The Cost of Variability

(or the importance of a robust servo)

Julien Ridoux jridoux@unimelb.edu.au
Darryl Veitch dveitch@unimelb.edu.au

ARC Special Research Centre for
Ultra-Broadband Information Networks
THE UNIVERSITY OF MELBOURNE

NICTA Victoria Research Laboratory
Dept. of Electrical & Electronic Engineering
THE UNIVERSITY OF MELBOURNE

Introduction

- **A perfect world**
  - Constant delays
  - Symmetric paths
  - No disconnection, no power outage
  - No change of network topology

- **Distribution of time becomes extremely easy**

- **Of course the reality is slightly different**
  - Network heterogeneity
  - Cheap, low quality, incompatible equipment
  - Evil IT guys

Why we should care about delays

- **Even for hardware solutions latency is an issue**
  - Variable delays are unavoidable (hence transparent clocks)
  - Lower quality hardware
  - Unexpected events (congestion, disruption, ...)
- **Software component can be introduced**
  - If slave does not require sub-microsecond accuracy
  - But still benefits from gold class IEEE 1588 Master clock
- **Servo design is crucial when facing destabilising events**
  - We compare PTPd against TSCclock
    - Ideal conditions, Network Congestion, Disruption event
    - Focus on variability and robustness
  - Advocate for robust and stable servo design
    - Feedback vs. Feedforward design
    - Robust delay filtering

PTPd

- **Software implementation of IEEE 1588**
  - http://ptpd.sourceforge.net
    - Correll et al., “Design Considerations for Software only Implementations of the IEEE 1588 Precision Time Protocol”, ISPCS 2005
  - Easy to install (Thanks!)

- **Servo used is a Proportional-Integral (PI) controller**
  - Feedback algorithm
  - Tries to correct clock rate and clock offset simultaneously
  - Difficult “tuning” between fast convergence and oscillations
    - Short term tracking vs. rate stability
  - Stability not guaranteed in noisy environments

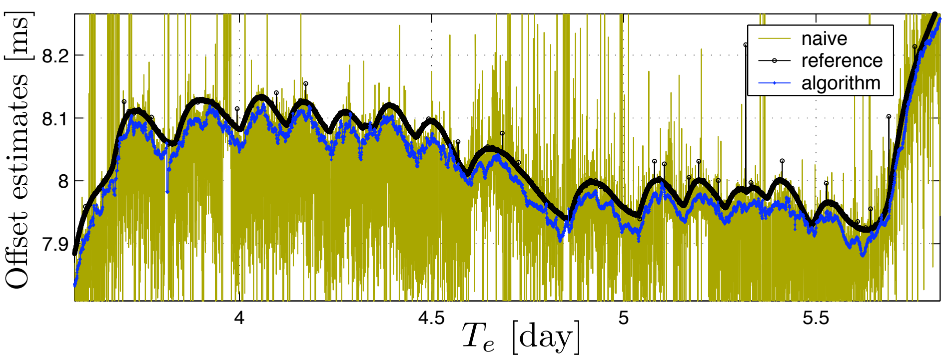
The TSCclock

- **The TSCclock is**
  - the result of a long lasting research effort at the UoM
  - a set of algorithms and filtering tools
  - a software implementation of a Robust Absolute and Difference clock (RADclock)
  - http://www.cubinlab.ee.unimelb.edu.au/tscclock
- **Main objective: replace the *ntpd* daemon**
  - Works on LAN and WAN
  - Designed for noisy environments, emphasis on robustness
- **The TSCclock is complementary to IEEE 1588**
  - is a servo controller, not a protocol
  - can be used with different master clocks

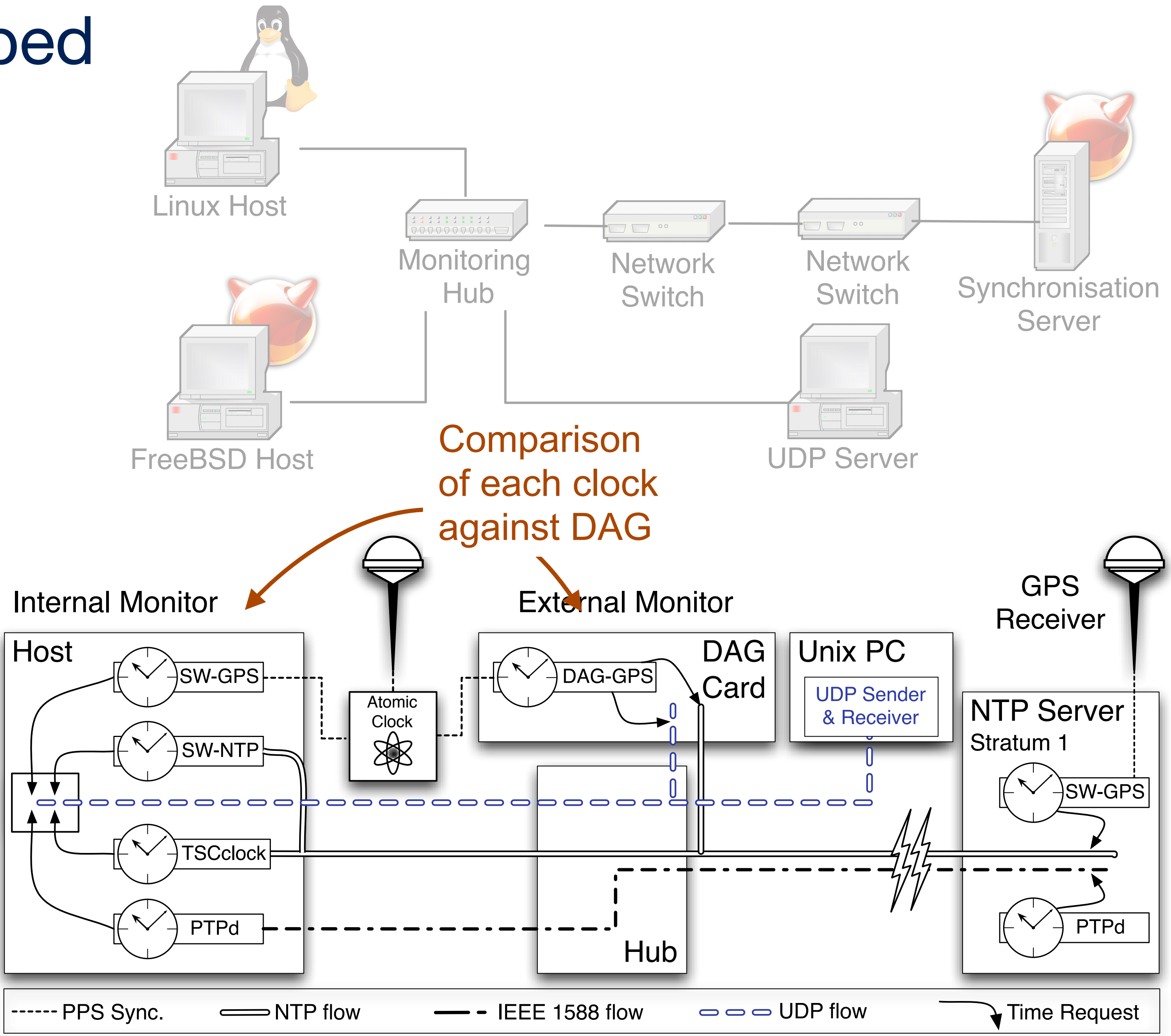
The TSCclock

- **TSCclock uses the CPU cycle Time-Stamp Counter (TSC)**
  - Runs on common hardware PC architecture

- **Feedforward algorithm**
- No feedback loop "locking onto" the input signal
- Estimate the long-term average oscillator rate
  - Non-Linear filtering
  - High stability
- Tracks drift continuously
  - Not fed back into the filtering and rate estimate
  - Correction applied when needed



Testbed



Linux Host
Monitoring Hub
Network Switch
Network Switch
Synchronisation Server
FreeBSD Host
UDP Server
Comparison of each clock against DAG
Internal Monitor
External Monitor
GPS Receiver
Host
SW-GPS
SW-NTP
TSCclock
PTPd
Atomic Clock
DAG-GPS
DAG Card
Unix PC
UDP Sender & Receiver
NTP Server
Stratum 1
SW-GPS
PTPd
Hub
PPS Sync.
NTP flow
IEEE 1588 flow
UDP flow
Time Request

Fair comparison

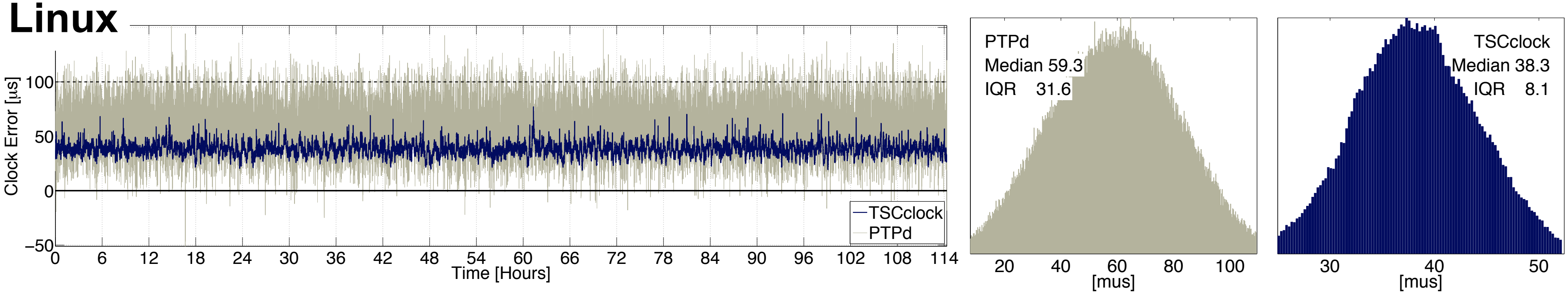
- **Same hardware support for each solution**
  - Clocks run in parallel
  - Same system noise
  - Same temperature environment

- **Use of defaults parameters**
  - No tuning of the servo
    - IEEE 1588 objective: "*The default behavior of the protocol will allow simple systems to be installed and operated without requiring the administrative attention of users*"
  - Shared master polling frequency
    - Period = 16 seconds

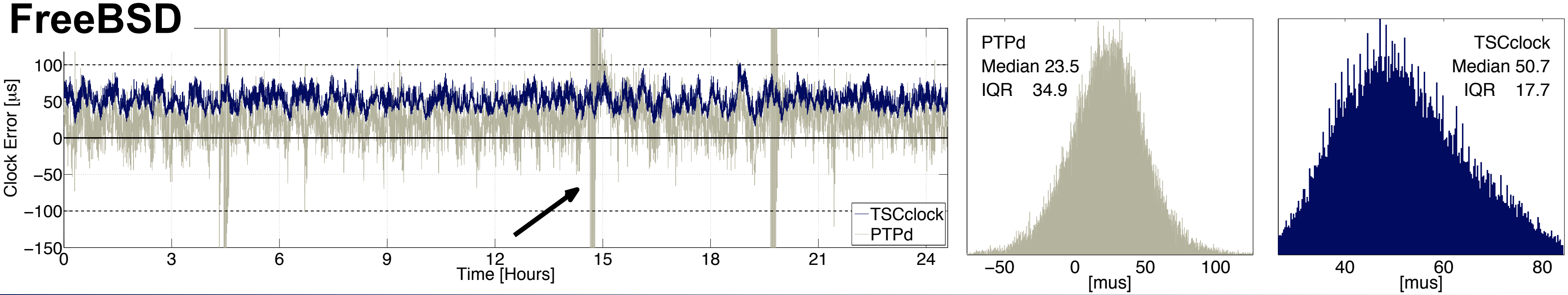
Ideal conditions

- **Focus on stability / robustness of clocks**
  - IQR of PTPd error larger than the TSCclock one
  - Both clock suffer from higher system noise in FreeBSD host
- **Average error not the focus of the talk**
  - Asymmetry issues (see later)

Linux

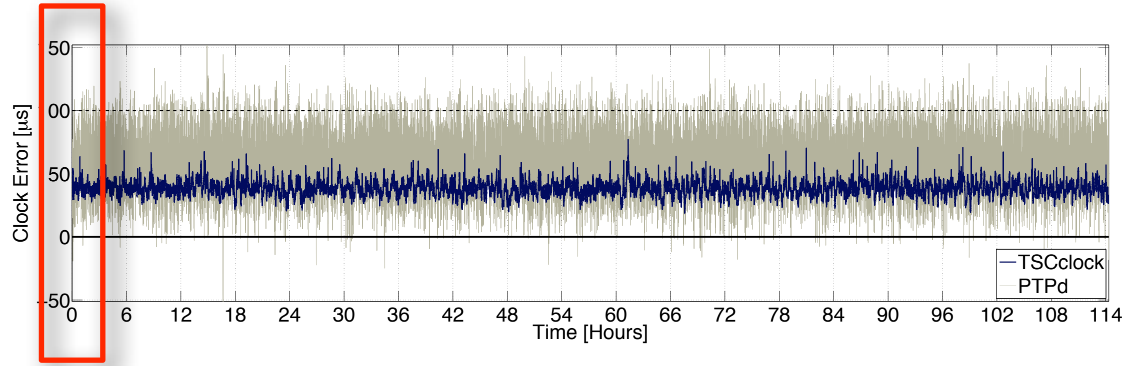


FreeBSD

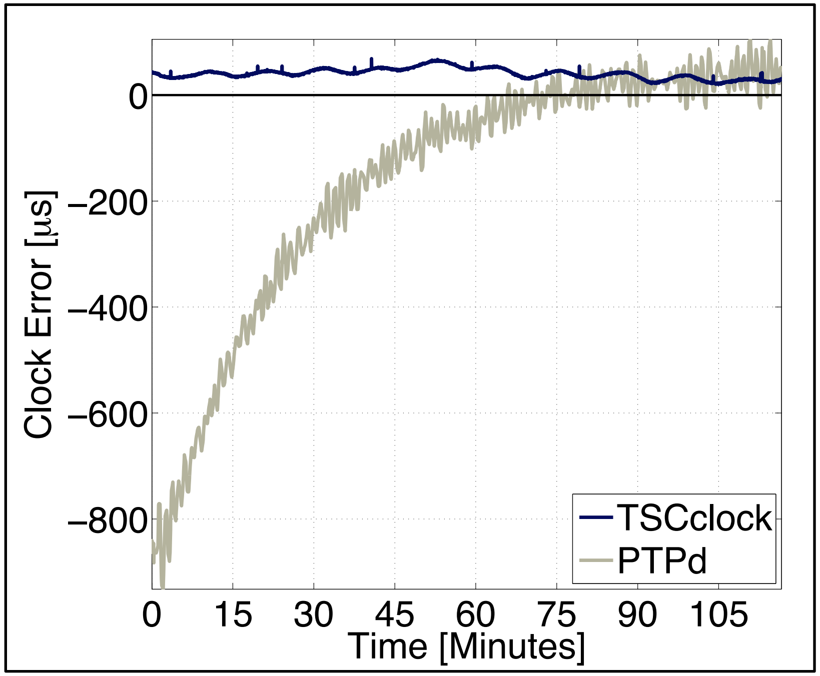


Convergence time

Linux

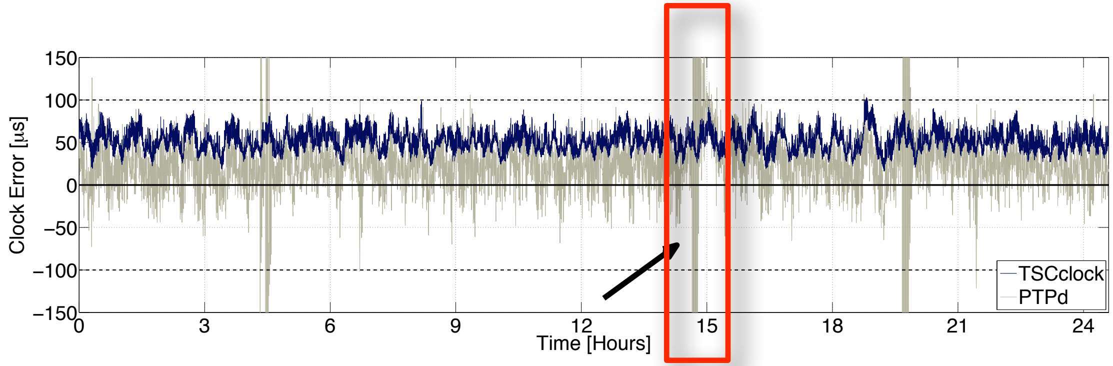


- **Linux Client**
  - Starts alone on network
- **Startup convergence**
  - PTPd: 90 minutes
  - TSCclock: ~immediate



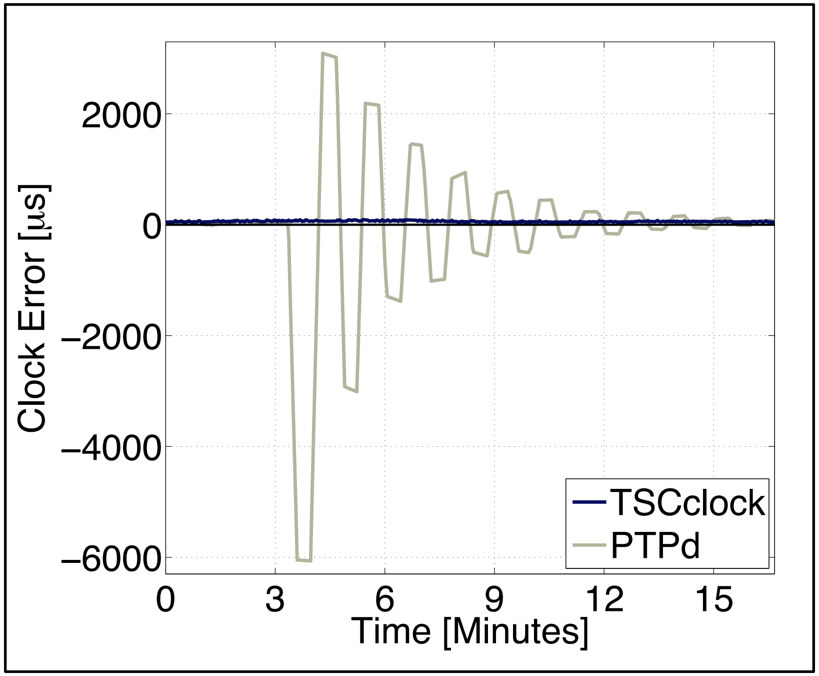
System / Hardware imperfection

FreeBSD



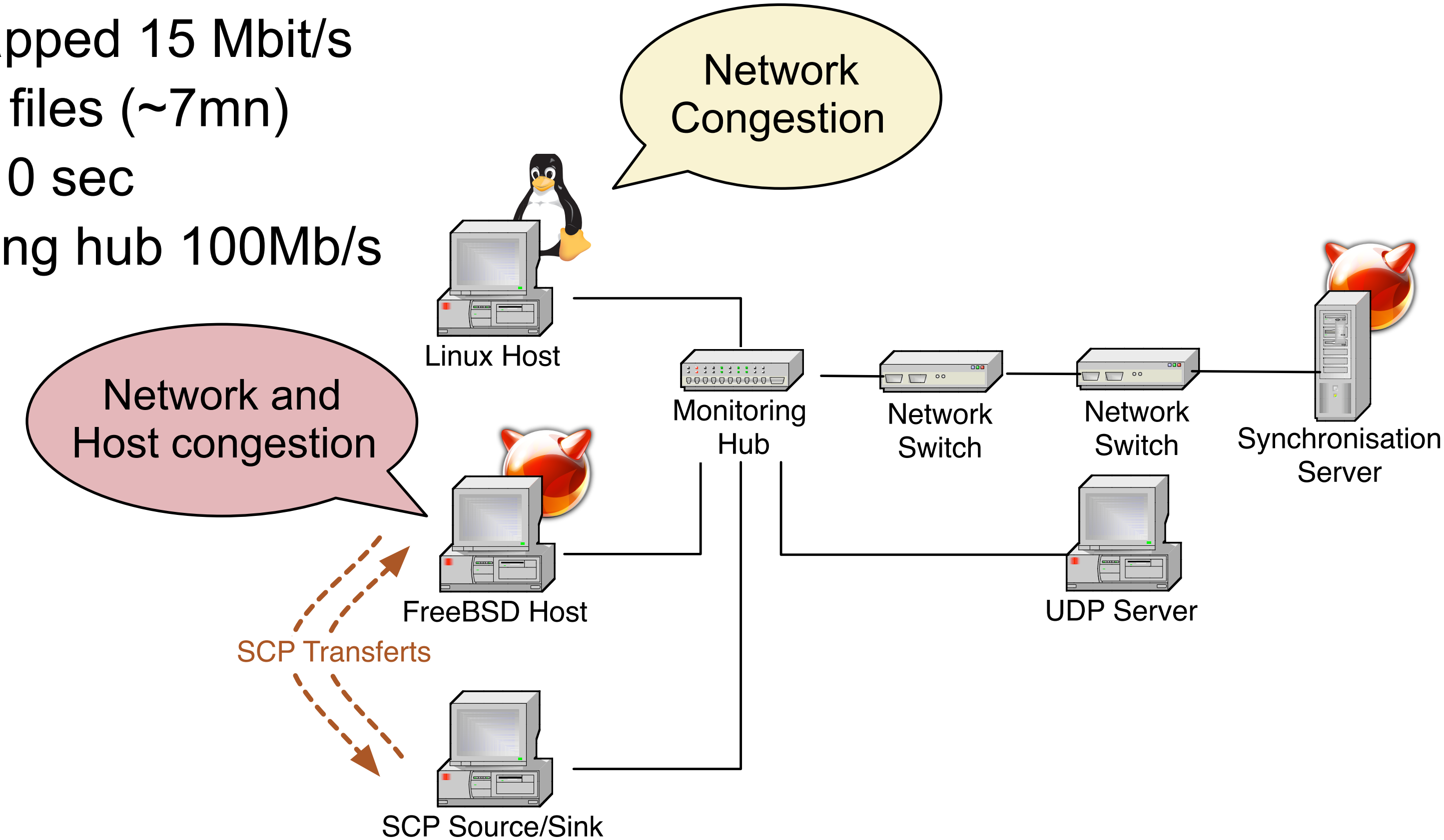
- **FreeBSD client**
  - Unintentional events
  - System specific
  - Unusual large noise

- **Reaction from clocks:**
  - PTPd: large jump and oscillation
  - TSCclock: unaffected



Network Congestion

- **Add extra host to create cross-traffic**
- **Bi-directional SCP transfers**
  - Each capped 15 Mbit/s
  - 750 MB files (~7mn)
  - Pause 10 sec
  - Monitoring hub 100Mb/s



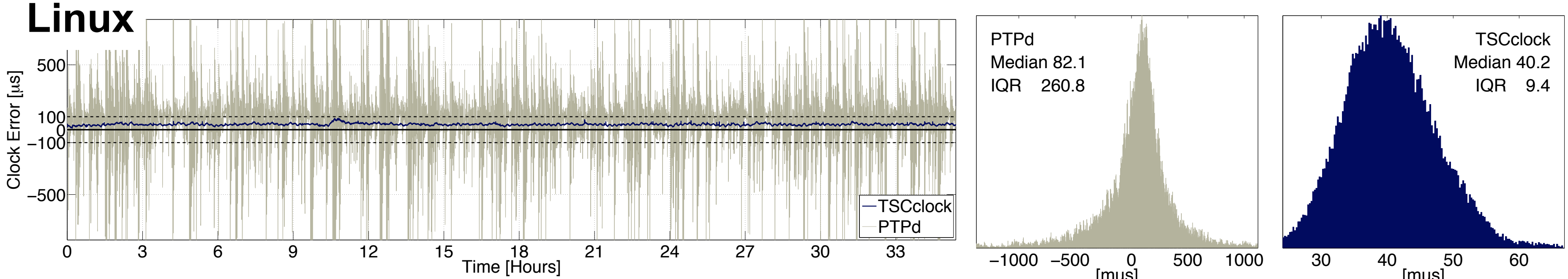
Network Congestion

Previous IQR (ideal conditions)

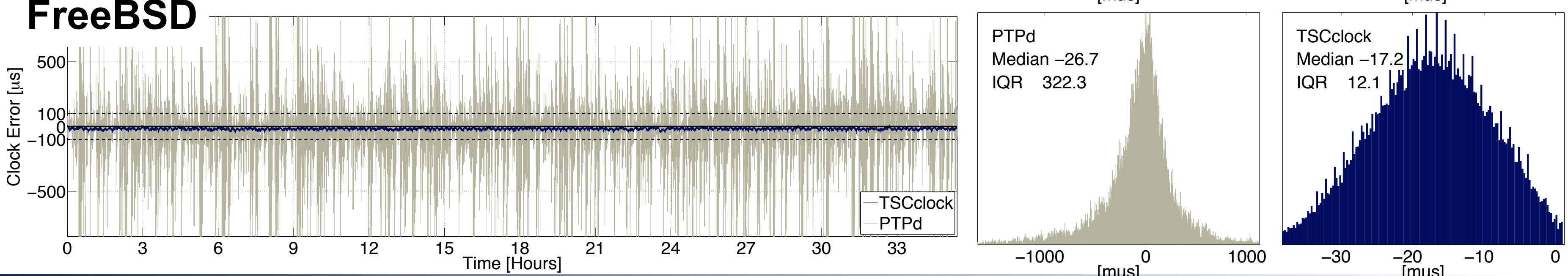
	PTPd	TSCclock
Linux	31.6 µs	8.1 µs
FreeBSD	34.9 µs	17.7 µs

- **Linux: Network congestion only**
  - Large impact on PTPd
  - TSCclock barely affected (robustness)
- **FreeBSD: Network and Host congestion**
  - Impact on PTPd even worse
  - TSCclock still not affected

Linux

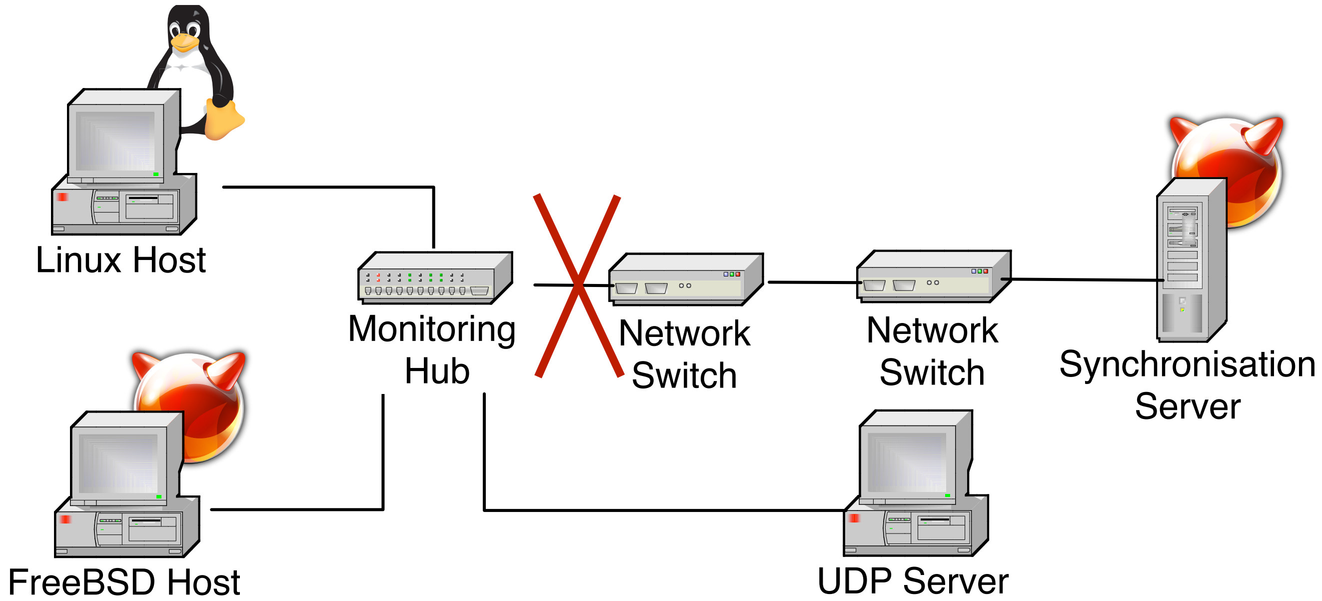


FreeBSD



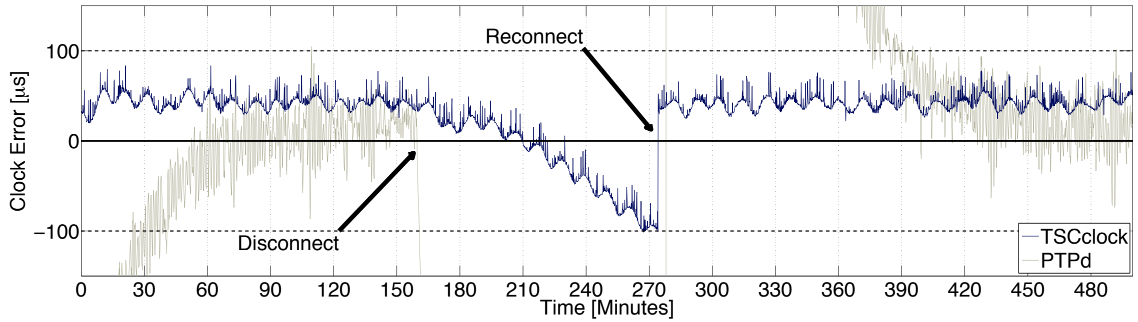
Disconnection

- **Disconnection scenario**
  - Back to ideal conditions
  - Let the clocks converge
  - Disconnect from the time server



Disconnection

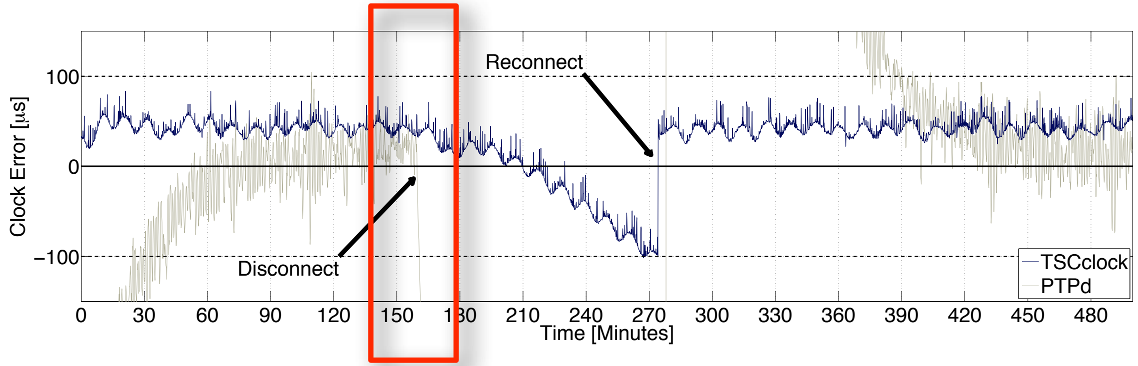
FreeBSD



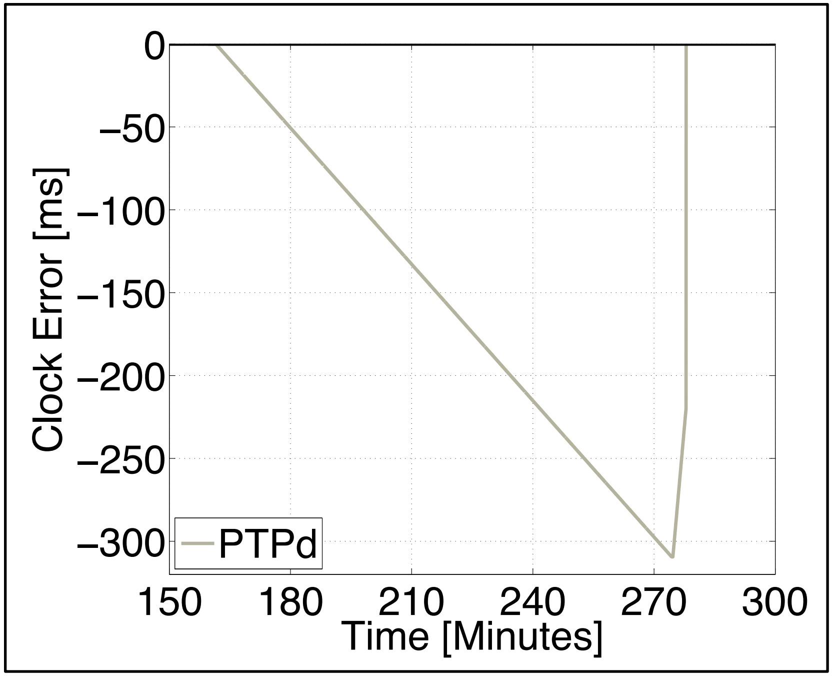
- **Disconnected for 2 hours**
  - PTPd: local sudden change with worse error -300 ms !!
  - TSCclock: local stability and gradual drift of the oscillator
- **Reconnection**
  - PTPd: needs more than an hour to recover, plus oscillation
  - TSCclock: ~instant recovery

Disconnection

FreeBSD

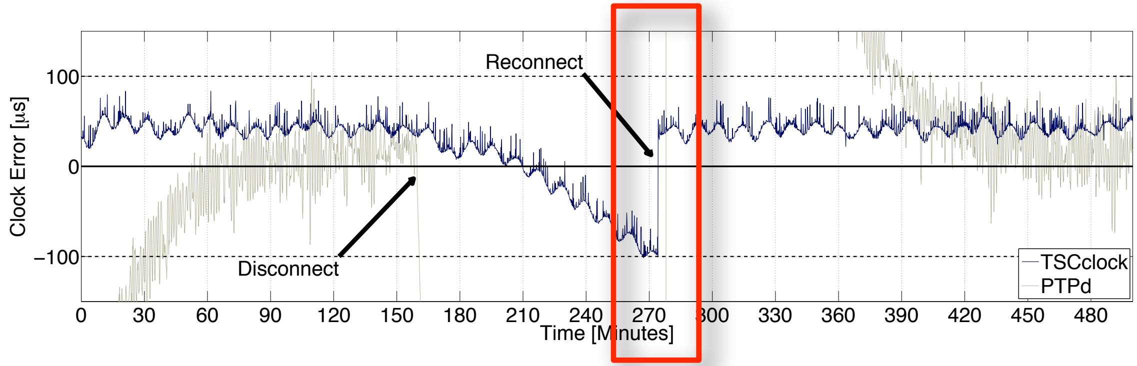


- **Disconnected for 2 hours**
  - PTPd: local sudden change with worse error -300 ms !!
  - TSCclock: local stability and gradual drift of the oscillator
- **Reconnection**
  - PTPd: needs more than an hour to recover, plus oscillation
  - TSCclock: ~instant recovery



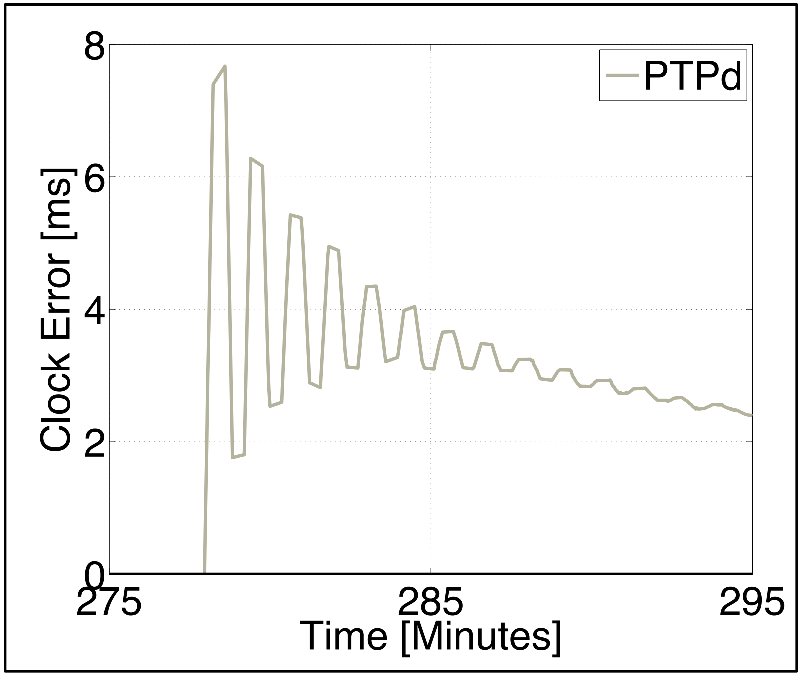
Disconnection

FreeBSD



- **Disconnected for 2 hours**
  - PTPd: local sudden change with worse error -300 ms !!
  - TSCclock: local stability and gradual drift of the oscillator

- **Reconnection**
  - PTPd: needs more than an hour to recover, plus oscillation
  - TSCclock: ~instant recovery



Conclusion

- **Direct results from the comparison**
  - TSCclock much less variable than PTPd under ideal conditions
  - TSCclock more robust than PTPd under noisy conditions
    - System hiccups, congestion, disconnection
    - Cause can be traced to servo design
- **More generally**
  - IEEE 1588 implementations may suffer from variability
    - Could use transparent clocks ($$)
  - Latency variability of a component on the path puts servo at risk
    - Expensive master / transparent clock pointless if slave servo not robust
    - PI controllers may perform badly with variable latencies
    - A feedforward servo (TSCclock)
      - offers greater stability and performance
      - suitable for hardware and software implementations of IEEE 1588