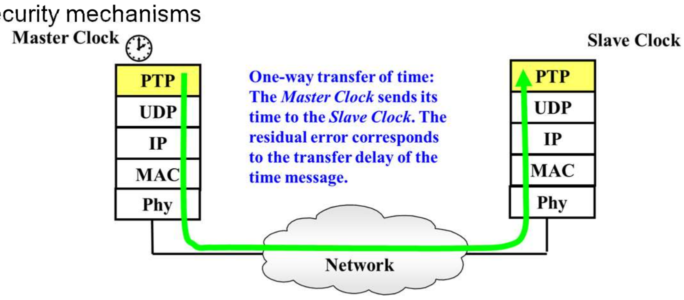
- IEEE 1588 – 2008 (aka PTP v2) was approved 27th of March 2008.
- Activities have been started to revise the standard. The result will be a new edition of the standard (most probably IEEE 1588 – 2017), but not necessarily a new version of PTP (i.e. PTP v3): Topics are:
  - Architectural aspects (layering, i.e. separation of media dependent parts)
  - Provisions for improved accuracy of better than 1 ns
  - Specification of security mechanisms



Hans Weibel – IEEE1588 Tutorial

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Fundamental Features (1)

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- Can run over Layer 2 or UDP (multicast)
  - Port 319 for messages that need timestamping / port 320 for all other messages
  - 48 bit unsigned seconds
  - 32-bit unsigned nanoseconds
  - TIA – with POSIX epoch
- Distinguishes three types of clock
  - Ordinary Clock (OC) Has a single PTP port in a domain and maintains the timescale of the domain
  - Boundary Clock (BC) Has multiple PTP ports in a domain and maintains the timescale of the domain
  - Transparent Clock Measures the time taken for a PTP event message to transit the device
    - Peer-to-peer transparent clocks (P2P TC) provide corrections for the propagation delay of the link in addition to the transit time
    - End-to-end transparent clock (E2E TC)

LEARNING AIM: The students will be able to explain the key features of PTP

http://www.chronos.co.uk/files/pdfs/itsf/2007/workshop/itsf-ntpv4-1588-nov07-v2.pdf

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Fundamental Features (2)

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- Master-Slave protocol
- Best Master Algorithm decides which potential grandmaster is active
  - Potential grandmasters exchange Announce messages
  - BMCA is executed on each OC/BC port by comparing data sets (i.e. a node compares its own data set with the one received by Announce → which one describes the better clock?)
  - The comparison is based on the following attributes in the respective order
    - Priority1: a configurable clock priority
    - clockClass: a clock 's traceability
    - clockAccuracy: a clock's accuracy
    - offsetScaledLogVariance: a clock's stability
    - Priority2: a configurable second order clock priority
    - clockIdentity: a clock's unique identifier (the tie-breaker if all other attributes are equal)
  - Based on this comparison a state decision is taken → the port state is set to either MASTER, SLAVE, or PASSIVE

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Fundamental Operation (1)

Determination of Phase Change Rate (Drift) – one-step clock

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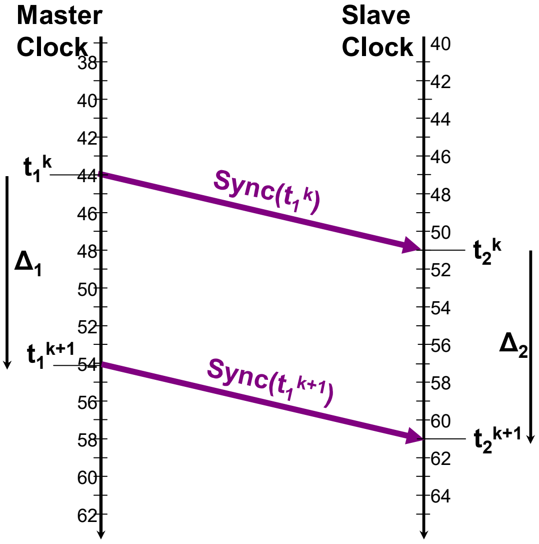

One-step clock:
Special hardware required in order to insert timestamp t_1 on the fly

$$\Delta_1 = t_1^{k+1} - t_1^k$$

$$\Delta_2 = t_2^{k+1} - t_2^k$$

$$\text{Drift} = \frac{\Delta_2 - \Delta_1}{\Delta_2}$$

Fundamental Operation (2)

Determination of Phase Change Rate (Drift) – two-step clock

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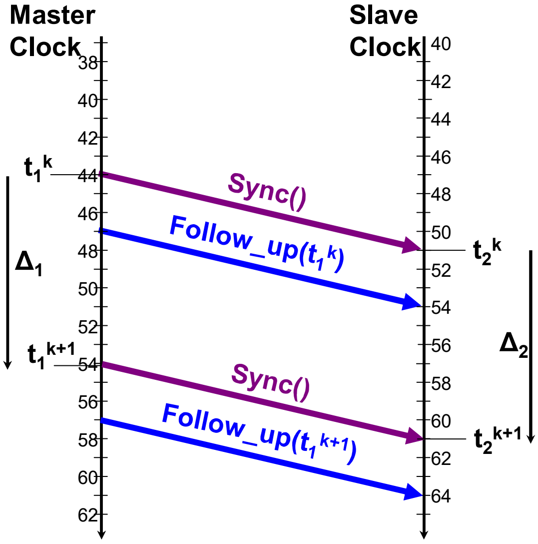

Two-step clock:
No need to modify Sync message on the fly

$$\Delta_1 = t_1^{k+1} - t_1^k$$

$$\Delta_2 = t_2^{k+1} - t_2^k$$

$$\text{Drift} = \frac{\Delta_2 - \Delta_1}{\Delta_2}$$

Fundamental Operation (3)

Delay and Offset Determination

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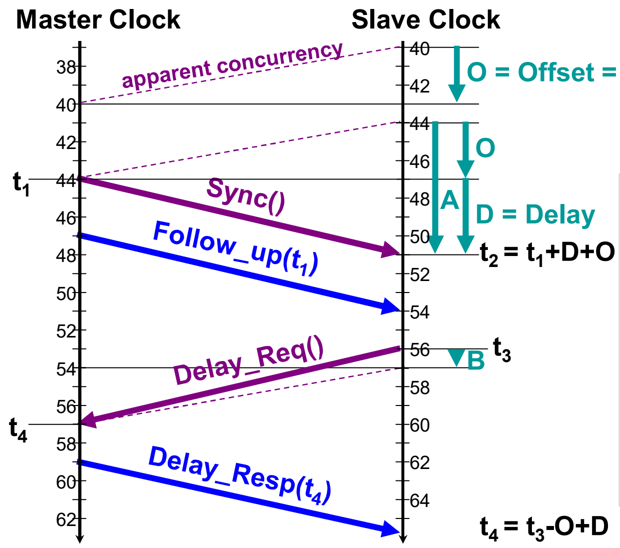

measured values t_1, t_2, t_3, t_4

$A = t_2 - t_1 = D + O$

$B = t_4 - t_3 = D - O$

Delay D $= \frac{A + B}{2}$

Offset O $= \frac{A - B}{2}$

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Precision Time Protocol (4)

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- The rate of each message type (i.e. Sync, Announce and Delay_Req) can independently be chosen
- The required frequency of clock adjustments depends on oscillator stability and expected accuracy
  - Sync and Delay_Req message rate can be up to 128 Sync messages per second. Be aware of the dimensions:
    - 1 ppm of oscillator deviation results in 1 µs per second (or 1s/12 days)
    - a cheap quartz has a temperature dependency of about 1 ppm/^{0}C or more
  - The Announce rate influences the speed of BMCA execution
- Sync and Follow_up messages are sent as multicasts
  - the master can serve all slaves of a segment with one single message
  - each slave can calculate its drift and offset individually
- Delay_Req and Delay_Resp messages have point-to-point significance, but are sent per multicast as well (no address administration required)
  - because the delay is assumed not to change quickly, it is not measured as frequent as the offset is, but the resulting network load grows with $(\#slaves)^2$

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Timestamps (1)

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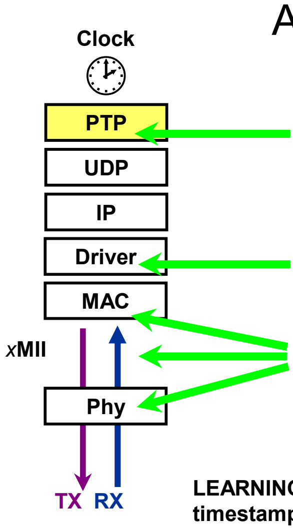
Accuracy of timestamps



timestamping in the application layer (above socket)
→ exposed to delays in protocol stack and scheduling

timestamping at network interrupt level
→ exposed to interrupt latency and network load

timestamping with hardware assistance
→most accurate timestamps
→tapping or intercepting the *x*MII or integrated into the PHY or the MAC function

LEARNING AIM: The students will be able to discuss timestamps placement

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Timestamps (4)

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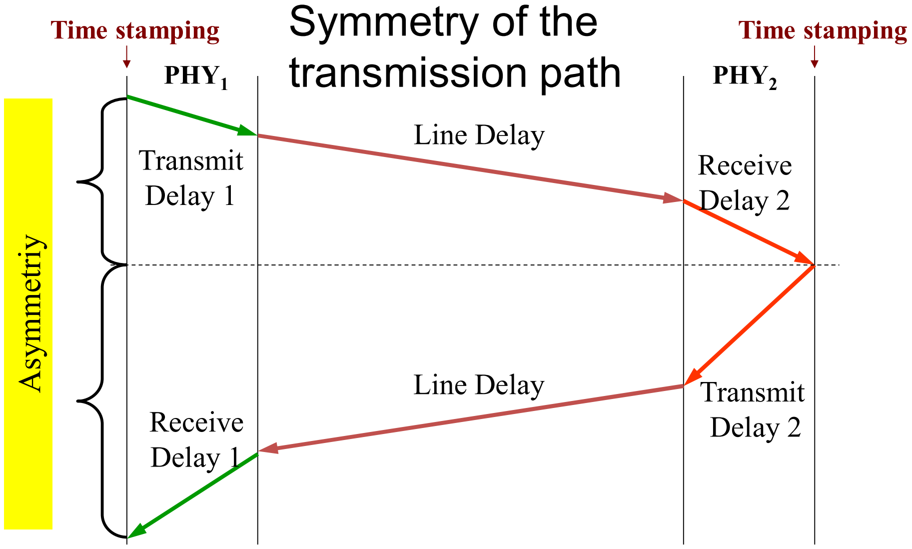
Symmetry of the transmission path



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Conclusion: PTP V's NTP

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- NTP is a request-response protocol based on peer-to-peer
- NTP is geared to getting precision time from internet-distributed sources
- NTP requires a relatively sophisticated client
- UDP/IPv4 and UDP/IPv6 only allowable transports

- PTP is a broadcast protocol based on controller-responder
- PTP is geared to getting precision time from a local source
- PTP has a relatively simple client
- PTP supports a dynamic controller selection based on Best Master Clock algorithm)
- Multiple transports allowed: UDP/IPv4, UDP/IPv6, IEEE 802.3, DeviceNET, ControlNET, and IEC 61158 Type 10 currently defined)

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