Clock Synchronization over Packet Switched Network

Tanjila Ahmed

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UCDAVIS
UNIVERSITY OF CALIFORNIA

Agenda

- Synchronization Types
- Time Synchronization Problems
- Standards and Protocols
- Comparison
- Open Issues
- Conclusion

Article Review

M. L´evesque and D. Tipper,"A Survey of Clock Synchronization Over Packet-Switched Networks," *IEEE Communications Surveys & Tutorials,* vol. 18, no. 4, pp. 2926-2947, Nov. 2016.

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Synchronization Types

- Time Synchronization : Getting clocks to agree on the time of day eg. Packet based communication.(offset)
- Frequency Synchronization/ Syntonization : Getting clock run in same rate eg. TDM bases telecommunication.(skew)
- Phase Synchronization: Getting syntonized clocks in phase.(Drift)

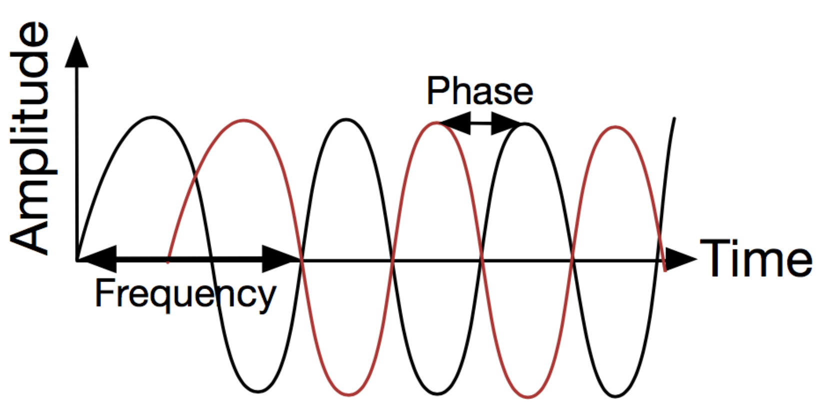

Fig. 1: Frequency and phase plot

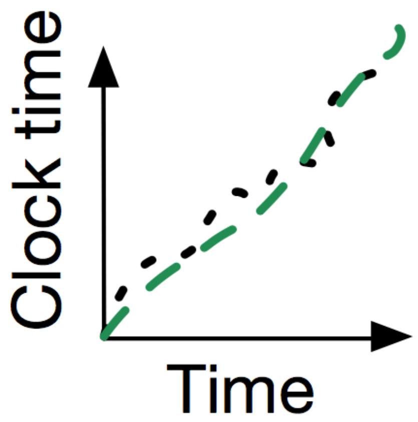

Fig. 2: Time synchronization

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Time Synchronization Problems

Multiple clocks in a distributed system needs to maintain same time !

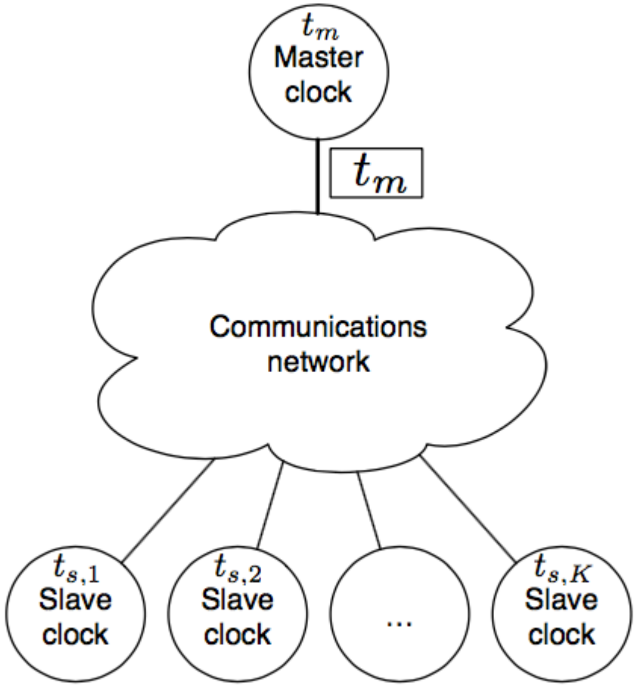

Fig. 3: Time Synchronization

$$t_{s,k} = t_m + \theta(t_m)$$

$t_{s,k}$ = *time at k^{th} slave*
t_m = *time at master*
θ = *Offset*

$$t_{s,k} \leftarrow t_m + \bar{d} + \theta,$$

$\bar{d}$ = *average delay between master and slave node*
θ = *offset*

The Problem is to find this Delay and Offset !

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Time Synchronization Problems

- Delay Asymmetry: Delay is calculated based on RTT assuming delays between master to slave is equal to slave to master node.

$$\bar{d} = \frac{RTT}{2} = \frac{D_{m\to k} + D_{k\to m}}{2},$$

However, $D_{m\to k} \neq D_{k\to m}$ always due to :

- Queueing delay
- Processing delay
- Different routing path
- Different cable length
- Variation in bandwidth

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Time Synchronization Problems

- Environment Factor: Environmental conditions changes frequency of a crystal oscillator.
  - Temperature
  - Humidity
  - Pressure
  - Vibration
- Reference Clock :

1. Atomic Clock

Oscillator Type	Accuracy	Cost
Quartz crystal	10^{-5} to 10^{-4}	Inexpensive
Rubidium	10^{-9}	$800 USD
Cesium	10^{-13} to 10^{-12}	$50000 USD

2. Global Navigation Satellite Systems:
   - Poor indoor coverage
   - Expensive receivers required

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Standards and Protocols: NTP

Network Time Protocol

- UDP
- GNSS/Atomic Clock
- Millisecond level accuracy
- Sever/Client
- Low Polling Frequency
- No additional hardware required

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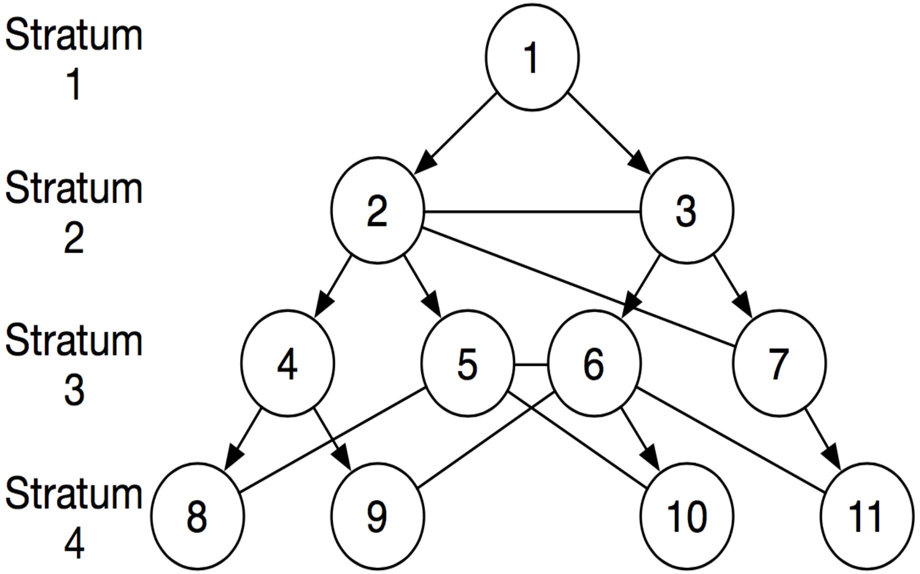
Standards and Protocols: NTP



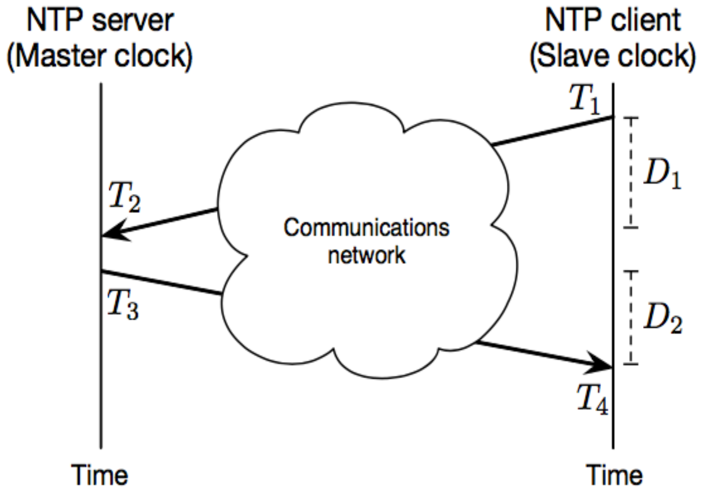


Fig. 4: NTP mechanism

Estimated delays between server-client : $D_1 = T_2 - T_1$ and $D_2 = T_4 - T_3$

Clock Offset: $\theta_{NTP} = \frac{1}{2}(D_1 - D_2)$

$$t_{s,k} \leftarrow t_{s,k} - \theta_{NTP}.$$

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Standards and Protocols: PTP

Precision Time Protocol

- Application Layer
- Sub microsecond/nano second accuracy
- Master/Slave
- Configurable update interval(once/second)
- Additional hardware required for high accuracy

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Standards and Protocols: PTP

Best master clock algorithm(BMC) to select the master clock.
Clock offset = ½*((T2-T1) – (T4-T3))

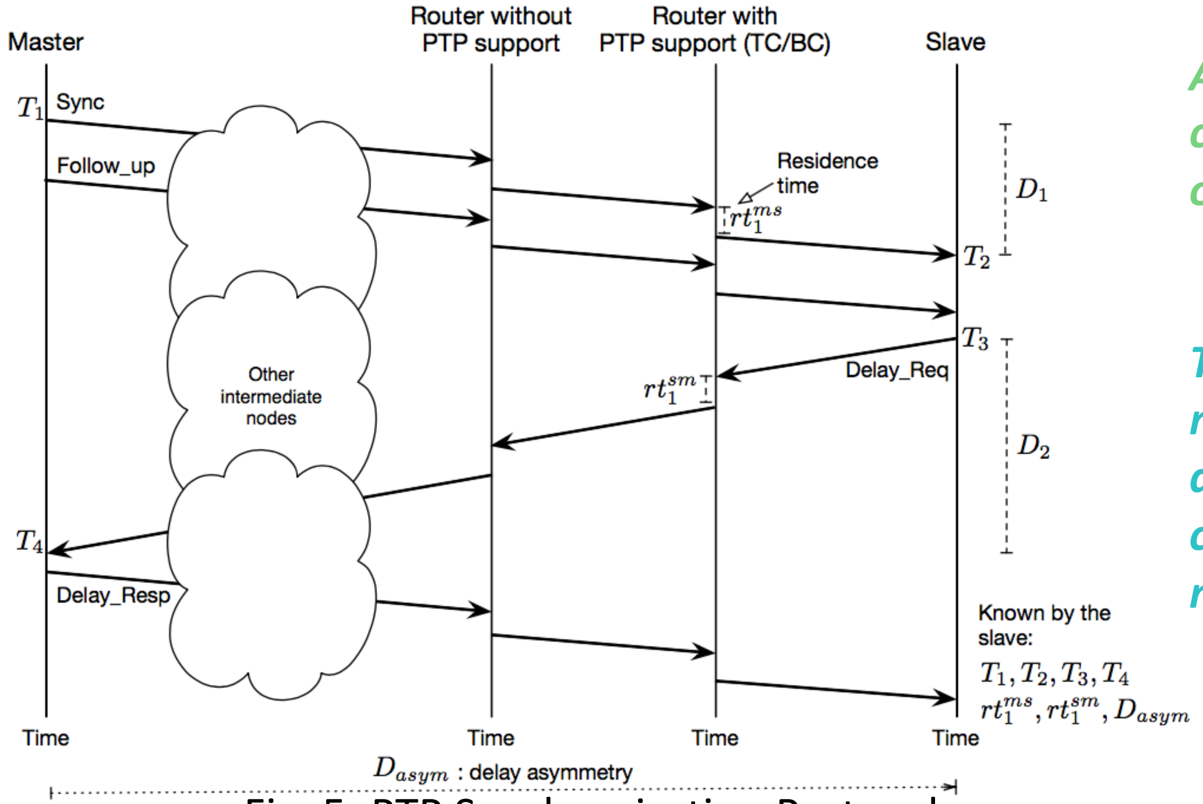

Fig. 5: PTP Synchronization Protocol

A boundary clock has multiple network connections and can accurately synchronize one network segment to another.

The transparent clock modifies PTP messages as they pass through the device. Timestamps in the messages are corrected for time spent traversing the network equipment.

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Standards and Protocols: SyncE

Synchronous Ethernet (SyncE) - ITU-T G.8262

- Physical Layer
- Synchronizes Frequency
- Master/Slave
- PLL used to remove jitter
- Chain of Synchronous clock

Standards and Protocols: SyncE

Synchronous Ethernet (SyncE) - ITU-T G.8262 :

Transfer frequency over Ethernet physical layer.

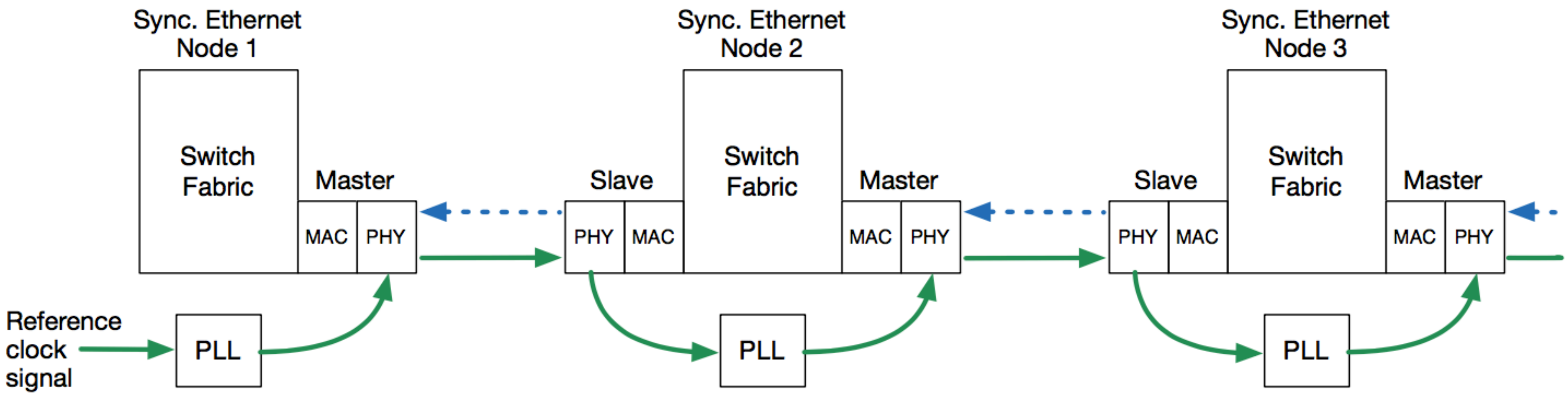

Fig. 6: SyncE mechanism

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Standards and Protocols: White Rabbit

White Rabbit

- CERN, GSI Helmholtz Centre(heavy ion research) ,universities and industries.
- Sub-nanosecond accuracy
- PTP & SyncE
- Open hardware open software
- Additional hardware support required

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Comparison

	NTP (RFC 5905-5908)	PTP (IEEE 1588-2008)	SyncE (ITU-T G.8262)	White Rabbit
Applications	Internet, large-scale networks.	Telecommunications, industrial automation, smart grid, and audio video bridging.	Telecommunications and industrial automation.	Particle accelerator, cosmic particle detector.
Target Accuracy	Millisecond.	Microsecond.	$\pm$4.6 ppm.	Sub-nanosecond.
Asymmetry Mitigation	No.	Yes: (*i*) Residence time measurement, (*ii*) Asymmetry parameter D_{asym}, and (*iii*) Peer-to-peer path correction.	Not required.	Yes.
Pros	Cost-effective. Easy to implement and deploy.	Reliable synchronization. High accuracy.	Based on Ethernet. High accuracy. Reliable end-to-end exchange.	Sub-nanosecond accuracy. Deterministic packet delivery.
Cons	Unreliable synchronization (operates as a black box). Millisecond to second accuracy.	Most nodes need to implement the protocol. Installation expensive.	Operates at the physical layer - all nodes need to implement SyncE. Can distribute the frequency only.	Need to support both PTP and SyncE, costly.

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Open Issues

- Cost-effective synchronization over multi-hop asymmetric connections
- Security and synchronization on devices with limited resources

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Reference

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Thanks!