One-way Delay Measurement Using NTP Synchronization

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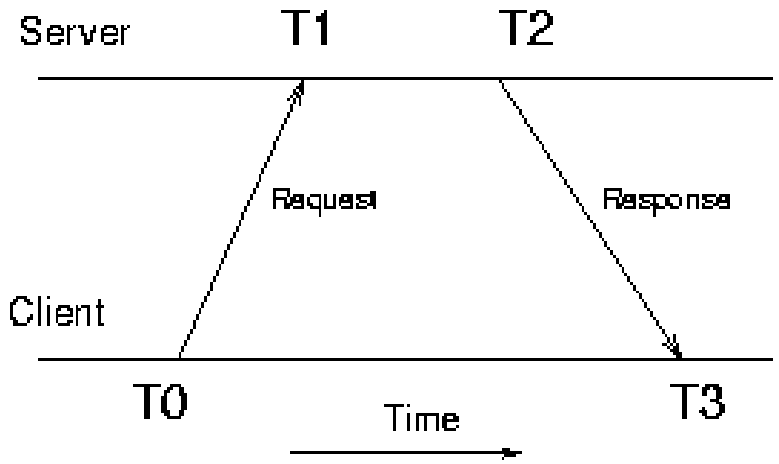
One-way Delay

- theory (RFC 2679): difference between time of last bit of packet "on-wire" at receiver and first bit of packet "on-wire" at sender
  - requires specialized HW
  - reflects OWD at physical layer
- practice: OWD = Tr - Ts
  - Tr ..... timestamp of packet receiving
  - Ts ..... timestamp of packet sending
  - OWD measured at application layer
  - Ts might be included into packet -> only one packet
- problem: time synchronization at both sites

Methods of Synchronization

- external time source
  - receiver of time information (GPS, DCF, Loran-C, WWV)
  - atom clock (cesium, rubidium)
  - exact, high accurate (μs order)
  - expensive, not scalable, external system installation
- synchronization via network (NTP)
  - NTP server
  - cheap, scalable
  - sensitive to network parameters
  - lower accuracy, difficult to estimate real accuracy

Algorithm of NTP



$$\delta = (t3 - t0) - (t2 - t1)$$

$$\theta_0 = ((t1 - t0) + (t2 - t3)) / 2$$

$$\theta_0 - \delta/2 \leq \theta \leq \theta_0 + \delta/2$$

- symmetrical delay assumed
- uncertainty $\leq$ half of round-trip delay

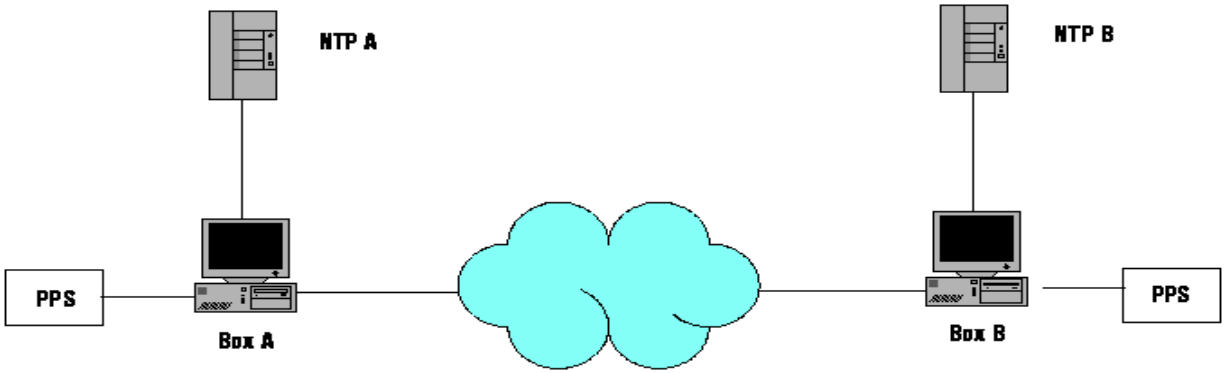
Sources of NTP Inaccuracy

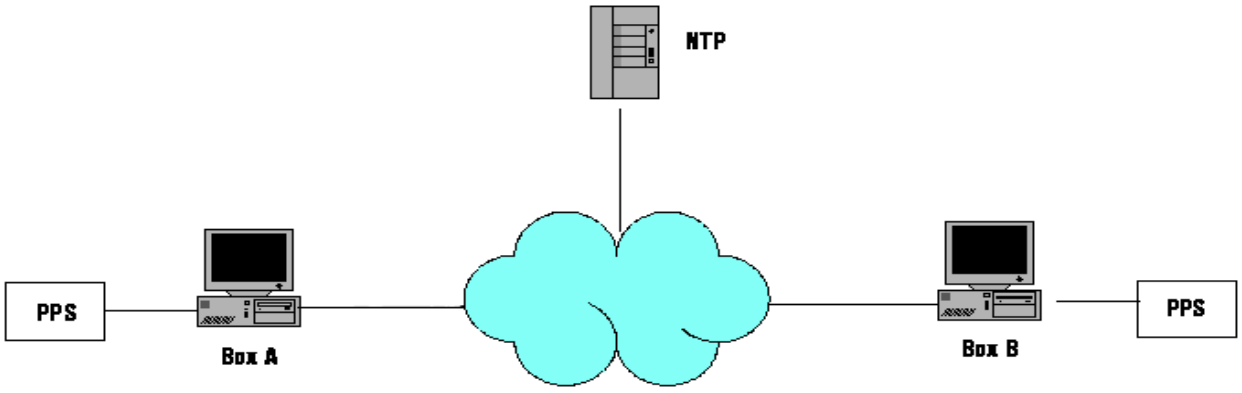
- internal origin
  - locked loop phenomenon
  - system reports as known offset - can be used for correction
- filterable external origin
  - jitter of propagation delay
  - asymmetry in delay due to accidental network load
- unfilterable external origin
  - asymmetry in delay due to long time network load
  - asymmetry in routing

Configuration for High Accuracy

- multiple NTP servers
  - higher robustness
  - Selection and Clustering algorithm
  - accuracy decreased by several milliseconds
- one NTP server
  - vulnerability
  - high accuracy
- default polling interval
  - self-adjusted: up to 1024 s
- explicit polling interval
  - best accuracy: 16 - 64 s

OWD Measurement Setup I + II





Measured Values

- Ts - timestamp of packet sending (from application)
- Tr - timestamp of packet receiving (from application)
- Os - offset of sender clock (reported by NTP)
- Or - offset of receiver clock (reported by NTP)
- Ps - exact offset of sender clock (PPS capture log)
- Pr - exact offset of receiver clock (PPS capture log)

Calculated Values

- Raw one-way delay obtained from CRUDE log

  $OWD\_r = Tr - Ts$

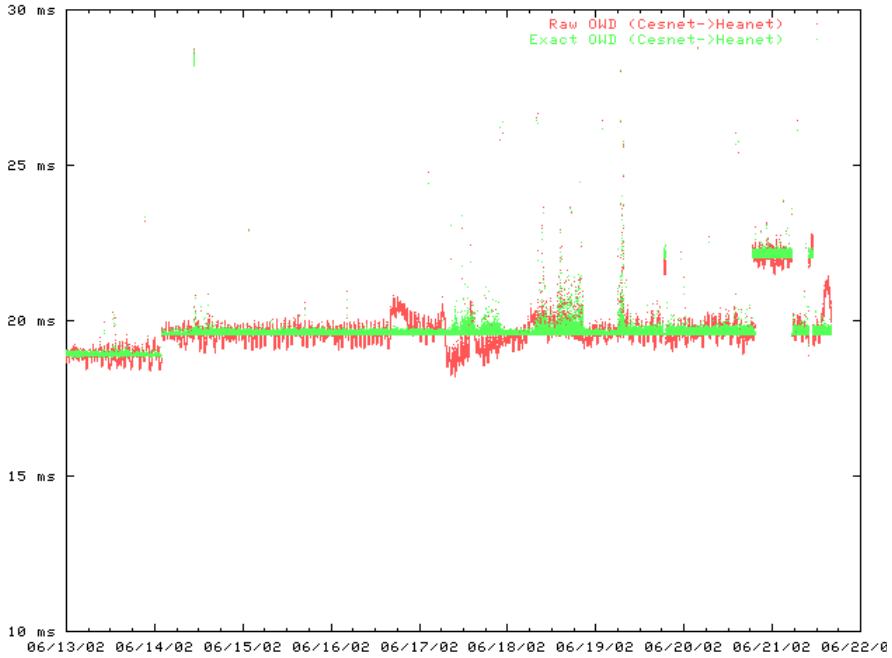
- One-way delay corrected by estimated NTP offsets

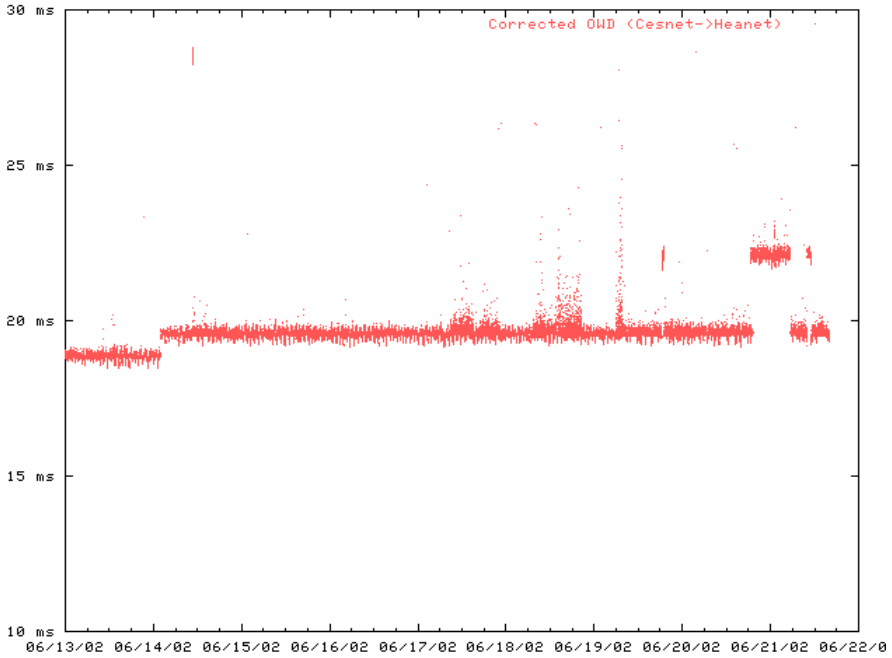
  $OWD\_n = Tr - Or - (Ts - Os)$

- Exact one-way delay calculated from GPS time

  $OWD\_e = Tr - Pr - (Ts - Ps)$

Results (setup I)

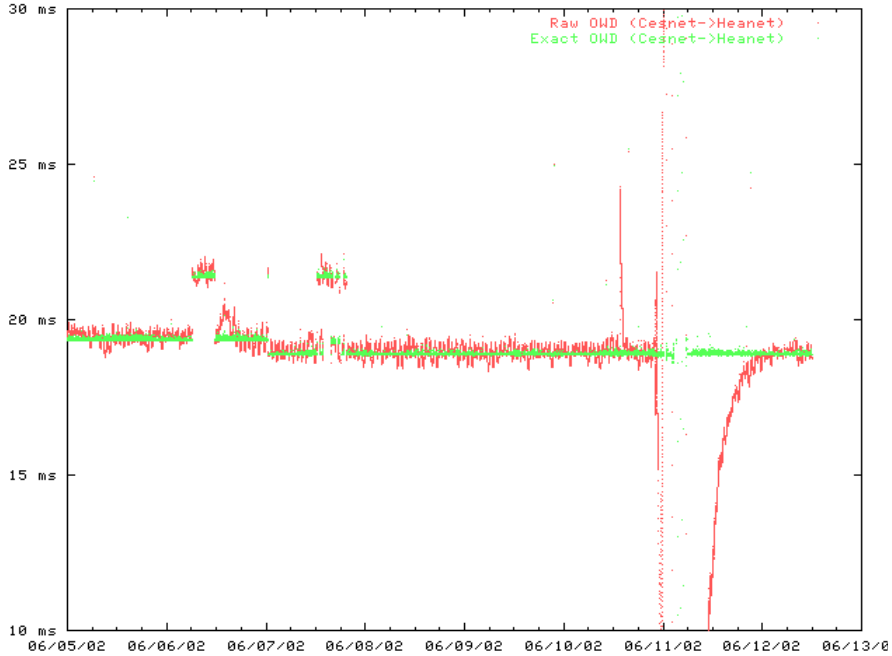


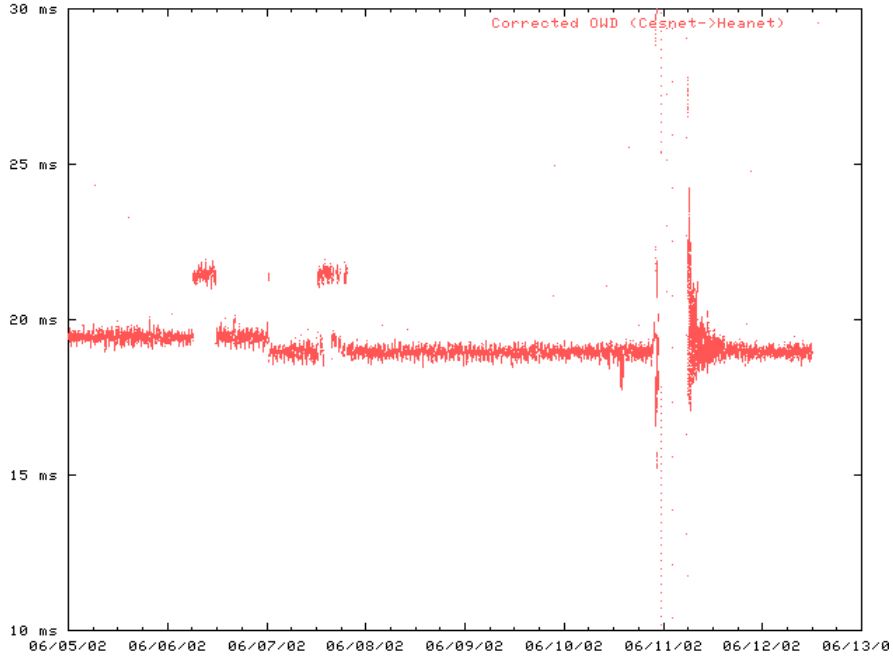


green - exact OWD
red - measured OWD

red - recalculated OWD

Results (setup II)

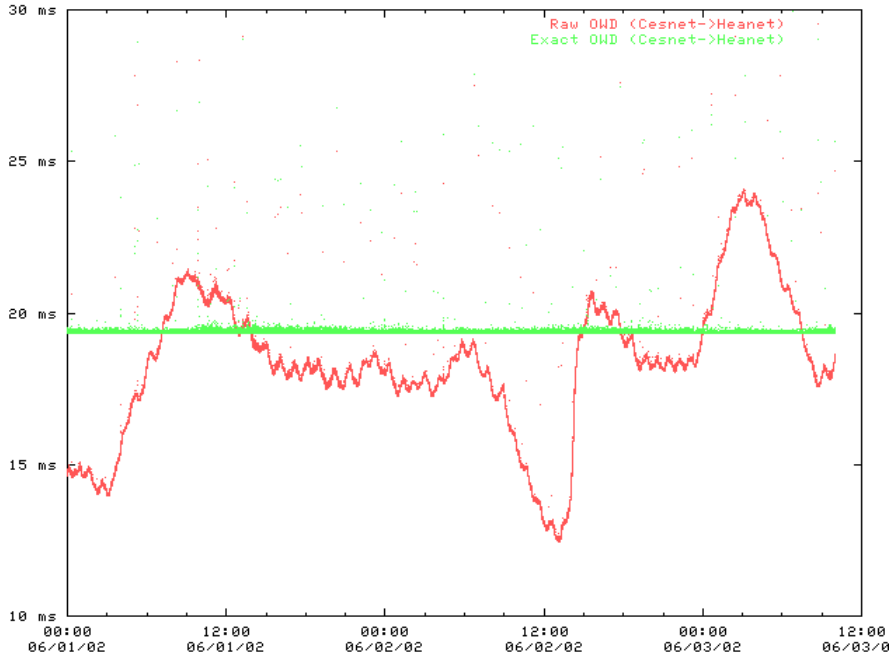


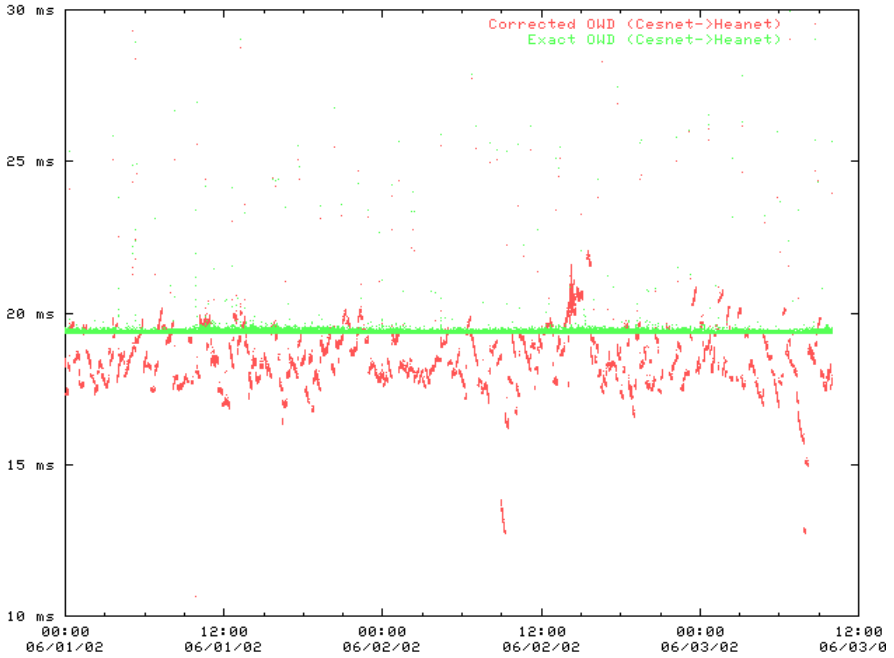


green - exact OWD
red - measured OWD

red - recalculated OWD

Results (setup IIa)

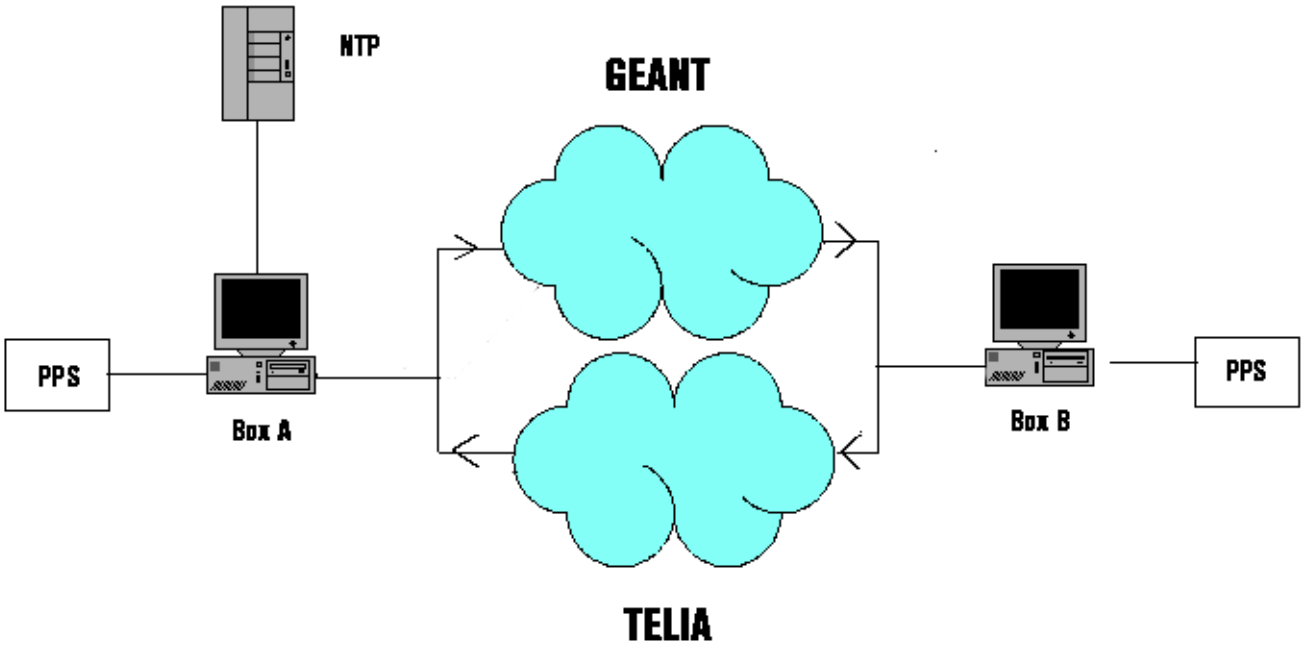




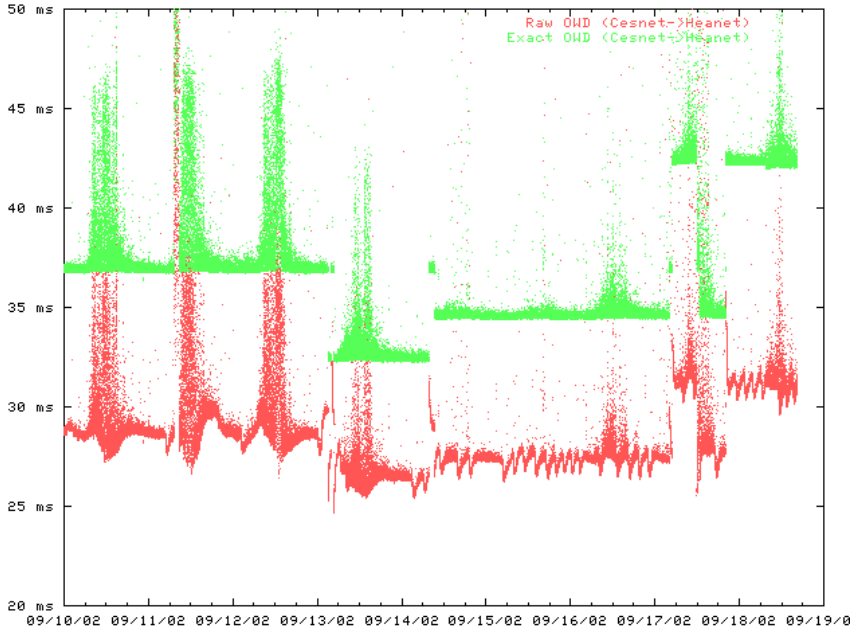
green - exact OWD
red - measured OWD

red - recalculated OWD

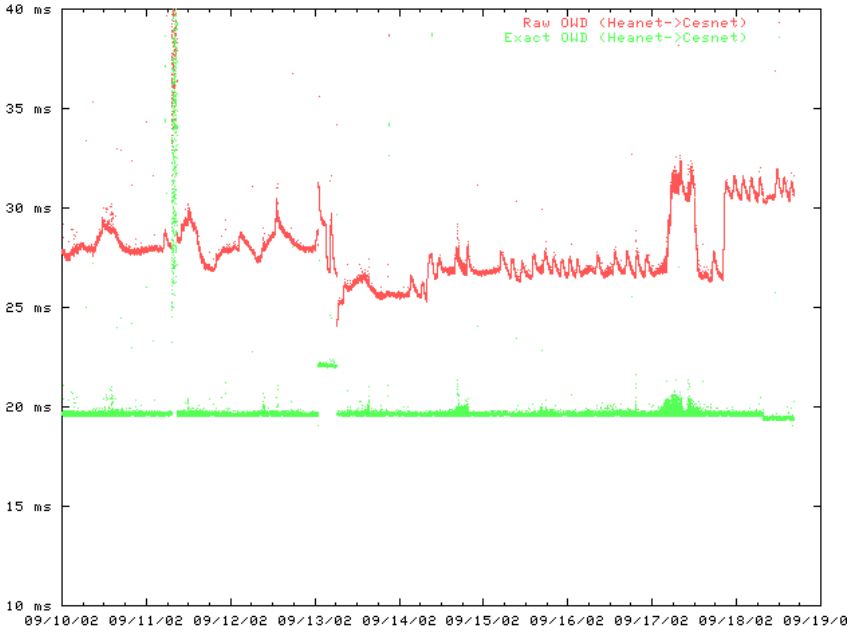
OWD Measurement Setup III



Results (setup III)



B -> A (via TELIA)
red: measured OWD (about 28ms)
green: exact OWD (about 37 ms)



A -> B (via GEANT)
red: measured OWD (about 28ms)
green: exact OWD (about 20 ms)

Conclusions

Setup I (local NTP server in each site of measurement)

- recalculation of OWD improves accuracy
- robust, estimated error in the order of 100 us
- assumed low offset between both NTP servers
- well suitable for OWD measurement

Setup II (one common NTP server)

- accuracy depends on NTP server position
- estimated error less than 1 ms (symmetric routing)
- careful setup of ntpd necessary (differs from default)
- suitable for OWD measurement

Conclusions (cont.)

Setup III (one NTP server, asymmetric routing)

- stable asymmetry in OWD can not be detected
- mean value of measured OWD in both directions is the same
- estimated error of measurement is one half of the asymmetry
- quite unsuitable for OWD measurement

Suggested NTP configuration

- never use multiple NTP servers per box of measurement
- careful selection of NTP server
  - symmetric path between NTP server and site of measurement
  - low RTT between NTP server and site of measurement
  - high and long time stability of NTP server
  - high accuracy of NTP server (stratum-1 or stratum-2)
- adjusted polling interval
  - example: server <NTP server> minpoll 6 maxpoll 6

Thank you