HOCHSCHULE OSNABRÜCK
UNIVERSITY OF APPLIED SCIENCES

TIME SENSITIVE NETWORKING VIA 5G – AN OVERVIEW AND RECENT ADVANCES

PRESENTED BY: FELIX KAHMANN, 28TH ITG-SYMPOSIUM MOBILE COMMUNICATION – TECHNOLOGIES AND APPLICATIONS, 15.05.2024, OSNABRÜCK

AGENDA

01 TSN Overview

02 TSN via 5G

03 Current State and Future Directions

04 Time Synchronization Testing Setup

05 Time Synchronization Testing Results

01 TSN OVERVIEW

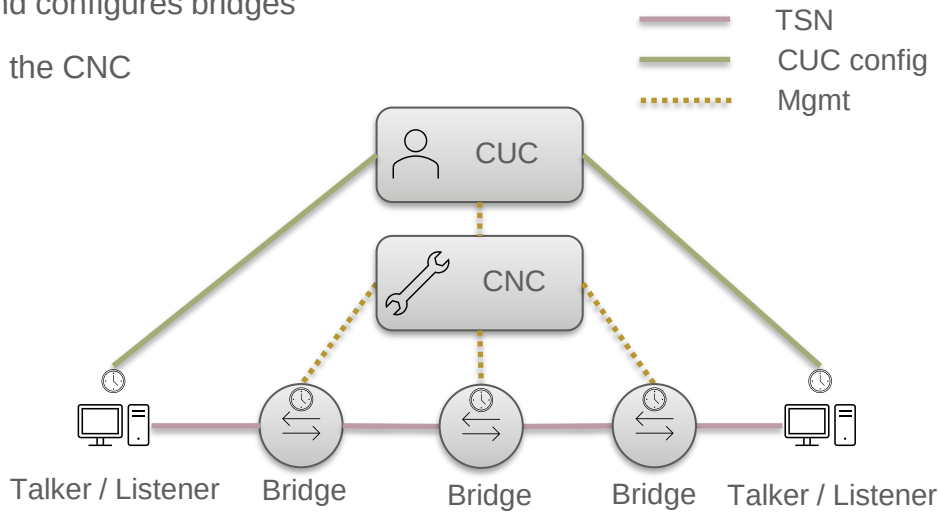
TIME SENSITIVE NETWORKING (TSN)

- Stack of standards of the IEEE 802 Working Group.
- Based on IEEE 802.1Q and IEEE 802.3 Ethernet
- Low latency network with guaranteed end-to-end packet transport.
- Amendments to classical Ethernet:
  1. Time Synchronization
  2. Bounded Low Latency
  3. Ultra Reliability
  4. Resource Management

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 802.1Qca	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

TSN OVERVIEW AND TOPOLOGY

- Centralized User Configuration (CUC) discovers and configures talkers / listeners
- Centralized Network Configuration (CNC) discovers and configures bridges
- CUC gathers user information and communicates with the CNC to pass the configuration data
- TSN node can be either talker, listener or bridge
- Three different topology modes available:
  1. Fully distributed: no CNC / CUC
  2. Centralized NW / Distributed user: no CUC
  3. Fully centralized: CUC and CNC present



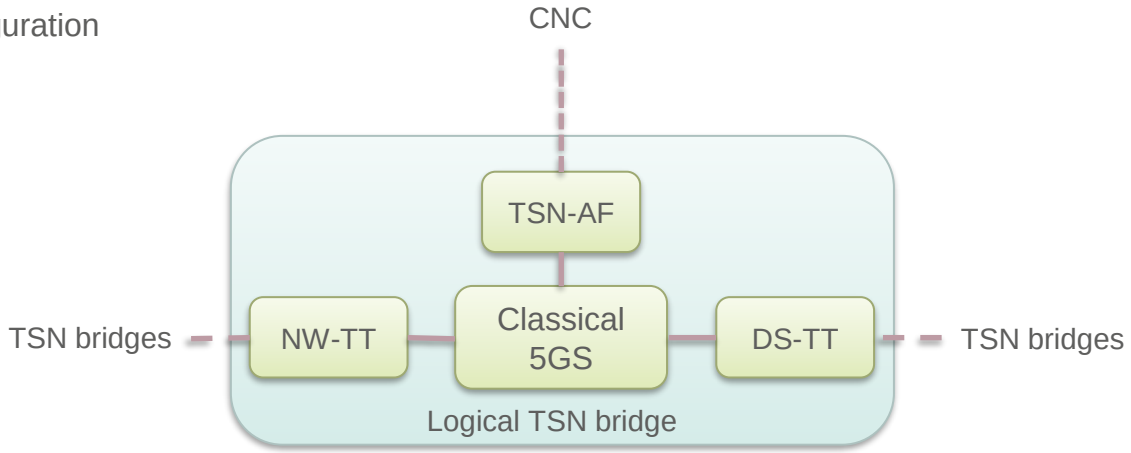
02 TSN VIA 5G

TSN VIA 5G - MOTIVATION

- Reliable and low latency communication via 5G
- Use of URLLC 5G with TSN as wireless fieldbus system
- Use-Cases for different industries possible:
  - Telemedicine
  - Wireless control of machines
  - Other time critical applications

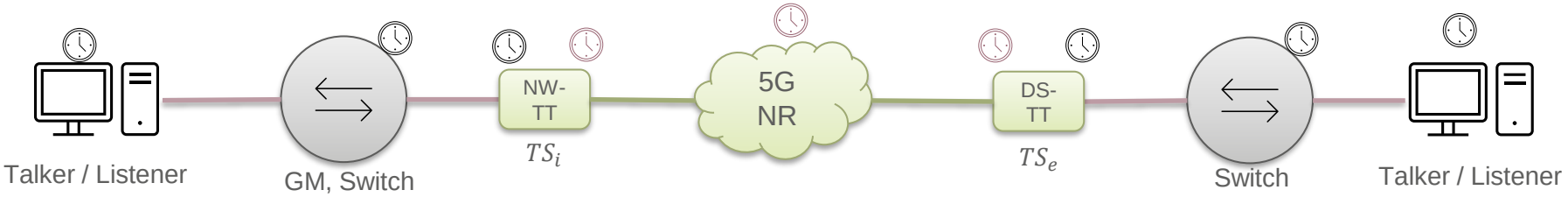
TSN 5G INTEROPERABILITY

- 5G system (5GS) acts as logical TSN bridge
- Required additional services and functionalities for the 5GS:
  - TSN Application Function (TSN-AF): Communicate with CNC and transforms TSN configuration to 5G configuration
  - Network-side TSN Translator (NW-TT)
  - Device-side TSN Translator (DS-TT)
- 5GS needs to support layer 2 PDUs



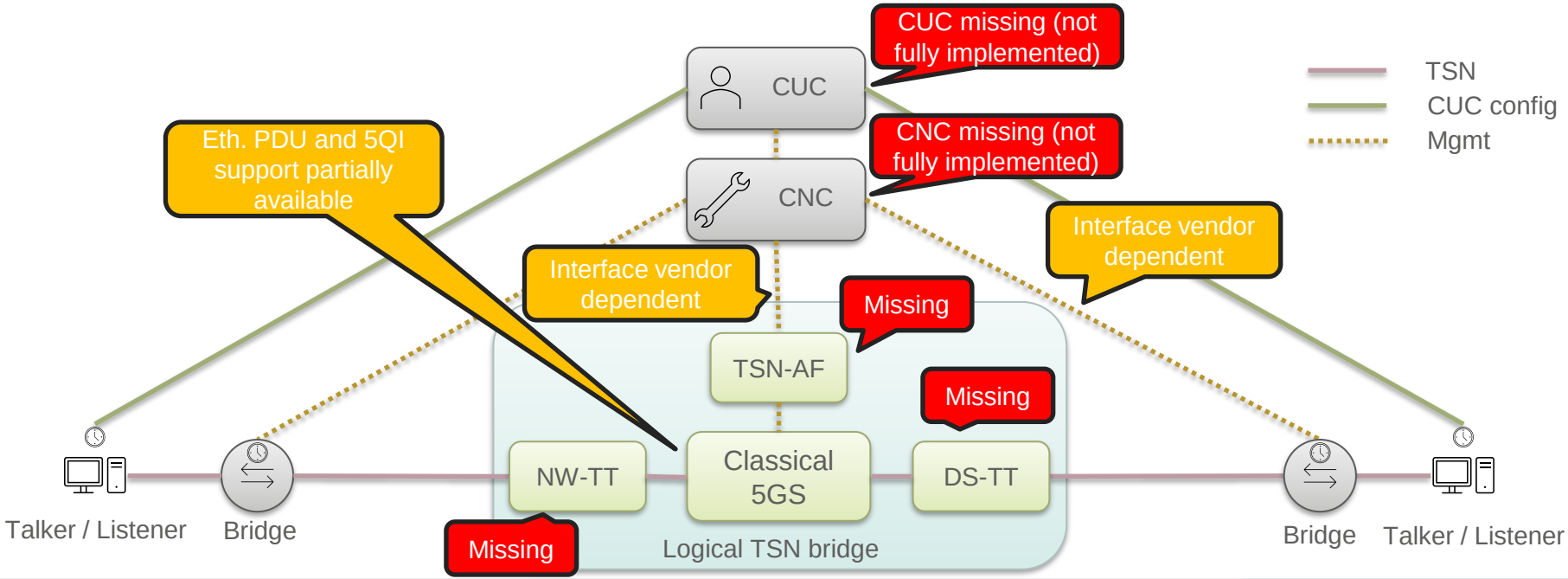
5GS AS A TSN BRIDGE – TIME SYNC

- 5GS as Transparent Clock:
  - 5GS forwards PTP frames to either sides of TSN network.
  - Updates the 5GS residence time in the correction field of the sync frame.
- NW-TT and DS-TT inserts ingress timestamps and egress timestamps in sync frames to compute 5GS residence time.
- $TS_e - TS_i$ gives the 5GS residence time.
- 5GS can have its own sync method for 5G devices e.g. SIB9.



03 CURRENT STATE AND FUTURE DIRECTIONS

5G CURRENT STATE



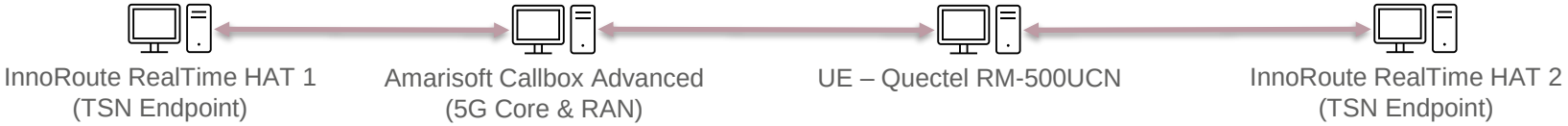
04 TIME SYNCHRONIZATION TESTING SETUP

5G END-END TESTING FOR TSN TIME SYNC

- Time Sync is the first step in TSN.
- TSN Time Synchronization over 5G must be successful, otherwise TAS timings will be out of sync in TSN network.
- TSN network (tested over 3 hops) alone can achieve synchronization accuracy of sub 100 nanoseconds.
  - Link delay of such network ~ 250ns.

- 5G system’s end-end delay varies depending on the 5GS configuration.
- End – End delays for different 5G configurations tested.
- For high delays and jitter, synchronization accuracy decreases.
  - Delay must be lowered as much as possible.

5G END-END TESTING FOR TSN TIME SYNC

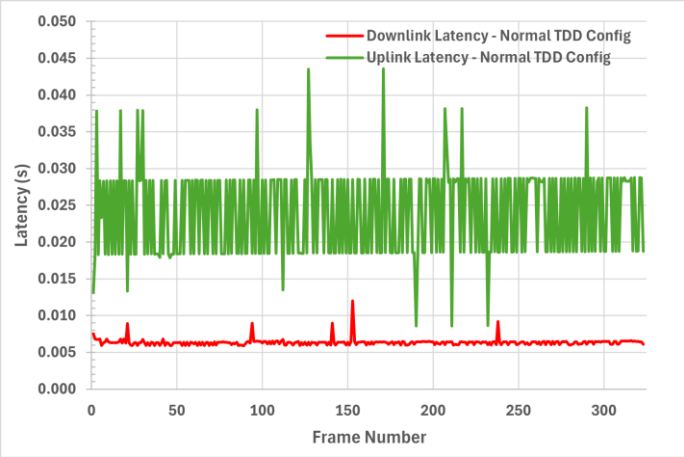


- Two TSN Endpoints connected to a 5G Core and a 5G UE.
- 5G Core, RAN, and UE supports Ethernet PDU sessions.
- RealTime HAT (RTH) generates Ethernet PDUs and send to the other RealTime HAT.
- Uplink: RTH2 → RTH1
- Downlink: RTH1 → RTH2
- 100 bytes Eth PDUs with 40ms interval between consecutive PDUs.

05 TIME SYNCHRONIZATION TESTING RESULTS

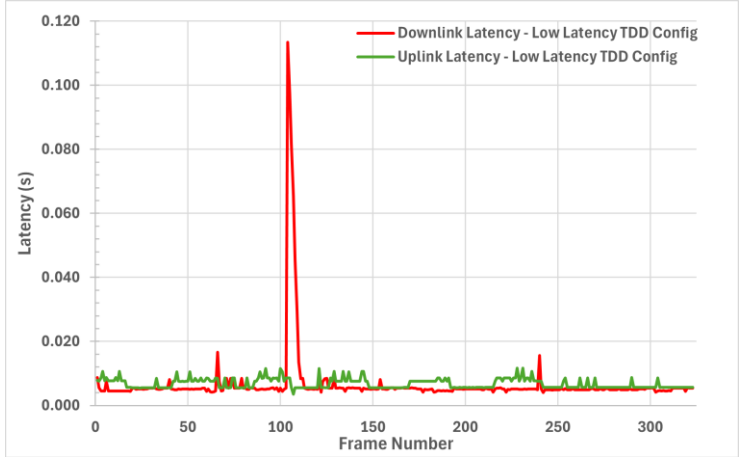
5G END-END TESTING FOR TSN TIME SYNC

5GS configuration 1: Normal TDD config
- 5ms Cycle length, 10 slots/cycle
- Slots: DL: 7, UL: 2, flexible: 1
- Flexible slots symbols: DL: 6, UL: 4, unused: 4



- Avg. Downlink latency: 6 ms
- Avg. Uplink latency: 26 ms

5GS configuration 2: Low Latency TDD config
- 1ms Cycle length → frequent Uplink transmissions
- Slots: DL: 1, UL: 0, flexible: 9
- Flexible slots symbols DL: 0, UL: 12, unused: 2



- Avg. Downlink latency: 5 ms
- Avg. Uplink latency: 7.5 ms

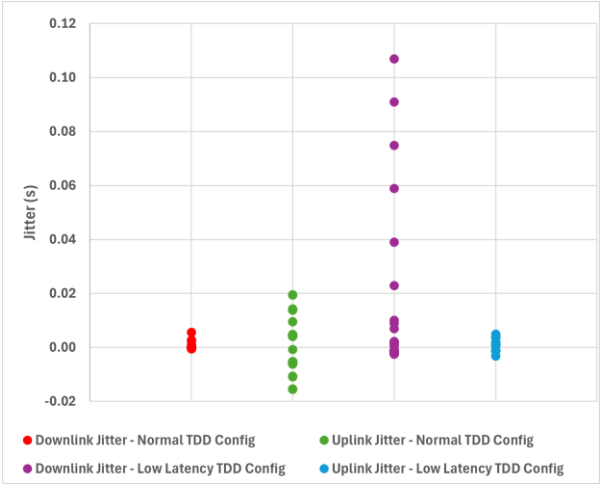
5G END-END TESTING FOR TSN TIME SYNC

- Low latency TDD configuration for 5G reduces the uplink latency which is beneficial for TSN Time Synchronization.
  - Compared to Ethernet latency of 250ns, 7.5ms is still very high.

- Both Uplink and Downlink latency needs to be reduced, if DS-TT, NW-TT are not used in the 5GS.
- Jitter in 5GS is also very high.

- Normal TDD Config:
  - Max UL jitter: ~ 20 ms
  - Max DL jitter: ~ 6 ms

- Low Latency TDD Config:
  - Max UL jitter: ~ 6.5 ms
  - Max DL jitter: ~ 15 ms



- While jitter with Low latency TDD config is reduced, it needs to be further reduced for TSN.

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS AND REMARKS?

Contact (corresponding authors):

Hochschule Osnabrück
Felix Kahmann M.Sc. felix.kahmann@hs-osnabrueck.de
Anas Bin Muslim, M.Sc. a.bin-muslim@hs-osnabrueck.de

Technische Universität Chemnitz
Syed Tasnimul Islam, M.Sc. syed-tasnimul.islam@etit.tu-chemnitz.de