Ensuring Reliable Networks TTTech

Synchronization Quality of IEEE 802.1AS in Large-Scale Industrial Automation Networks

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RETNET Real-Time Networks

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What is IEEE 802.1AS?

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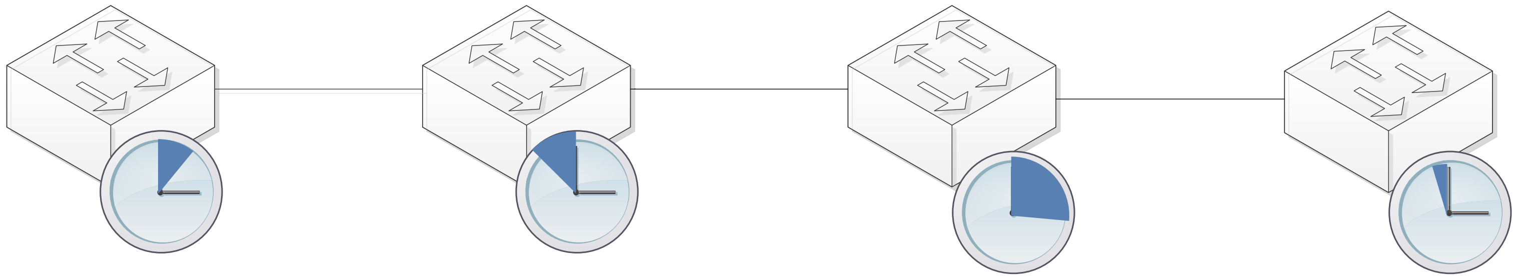
… it is a clock synchronization protocol

IEEE 802.1 Time Sensitive Networking (TSN)

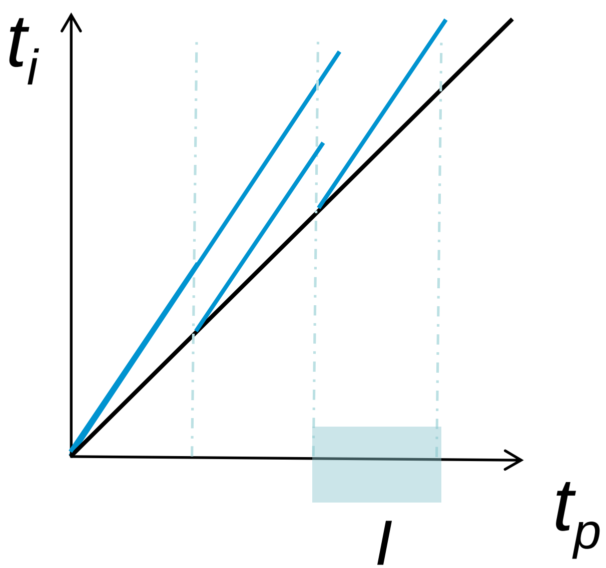
(previously IEEE 802.1 Audio Video Bridging (AVB))

- Adds real-time capabilities to switched Ethernet
  - Clock synchronization, scheduled traffic, redundancy
- To be used in Automotive or Industrial Automation
- Designed for up to 7-hops large networks

Clock Synchronization



Clocks drift!



- Drift rate (ρ)

$$t_i = t_p + \rho_i t_p = (1 + \rho_i) t_p$$

- Synchronization interval (I)
- Synchronization precision (p)

$$p = \max |t_p - t_i|$$

Clock Drift Model

Clock drift rate is caused by:

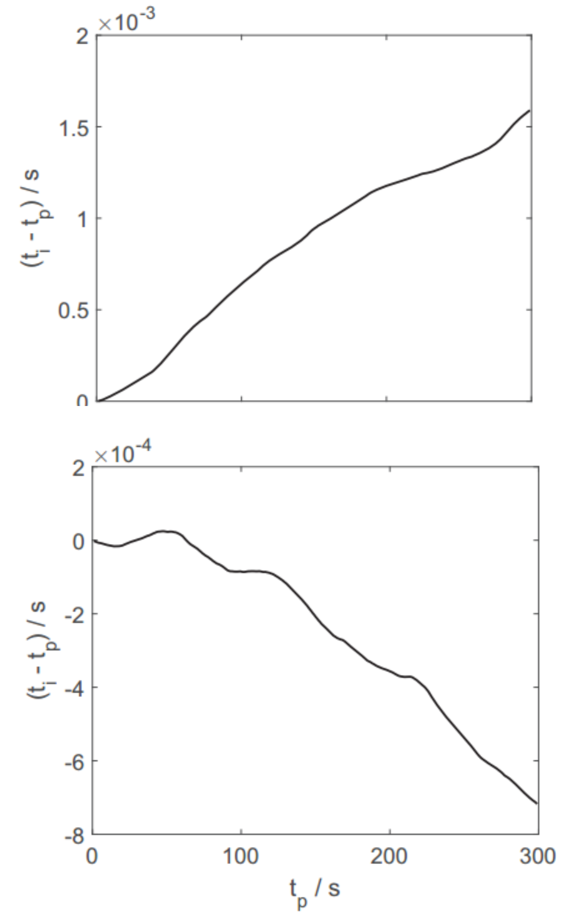
- the non-ideality of the physical oscillators
- environmental conditions

$$\rho(t) = \rho_0 + \rho'(t)$$

$$\rho_0 \in [\text{ -10,10 }] \text{ ppm}$$

$$\rho'(0) = 0 \text{ and}$$

$$\frac{\Delta\rho'}{\Delta t} \in [0, 1] \text{ ppm/s}$$



IEEE 802.1AS – Performance Requirements

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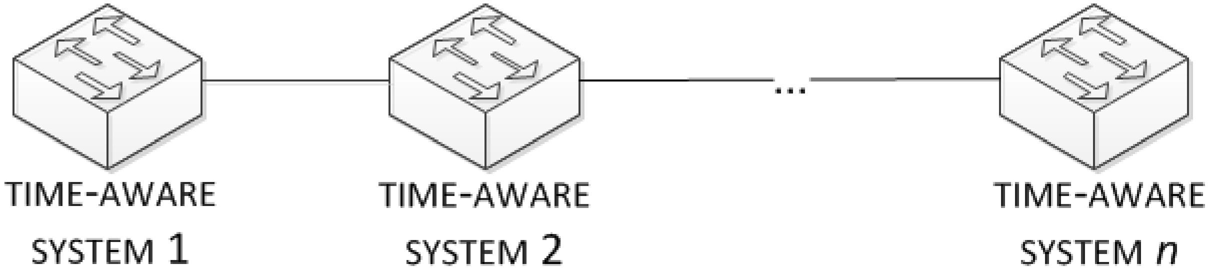
- Up to 7 hops → precision < 1 µs



- What happens for *n* = 100?

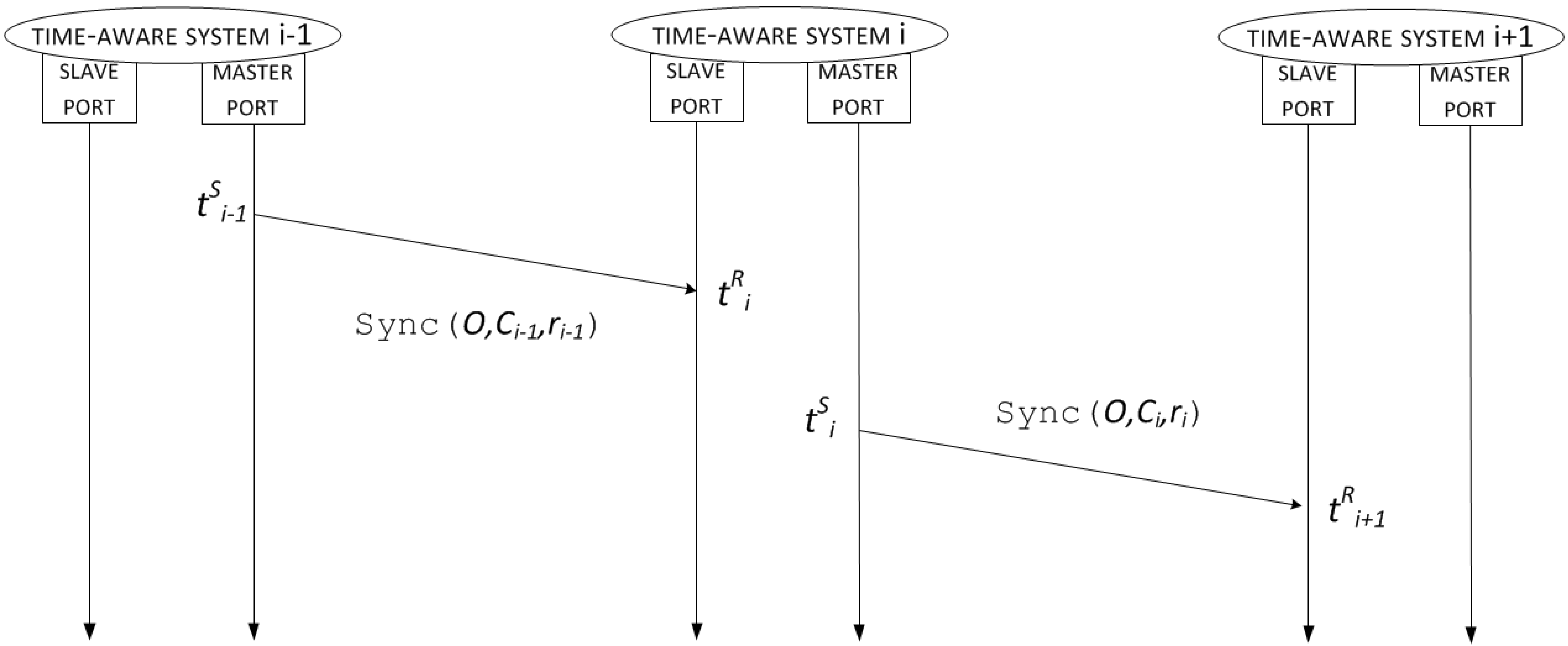
$$t_i = (1 + \rho_i) t_p$$

$$t_i - t_{GM} = (\rho_i - \rho_{GM}) t_p$$

$$p_i = (\rho_i - \rho_{GM}) I$$

does not depend on *n*!

IEEE 802.1AS –
Time Sync Transportation

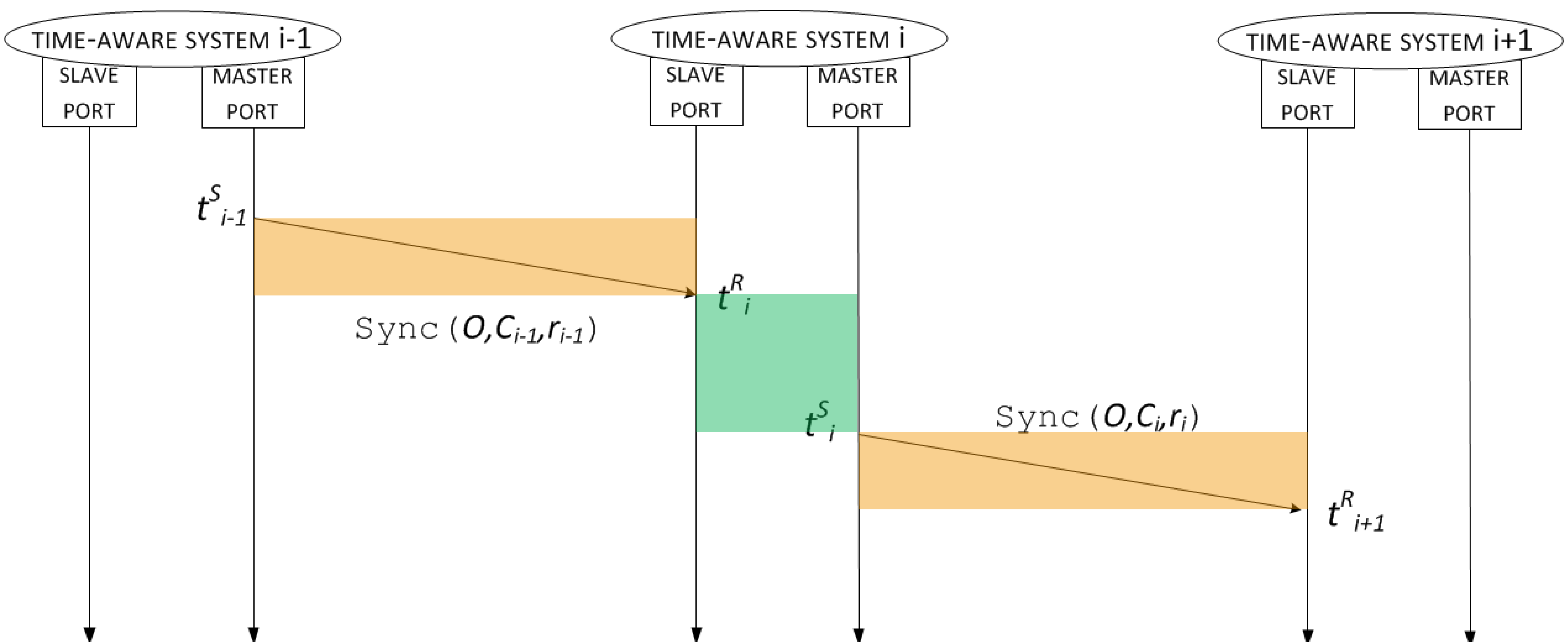


IEEE 802.1AS – Time Sync Parameters

- Origin Timestamp (*O*)
- Correction Field (*C*)
- Rate Ratio (*r*)

$$C_i = C_{i-1} + D_{i-1} + (t_i^S - t_i^R) r_i$$

$$r_i = r_{i-1} \times nr_i$$



IEEE 802.1AS – Neighbor Rate Ratio

nr_i : ratio between frequency of two consecutive clocks

$$t_{i-1} = \frac{(1+\rho_{i-1})}{(1+\rho_i)} t_i$$

$$nr_i = \frac{(1+\rho_{i-1})}{(1+\rho_i)}$$

- IEEE 802.1AS does not prescribe a method to measure it
- Measurement should be done within ± 0.1 ppm

IEEE 802.1AS – Time Sync Parameters

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- Origin Timestamp (*O*)
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$$C_i = C_{i-1} + D_{i-1} + (t_i^S - t_i^R) r_i$$

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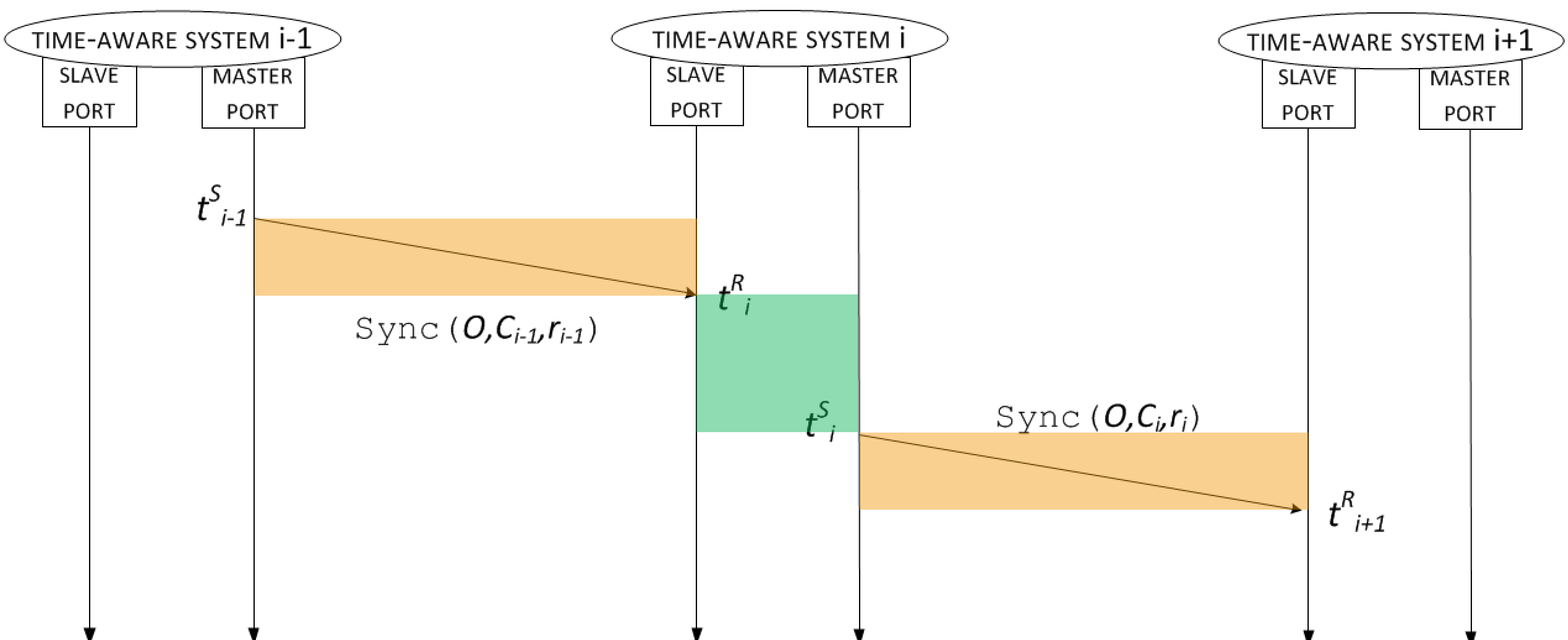
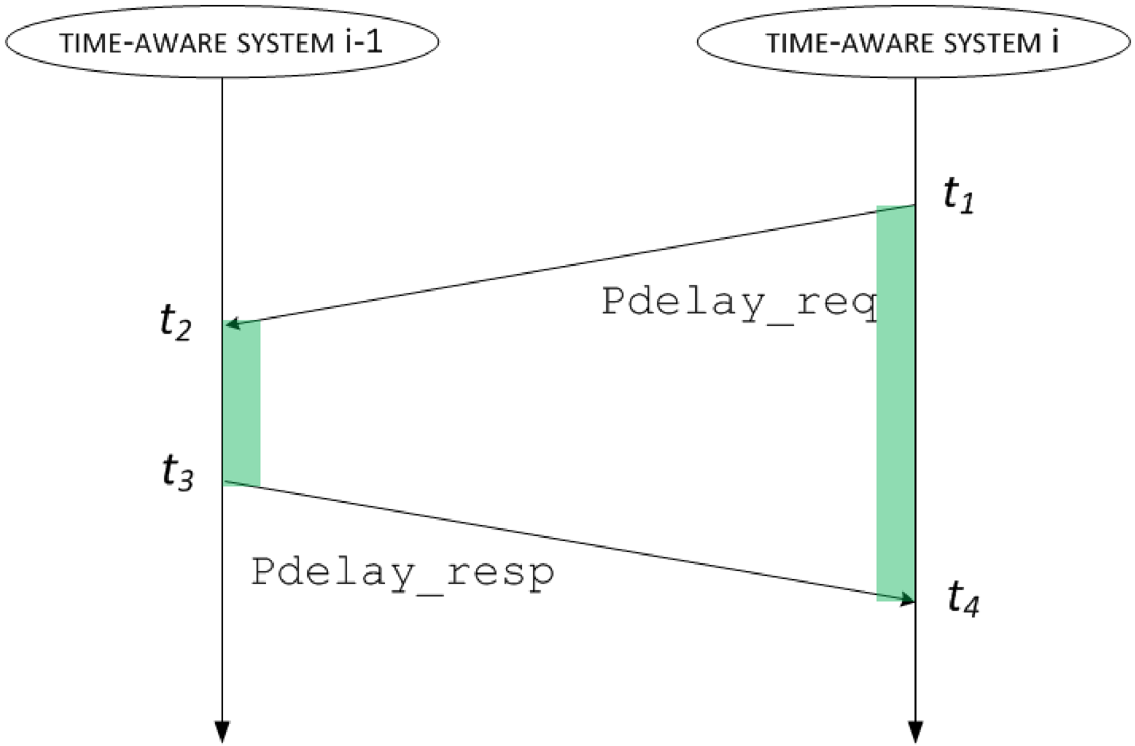


IEEE 802.1AS – Propagation Delay Measurements



$$D_i = \frac{1}{2}\left((t_4 - t_1) - nr_i \times (t_3 - t_2)\right)$$

IEEE 802.1AS – Time Sync Parameters

- Origin Timestamp (*O*)
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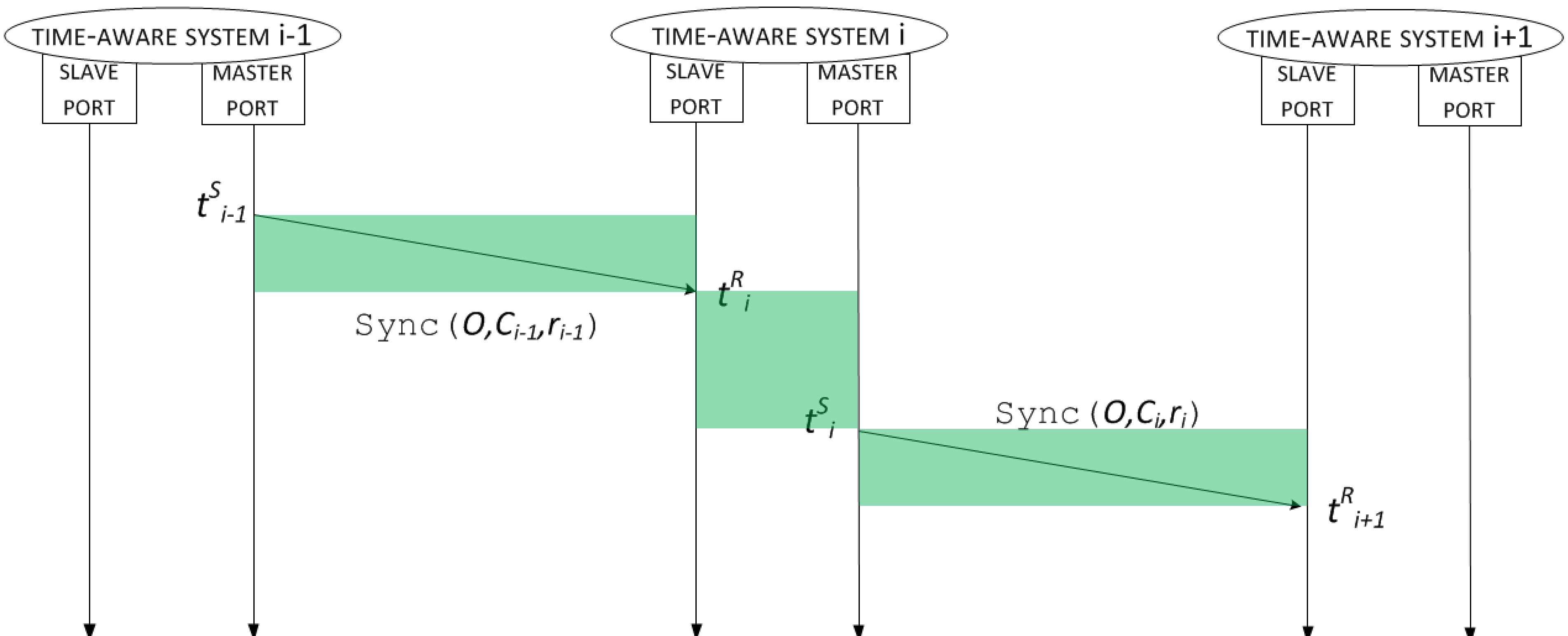
- Rate Ratio (*r*)

$$C_i = C_{i-1} + D_{i-1} + (t_i^S - t_i^R) r_i$$

$$r_i = r_{i-1} \times nr_i$$



Two reality bites…

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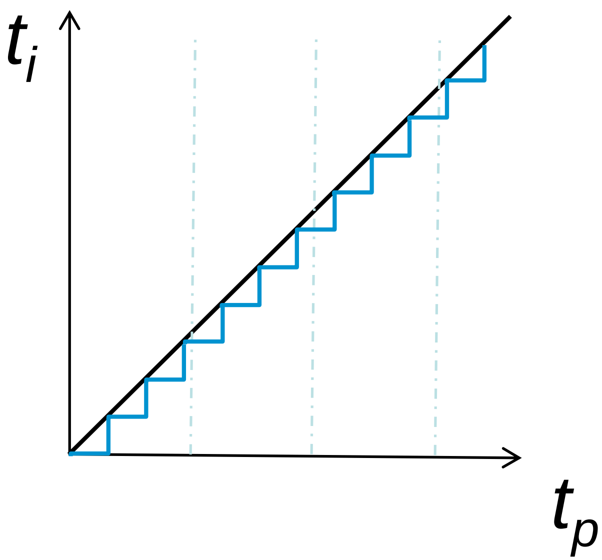
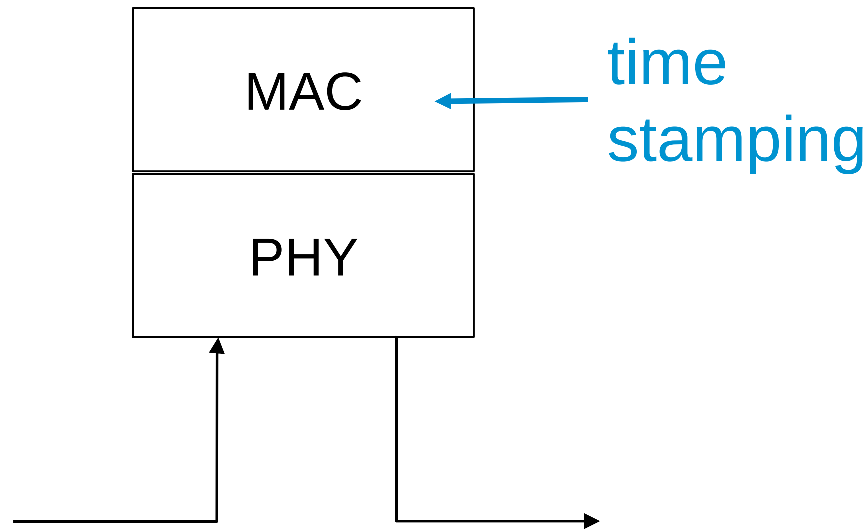
Clock Granularity



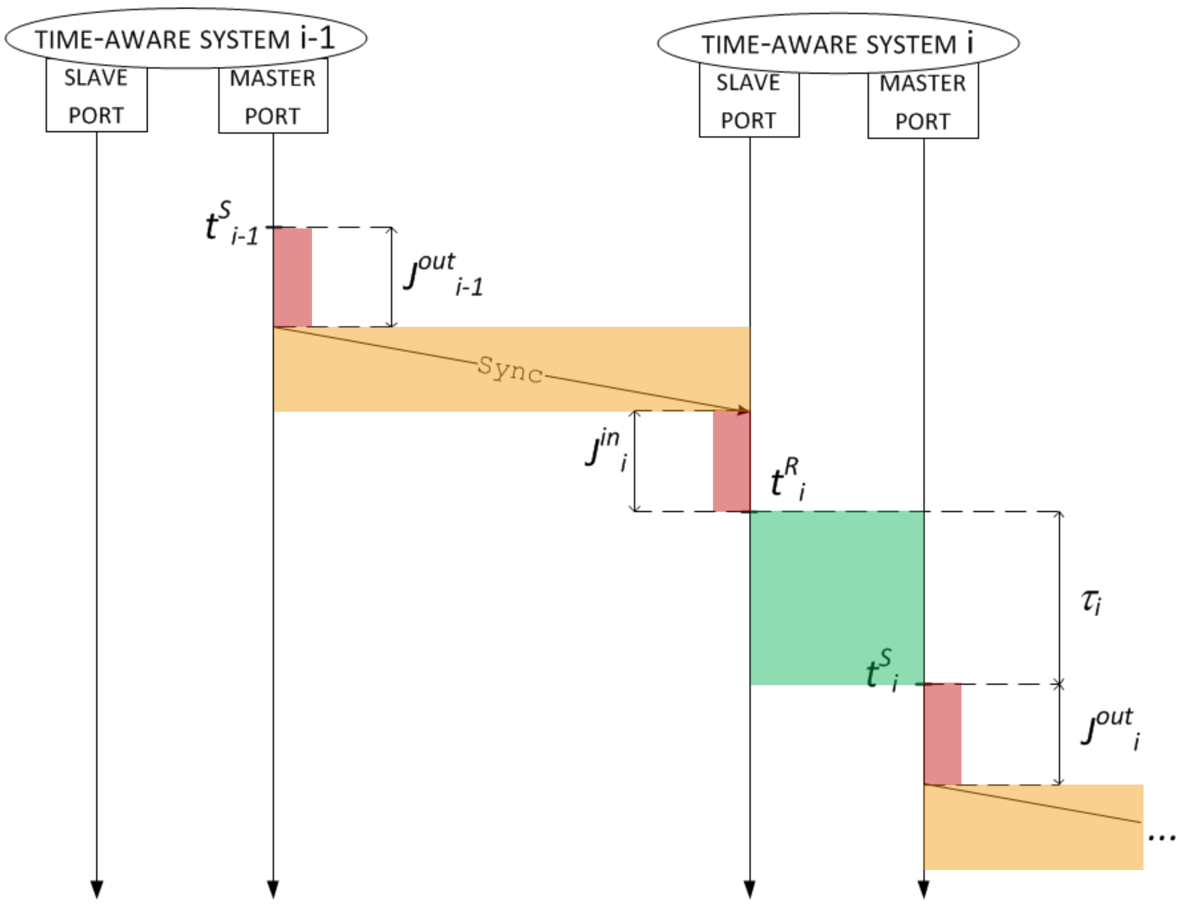
Clock Granularity = 8 ns

PHY Jitter



max PHY Jitter = 8 ns

IEEE 802.1AS – Realistic System Model



IEEE 802.1AS
Worst Case Analysis

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Assumptions:

- Same value for *D*, *nr* in each time-aware system
- Max error for the measurement of *D* and *nr*
- Max error in the timestamping
- Neighboring clocks are the fastest and slowest respectively

→ precision = 6.9 μs

IEEE 802.1AS – OMNeT++ Simulations

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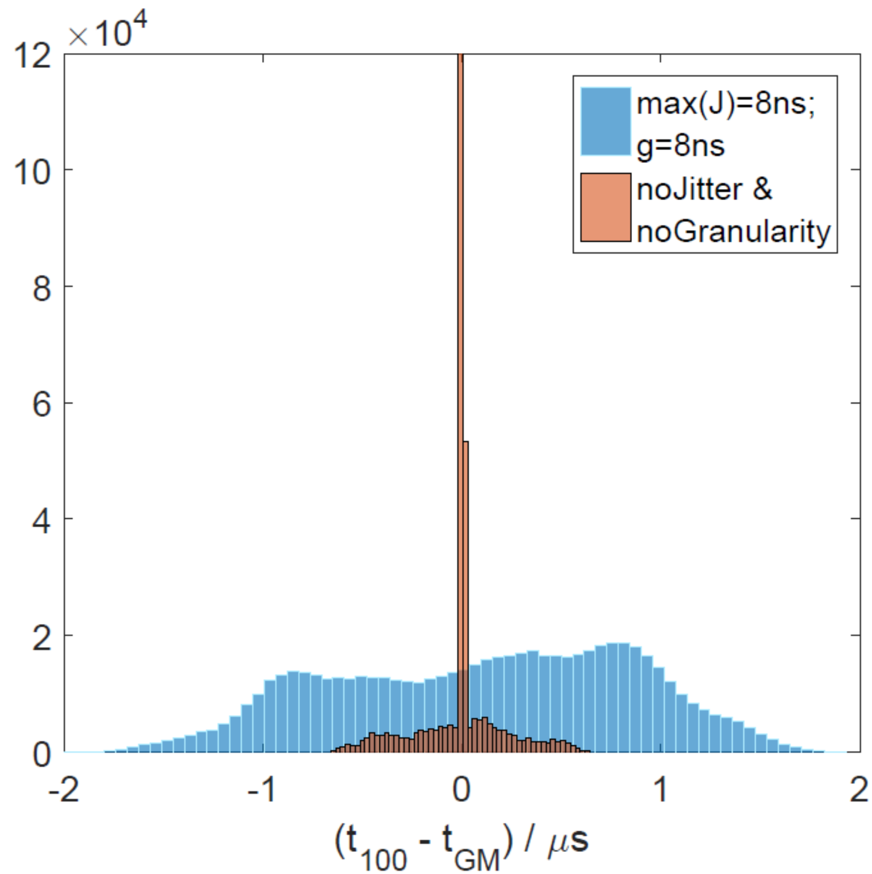

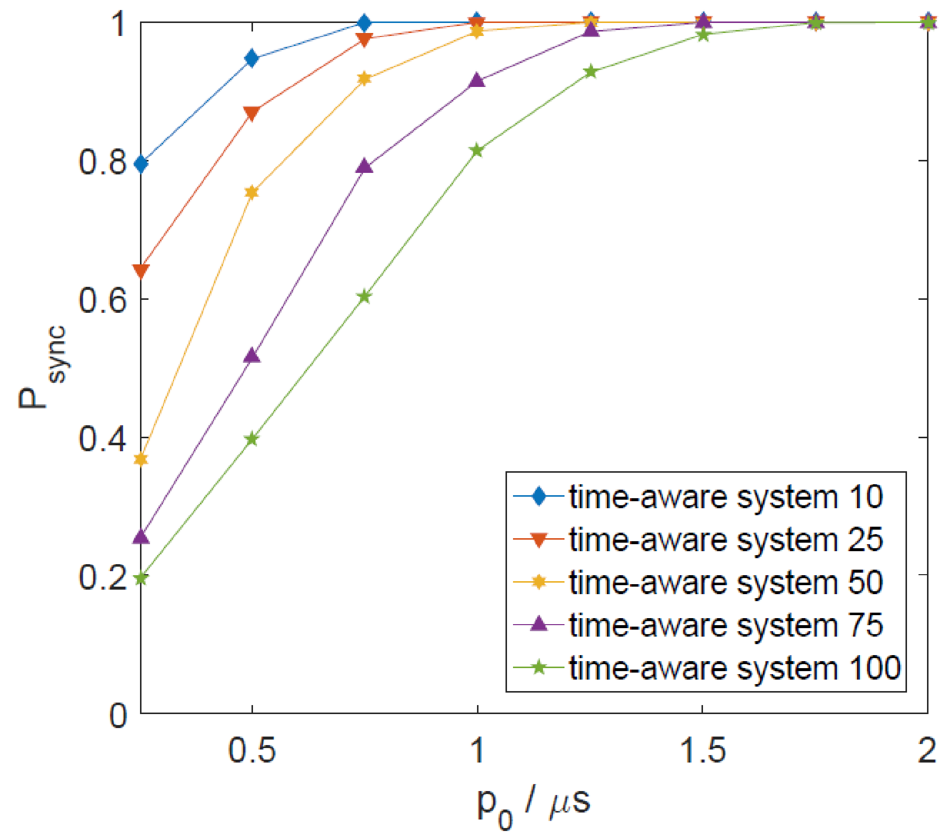

Conclusions

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- Precision of 1μs not achievable for large-scale networks (100 hops)
- Precision of 1 μs achievable for medium networks (30 hops)
- Precision of 2 μs achievable for large-scale networks

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