CptS 555 Research Project

Performance Analysis of Clock Synchronization using IEEE 1588 Protocol

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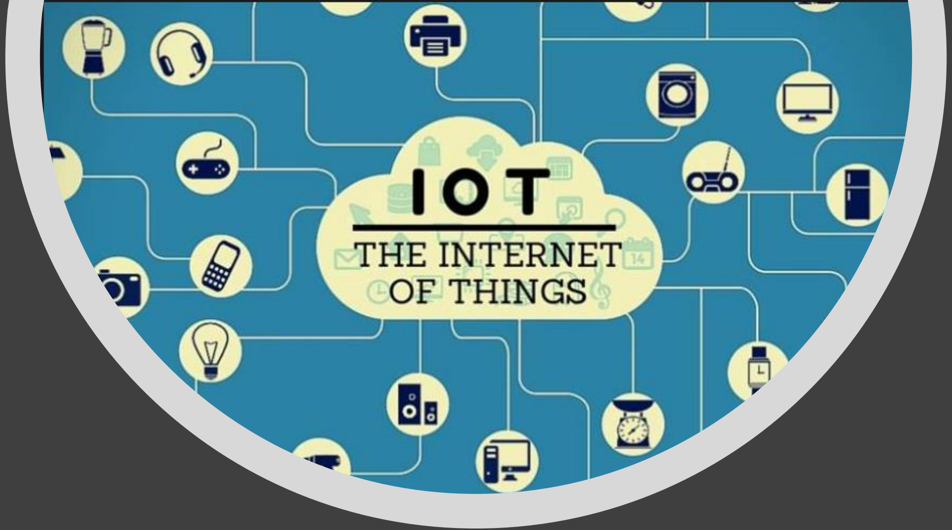
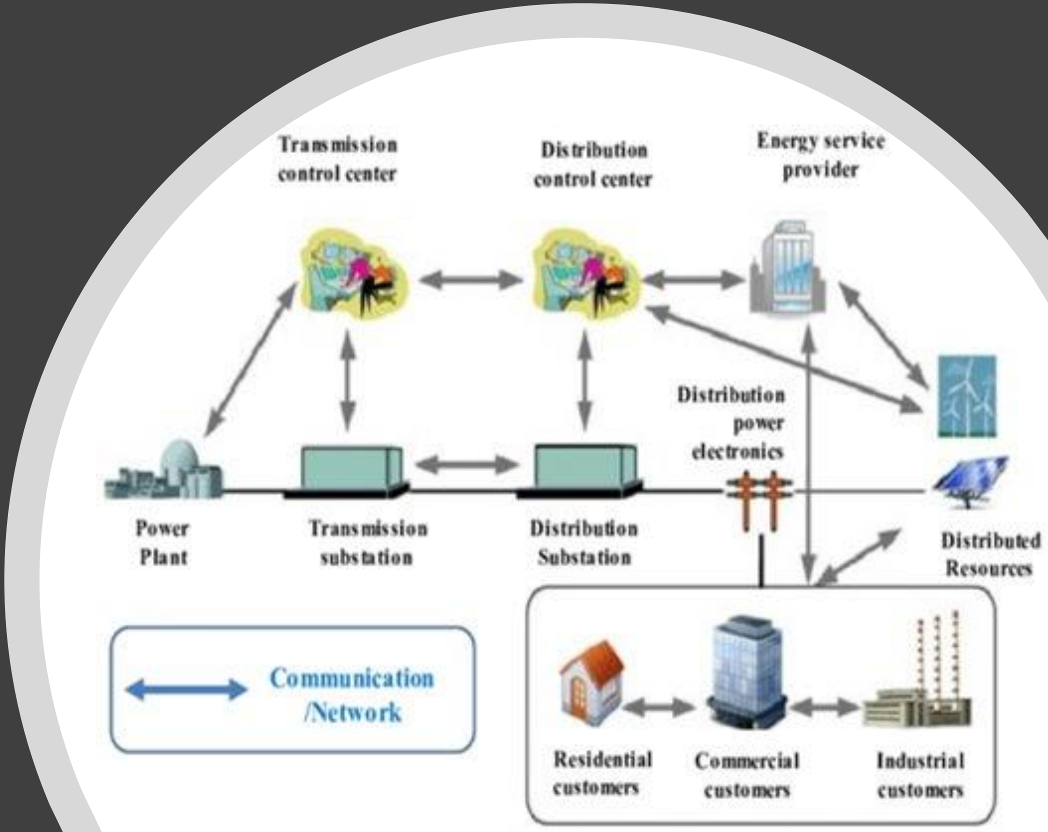
Introduction



Clock Synchronization is a must for monitoring any Distributed system

Applications:

- Smart Grid
- Smart Environments
- IoT System



Requirements of Clock Synchronization in Smart Grid

Application	Requirement
Traveling Wave Fault Detection and Location	100 to 500 ns
Synchrometrology (synchrophasors) Wide Area Protection Frequency Event Detection Anti-Islanding Droop Control Wide Area Power Oscillation Damping (WAPOD)	Better than 1 μs
Line Differential Relays	10 to 20 μs
Sequence of Events Recording	50 μs to ms
Digital Fault Recorder	1 ms
Communication Events	
Substation Local Area Networks (IEC 61850 GOOSE)	100 μs to 1 ms
Substation Local Area Networks (IEC 61850 Sample Values)	1μs

Source: National Institute of Standards and Technology (NIST)

Existing Solutions

- IEEE 1588 Precision Time Protocol (PTP)
- eLOng-RAnge Navigation (eLORAN)
- Iridium
- Network Time Protocol (NTP)
- Radio (e.g. NIST WWVB time signal radio station)
- Atomic clocks
- Different types of terrestrial and satellite-based propagation solutions

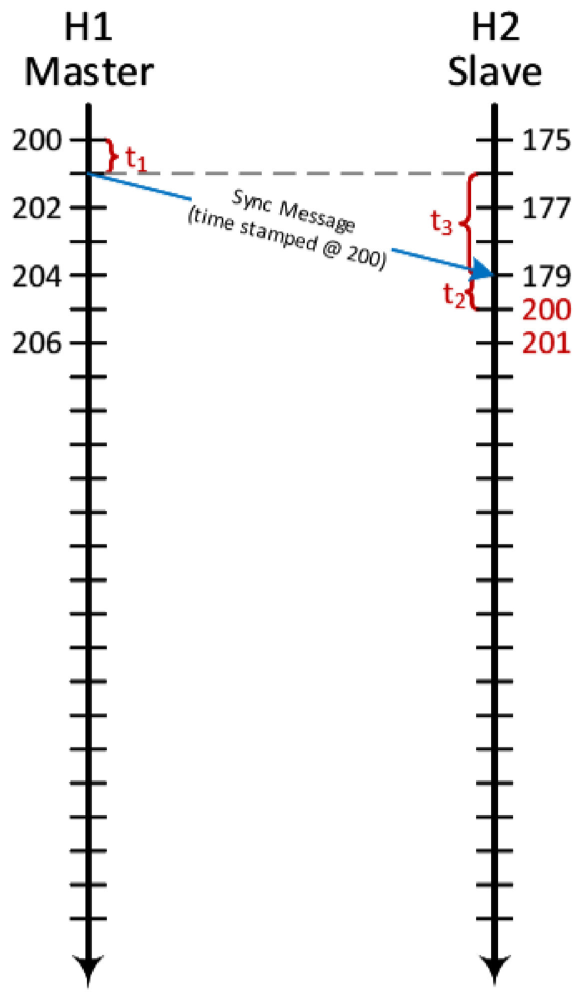
Clock Synchronization in LAN

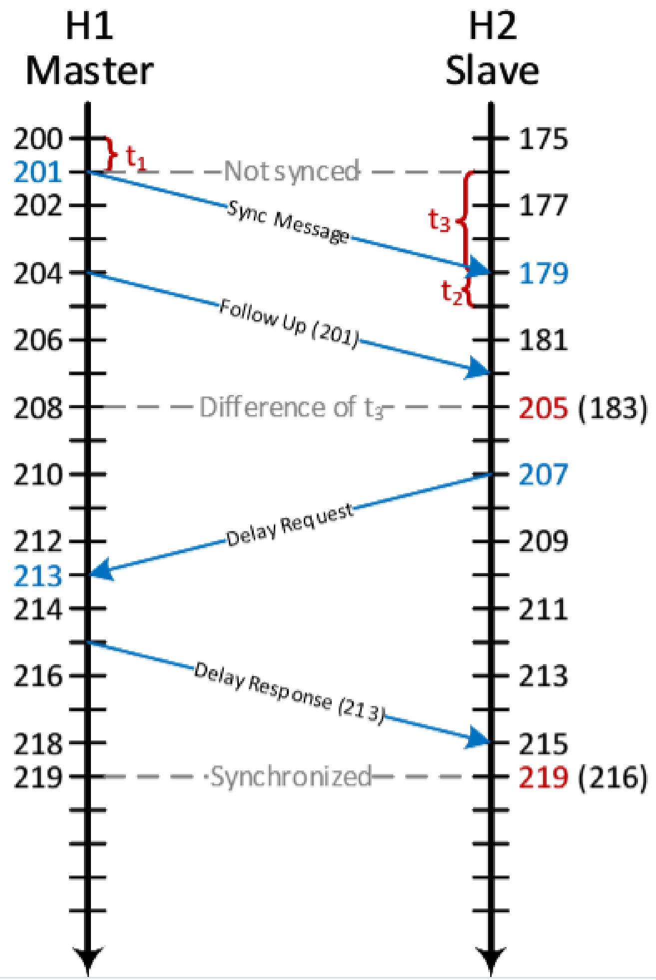
- Network topology change
- Bursts of network traffic in case of faults detected in the power system
- Security attacks including denial of service (DoS), masquerde and multi-cast poisoning

IEEE 1588 Precision Time Protocol (PTP)

- Self-organizing protocol
- Small requirements on the network bandwidth and computation footprint on endpoints or network devices
- Can achieve precise time synchronization in local area network (LAN) up to several nanosecond with help of hardware time stamping.
- Two versions : IEEE 1588-2002 v1 and IEEE 1588-2008 v2.

PTP Simple Example





PTP Time Synchronization

$$\tau_2 = \tau_1 + \Delta_t + 0.5\, T_{RTT}$$

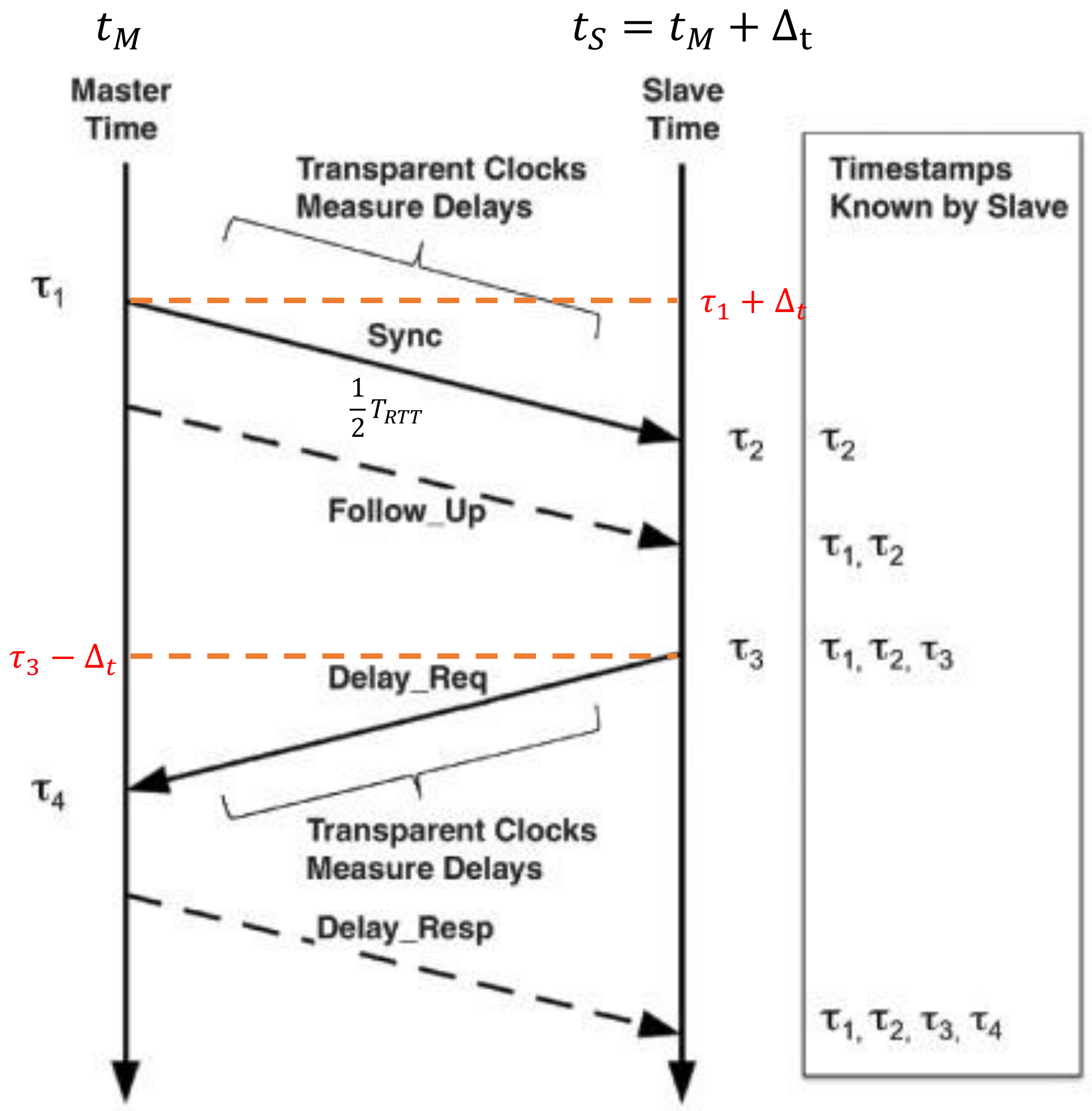
$$\tau_4 = \tau_3 - \Delta_t + 0.5\, T_{RTT}$$

- Offset Δ_t

$$\Delta_t = \frac{(\tau_2 - \tau_1) - (\tau_4 - \tau_3)}{2}$$

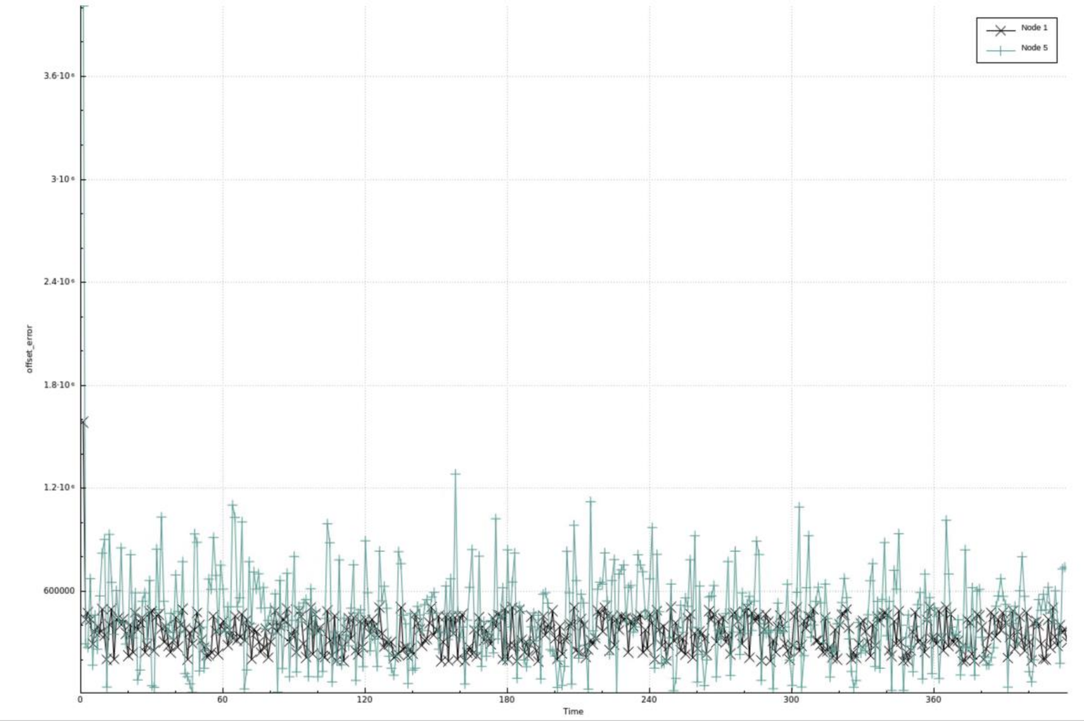
- Delay T_{RTT}

$$T_{RTT} = (\tau_2 - \tau_1) + (\tau_4 - \tau_3)$$

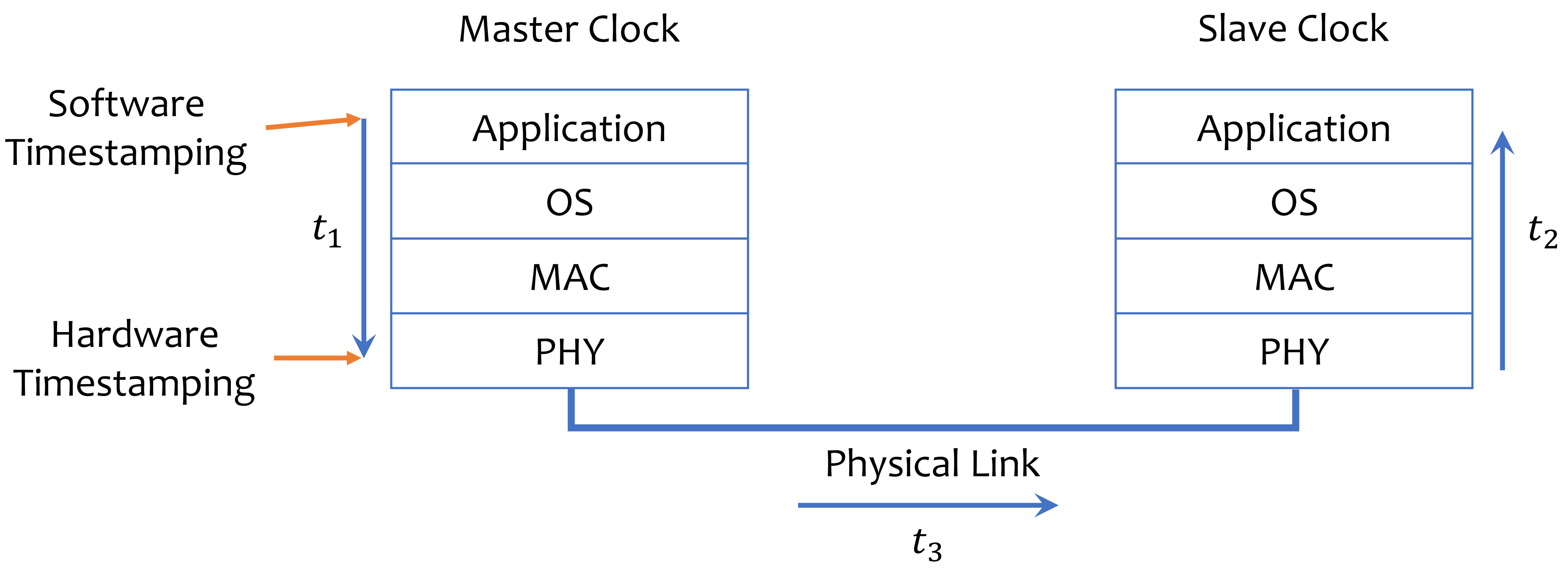


PTP Simulation Example

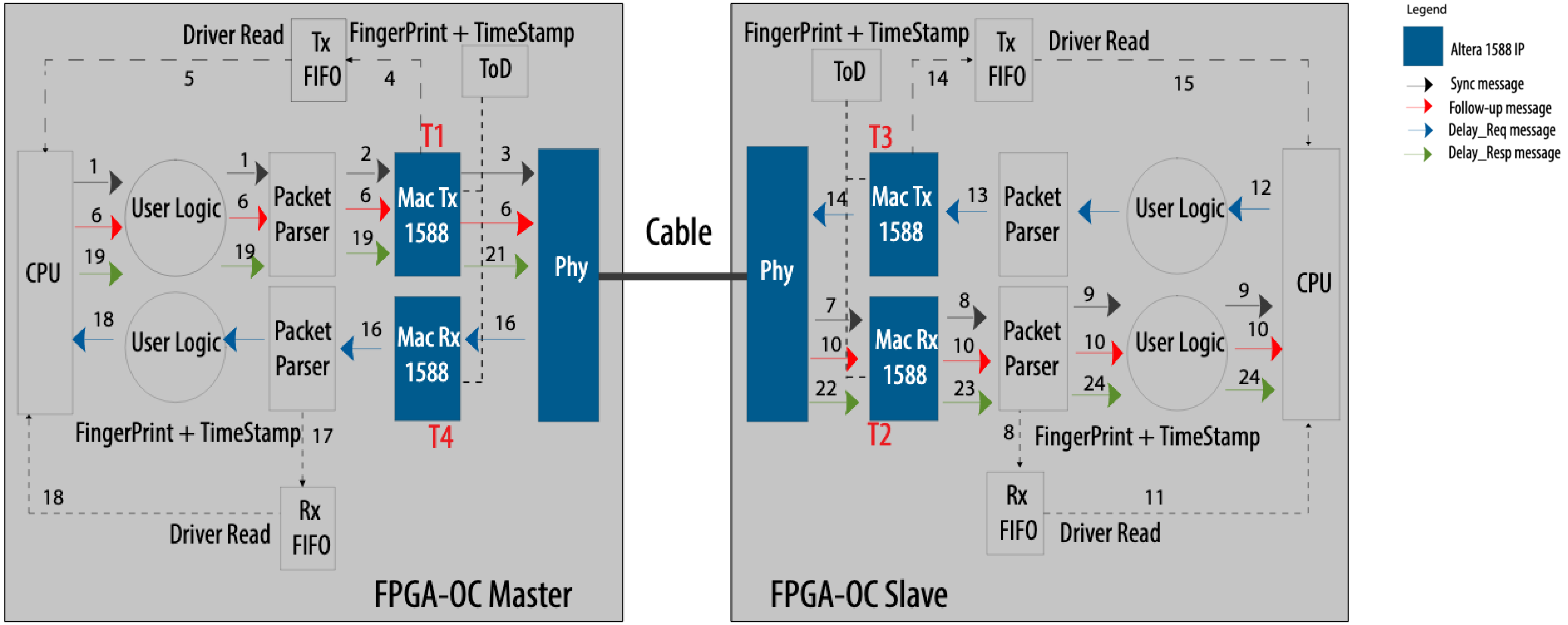
- Simulator: NS-3
  - Simulator virtual time
- Network Environment:
  - Wifi 802.11b adhoc OFDM
- Network Topology
  - 0 => 1 => 2 => 3 => 4 => 5



To Achieve High Precision



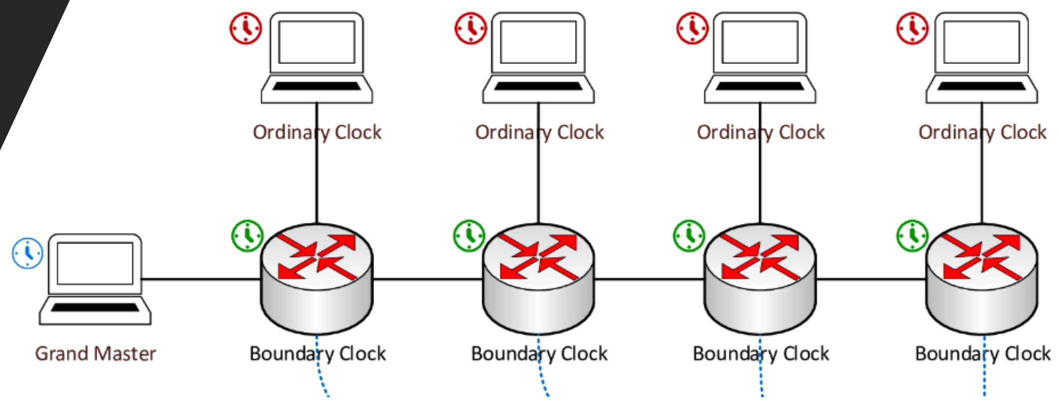
IEEE 1588 Hardware Timestamping



To Achieve High Precision

- Uncertainty in Network Delay
  - Point-to-Point Synchronization
  - Network Traffic

- Local Filtering
  - PI Filtering
  - Kalman Filtering



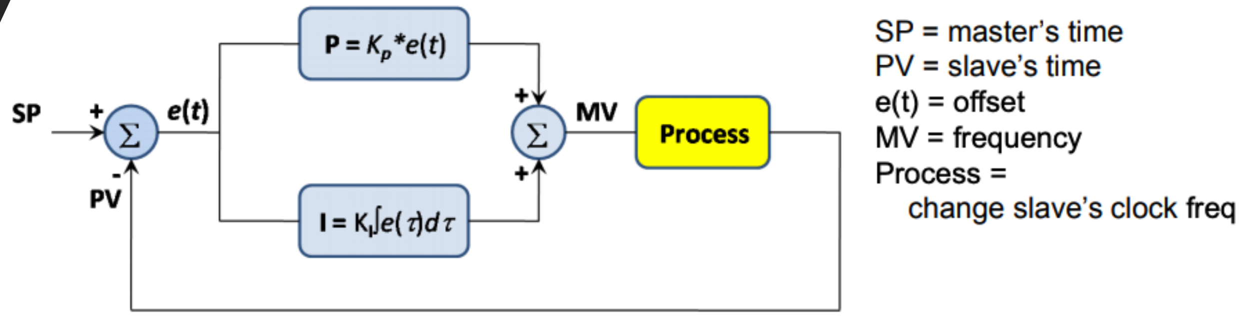


Figure: Basic block of Proportional + Integral controller. (excerpt from wikipedia)

Security Issues

Delay Attack:

- Constantly add delay in one direction

Multicast:

- Inject announcement and sync from false PTP master

Unicast:

- Capture switch/router, impersonate global master or alter sync message