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MODELLING TIME SYNCHRONIZATION IN WLANS IN OMNET++

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Overview

1. TSN AND ITS COMPONENTS
2. GENERALIZED PRECISION TIME PROTOCOL (GPTP)
3. GPTP IN WIRELESS TSNs
4. OMNET++ MODELLING & SIMULATIONS OF GPTP IN WLANs
5. CONCLUSION & FUTURE WORK

1. TIME SENSITIVE NETWORKING

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WHAT IS TSN?

Time Sensitive Networking - TSN

Extensions to Ethernet Standard

- Majority of extensions to IEEE 802.1Q (Bridges and Bridged Networks)
- Primarily on Layer 2 (MAC and LLC)

TSN provides

- Sub millisecond latency
- Deterministic delays and bounded latency
- Data prioritization
- Synchronized networks with < 1microsec time difference between devices

When complete, TSN standards will be compatible over

- Ethernet
- WLAN – IEEE 802.11be (from 2024)
- 5G (R17 onwards)

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WHAT IS TSN?

TSN

Synchronization
Time Synchronization

Ultra Reliability
Frame Replication, Stream Filtering etc

Bounded Low Latency
Traffic Shaping Scheduling etc

Resource Management
Stream Reservation, YANG models for devices management etc

TSN component	Standard	Description
Time Synchronization	IEEE 802.1 AS	gPTP for IEEE 1588v2
Ultra Reliability	IEEE 802.1CB	Frame Replication and Elimination for Reliability
	IEEE 8021.Qca	Path Control and Reservation
	IEEE 802.1Qci	Per-Stream filtering and Policing
Bounded Low Latency	IEEE 802.1Qbv	Time Scheduled Traffic
	IEEE 802.1Qav	Credit based Shaping
	IEEE 802.1Qbu	Frame Preemption
	IEEE 802.1Qch	Cyclic Queueing and Forwarding
Resource Management	IEEE 802.1Qcc	Stream Reservation Protocol Enhancements
	IEEE 802.1Qcp	YANG model for Bridging
	IEEE 802.1Qcw	YANG model for Traffic Scheduling, Per-Stream filtering, and Preemption
	IEEE 802.1Qcbcv	YANG model for Frame replication and Elimination for Reliability

2. GENERALIZED PRECISION TIME PROTOCOL (GPTP)

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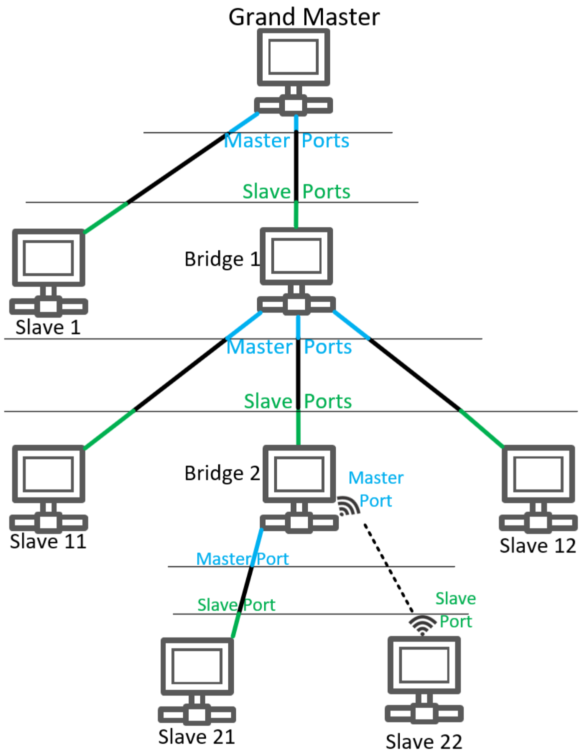
GPTP

Generalized Precision Time Protocol

- Also called Precision Time Protocol 2.0 (PTP v2)
- A profile of Precision Time Protocol defined in IEEE 1588-2008 standard
  - PTP (v1.0) was defined in IEEE1588-2002 standard
- Works with master slave principle
- Slaves in network synchronize with their masters
- Bridges serve as slave as well as masters
- Each gPTP capable port is either
  - Slave
  - Master
  - Passive
- Grand Master of network chosen by Best Master Clock Algorithm (BMCA)



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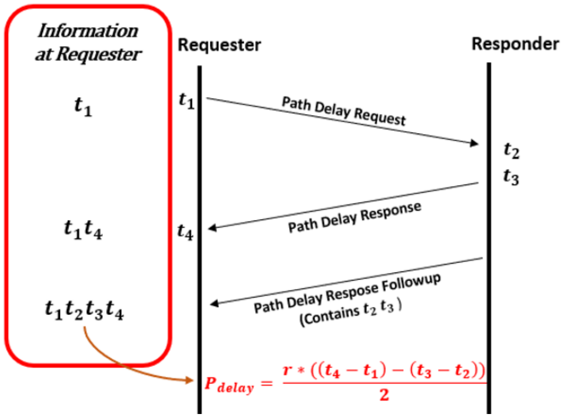
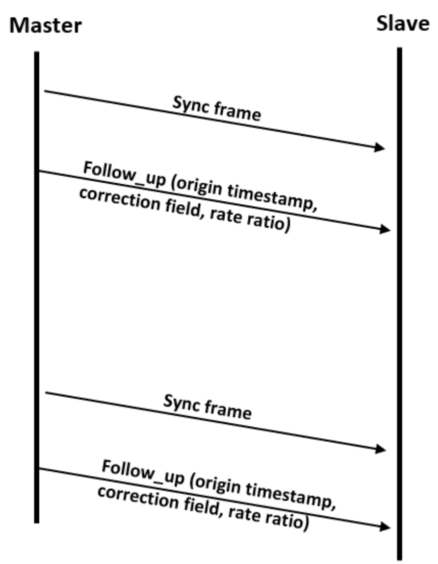
GPTP

- gPTP for TSN networks is adopted under IEEE 802.1AS standard
- Uses
    - ***Sync, Follow_up*** messages for time synchronization information
    - ***Pdelay_request, Pdelay_response, Pdelay_response_followup*** for propagation delay calculations
- Propagation delay information needed for synchronization
- Rate ratio $$rate\ ratio = \frac{f_{requester}}{f_{responder}}$$
- Correction field

Propagation delay information exchange





Clock synchronization information exchange

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3. GPTP IN WIRELESS TSNs

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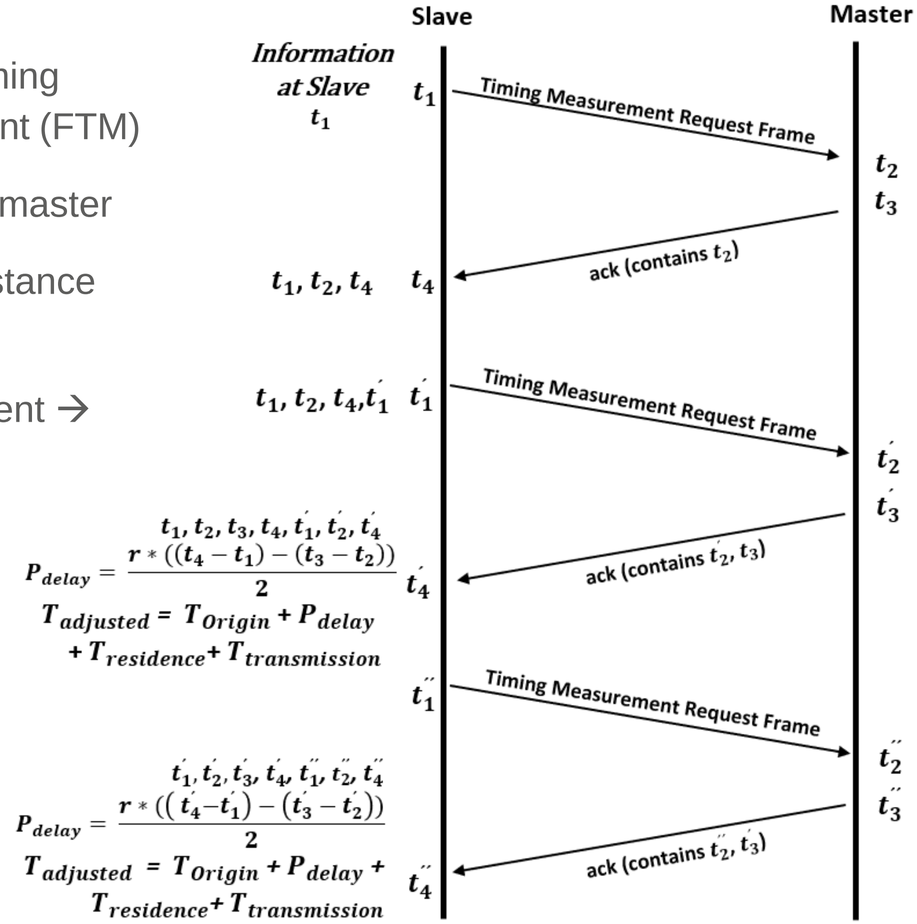
GPTP IN WIRELESS TSNs

- For wireless networks IEEE 802.1AS defines Timing Measurement (TM) and Fine Timing Measurement (FTM)
- TM → for precise synchronization of slaves with master
- FTM → allows a network node to measure its distance from another node
- Mobility in wireless networks, dynamic environment → variable propagation delay
  - Need to be calculated periodically
  - More often than in Ethernet TSN

Propagation delay measurement procedure for WLAN



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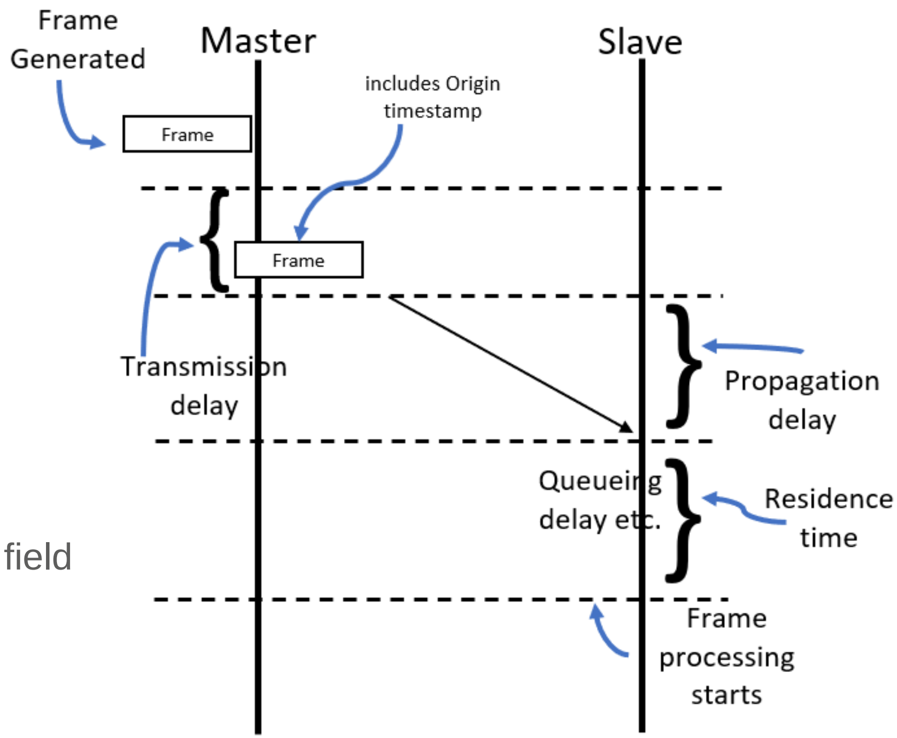
GPTP IN WIRELESS TSNs

Clock synchronization procedure for WLAN (from our OMNeT++ Model)



- For synchronization at bridges/slaves
  - Propagation delay
  - Rate ratio
  - Correction field
  - Transmission delay
  - Residence time
    - Queueing delay
    - Queue wait time
- Slaves synchronizing to bridges also use Correction field in equation

$$T_{slave} = T_{Origin} + P_{delay} + T_{residence} + T_{transmission}$$

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4. OMNET++ MODELLING & SIMULATIONS OF GPTP IN WLANs

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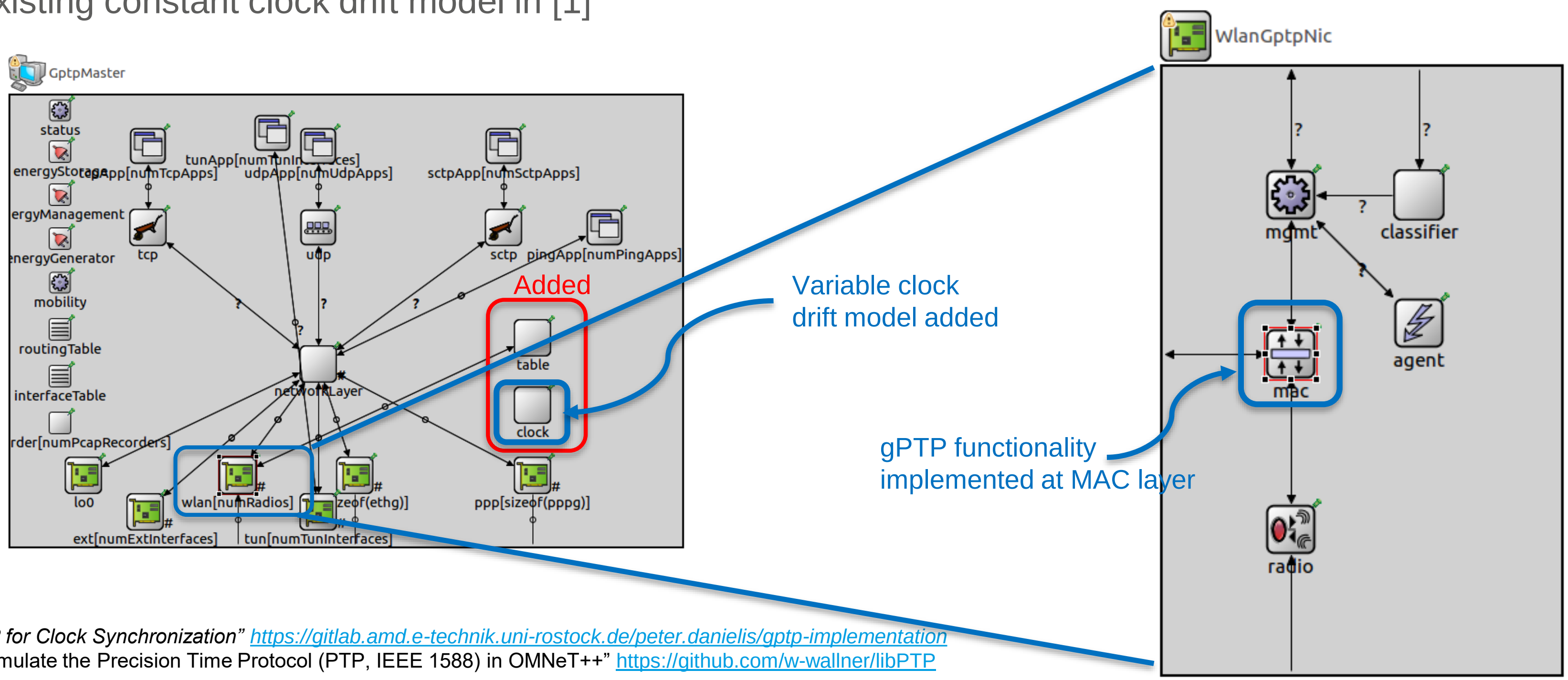
OMNET++ MODELLING

- Extension and modifications to “*IEEE 802.1AS gPTP for Clock Synchronization” [1]*
- WLAN Master, Slave, and bridge nodes
- WLAN TSN messages definitions
- Variable clock drift model based on Power Law Noise (extensions of LibPTP framework [2]) integrated with existing constant clock drift model in [1]



[1] “*IEEE 802.1AS gPTP for Clock Synchronization*” https://gitlab.amd.e-technik.uni-rostock.de/peter.danielis/gptp-implementation
[2] “libPTP - Library to simulate the Precision Time Protocol (PTP, IEEE 1588) in OMNeT++” https://github.com/w-wallner/libPTP

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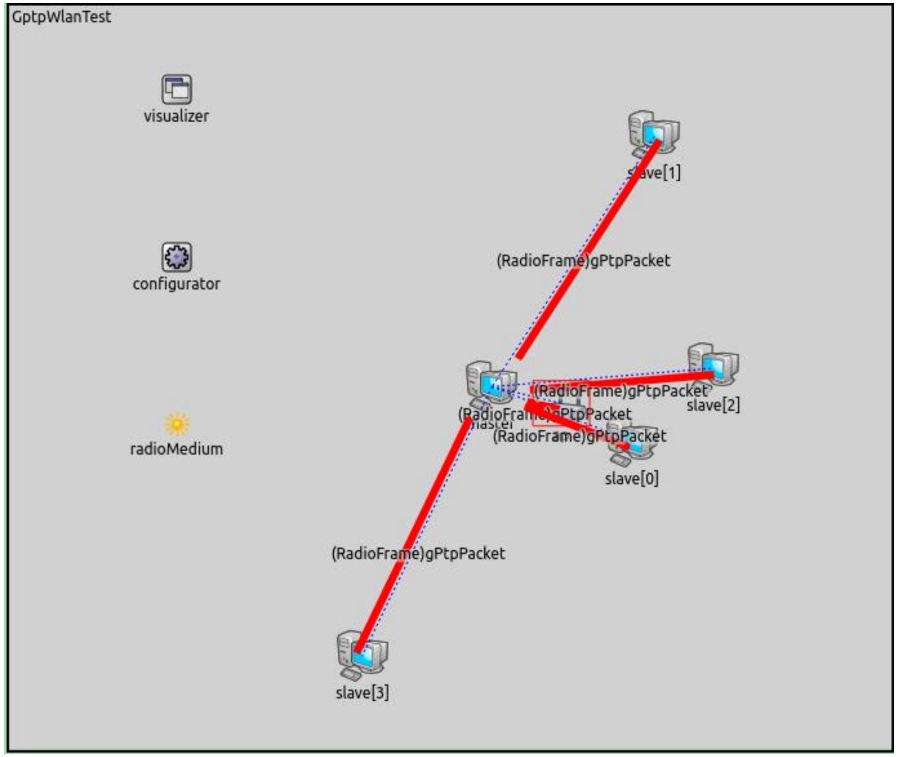
SIMULATIONS

- Simulations done with following parameters
  - Number of TSN nodes: [2, 5, 10, 15]
    - 1 master, rest slaves
  - Simulation area: 100m x 100m
  - Mobility model: Random waypoint
  - Waiting time: 0-5 sec
  - Movement speed: uniform[1,3] m/s
  - Simulation Time: 10 sec
  - Simulation time resolution: 1 ns
  - Timing measurement request interval: 125 ms
  - WLAN: IEEE 802.1g 54Mbps



  - Variable drift: 0-2ns drift per second (Average Oscillator Drift Model)
    - Drift values are between -2ns to +2ns meaning slave node lags or stays ahead of master node

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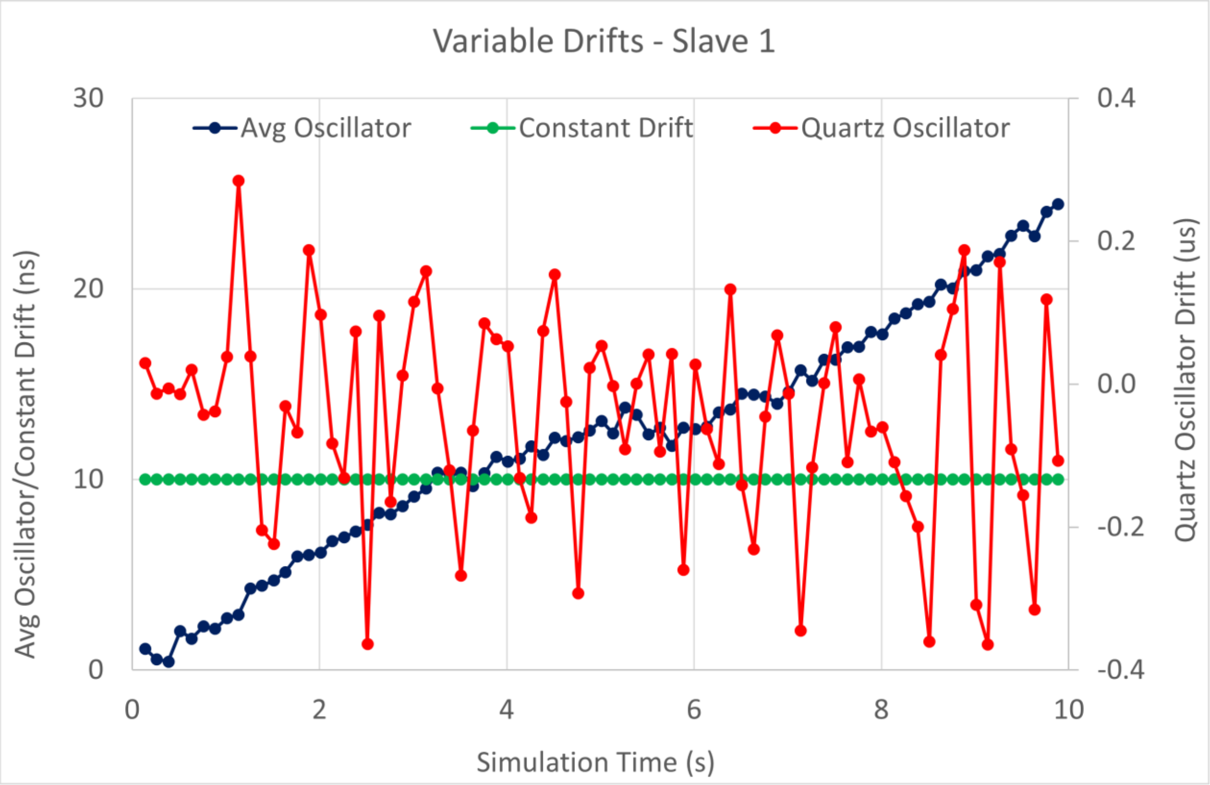
SIMULATION FINDINGS

Drift model comparison:

Average oscillator or Quartz Oscillator drift model provide realistic clock drift compared to constant clock drift or no drift at all



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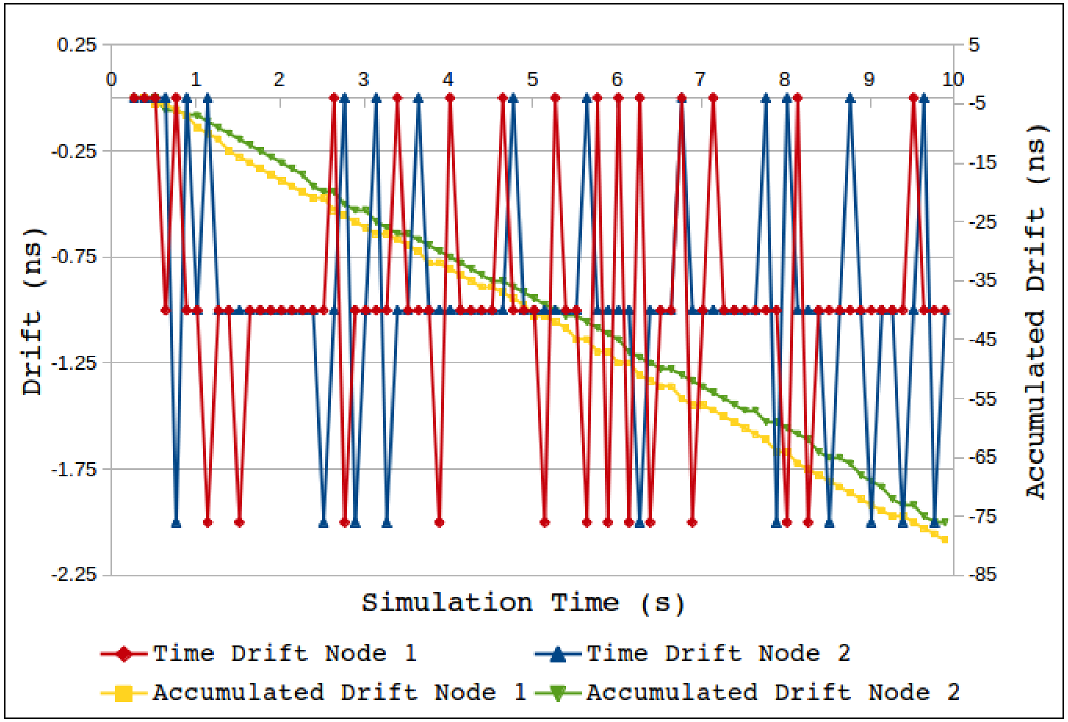
SIMULATION FINDINGS

Drifts of Slave 0 (node1) and Slave 1 (node 2) from 5 nodes simulation

Negative Drift (left side vertical axis) → both slaves lag behind master

Without synchronization (right side vertical axis) → After only 10 seconds simulation, drift has accumulated ~ 80ns

→ Periodic synchronization becomes necessary for TSN networks even if device's clock drift is between -2ns & +2ns



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SIMULATION FINDINGS

Time difference **before** synchronization (left vertical axis)

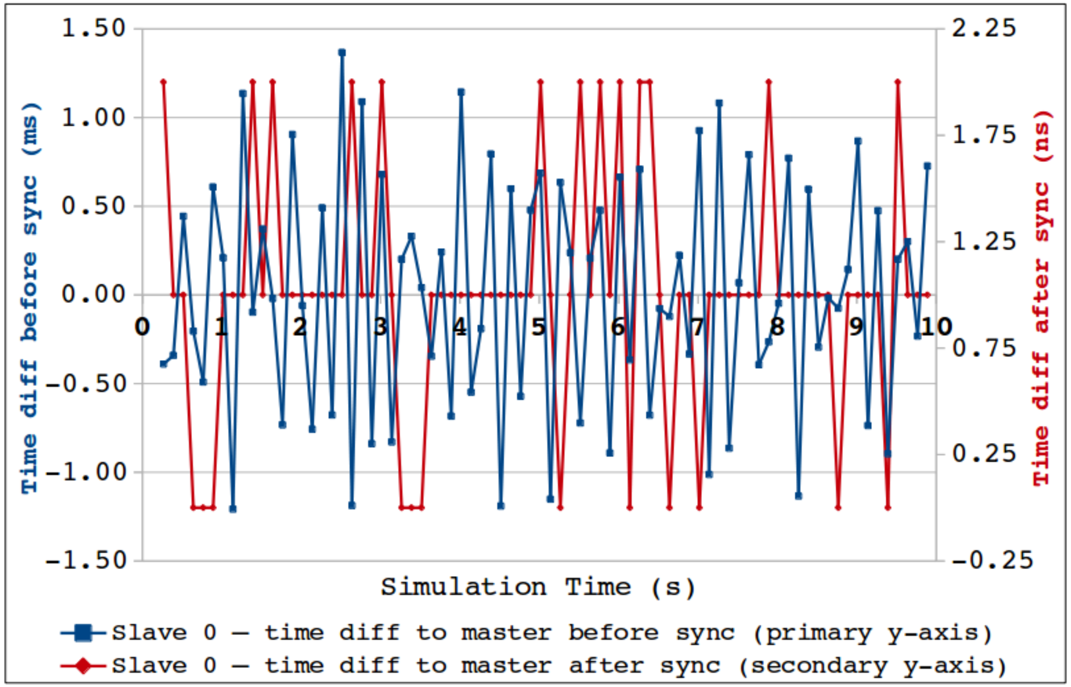
→ Slave lags or proceeds Master's clock in **milliseconds**

→ From -1.5ms to +1.5ms

Time difference **after** synchronization (right vertical axis)

→ Slave lags or proceeds Master's clock in **nanoseconds**

→ Between -0.25ns and 2.25ns



$$Time\ difference = Slave\ clock\ time\ - Master\ clock\ time$$

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5. CONCLUSION

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CONCLUSION AND FUTURE WORK

- Use of variable clock drift models instead of constant clock drift for TSN simulations for realistic scenarios
- Presented gPTP model implemented in Omnet++ based on INET framework can be used for time synchronization in Wireless TSN networks
- Simulation models for other Wireless TSN standards are needed e.g. Time Aware Shaper (TAS) etc
  - Available for Ethernet → needs to be updated for wireless networks
- Next steps:
  - Integration of Ethernet time synchronization with WLAN time synchronization
  - Modelling IEEE 802.1Qbv, TAS, Credit based Shaper (CBS) for wireless TSN
  - A complete framework for Wireless TSN simulations

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THANK YOU FOR YOUR ATTENTION!