DETERMINISTIC6G

Dependable6G Summer School 2025

# Lecture 3: Time Synchronization

KTH Stockholm, Sweden
Sep. 10, 2025

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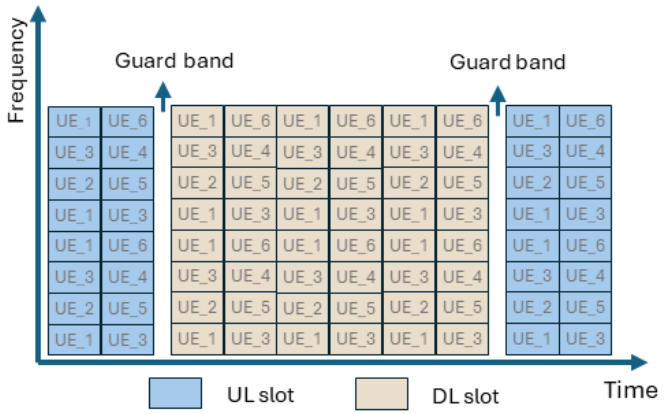
DETERMINISTIC6G has received funding from the European Union's Horizon Europe programme under grant agreement No 101096504.

# Agenda

- Importance and background
- Time synchronization for TSN
- Time synchronization for 5G-TSN networks
- Fault tolerance in time synchronization for 6G-TSN networks

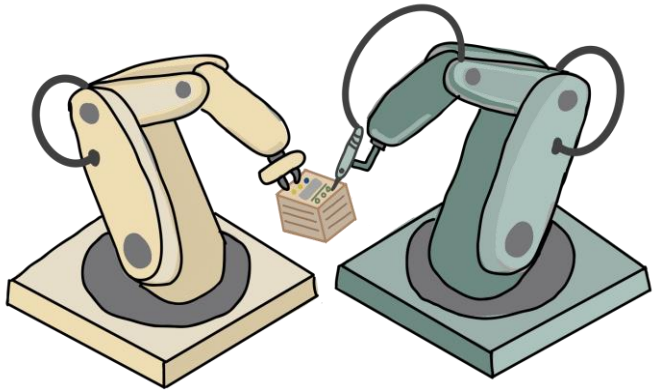
# Importance of Time Synchronization

## Network Synchronization



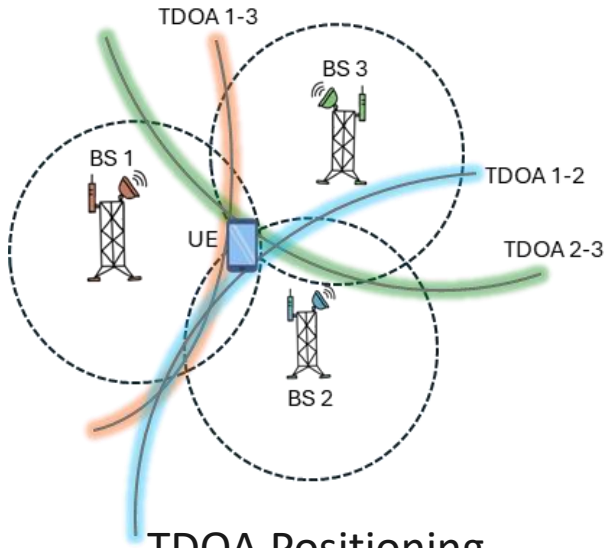

UL/DL scheduling

## Industrial Automation



Collaborative Robots

## Positioning




TDOA Positioning

# Time Synchronization Basics


**Architecture of a digital clock**

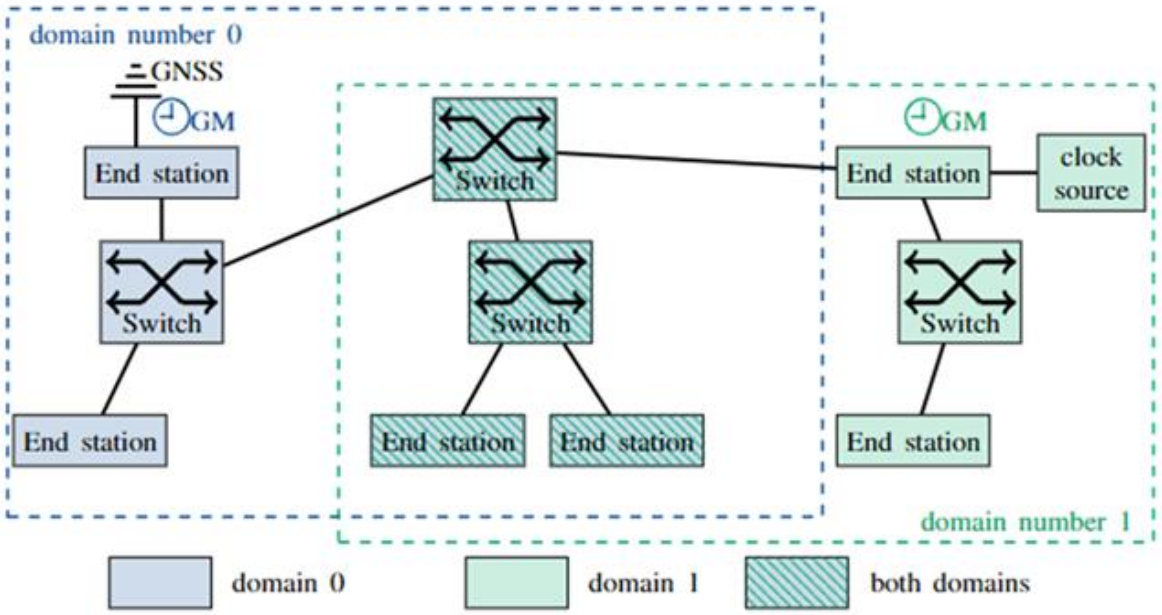
- Imperfect oscillators
- Alignment both in the frequency and time domains.
- Need for a reliable and high-quality accurate time reference source

# Terminology

- timeTransmitter (tT)
- timeReceiver (tR)
- Grandmaster (GM)

# Time Synchronization in TSN Networks

- The generalized Precision Time Protocol (gPTP) [IEEE 802.1AS ]
- Packet-based protocol
- Time-aware network
- Best timeTransmitter clock algorithm (BTCA)
- External port configuration
- Multiple time domains




Time-aware network with multiple gPTP domains

# BTCA and its Limitations

- BTCA uses
  - Dataset comparison algorithm
  - State decision algorithm
- BTCA‘s response to failures is considered to be slow
- Leads to undesireble downtime[1]
- Unable to achieve stable configuration

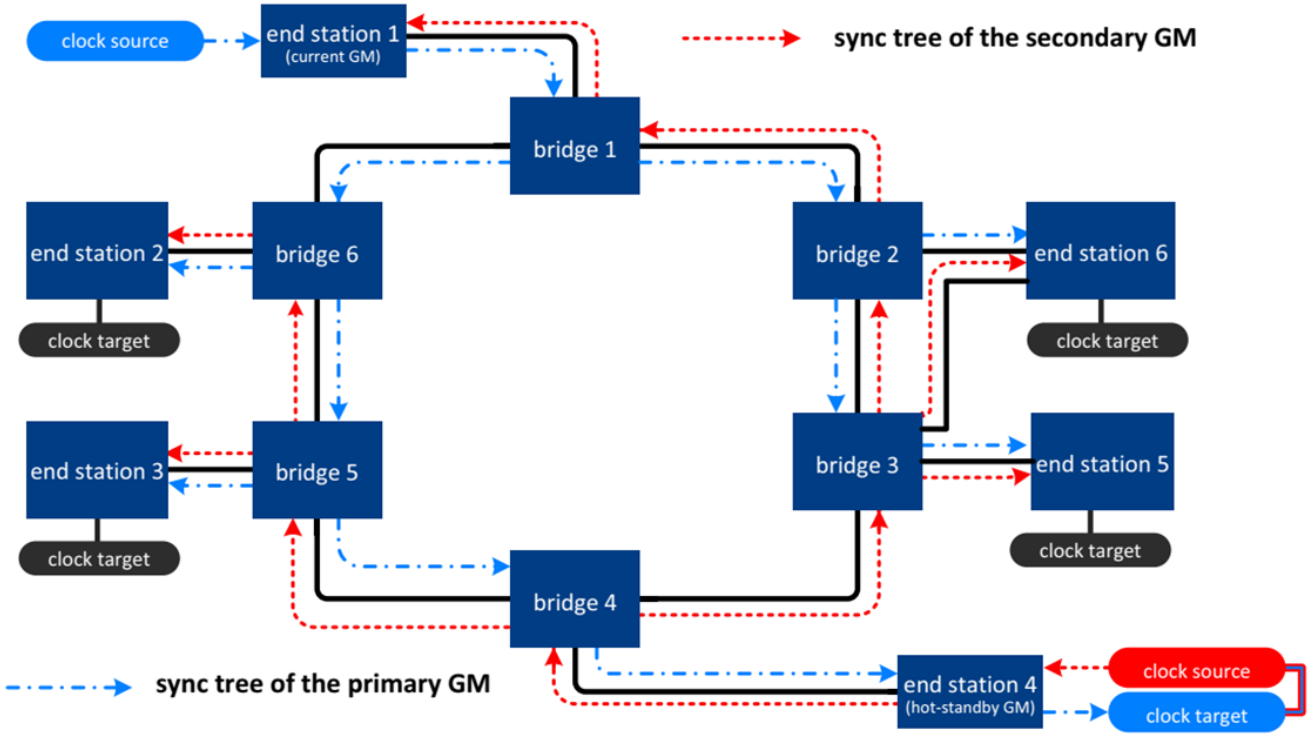
| Clock Attributes | |
|---|---|
| Priority1 | Considered before any other attribute |
| clockClass | Denotes the traceability of synchronized time of a GM |
| clockAccuracy | Denotes the time accuracy of a timeTransmitter |
| offsetScaledLogVariance | Characterizes the precision and frequency stability of a timeTransmitter |
| Priority2 | Used if above attributes are the same for candidate clocks |

Src: IEEE 802.1AS

[1] Mahin Ahmed et al. "First Analysis of Time Synchronization for TSN Networks with Hot Standby GM„, in *WFCS 2025*

# IEEE 802.1ASdm – Hot Standby Amendment

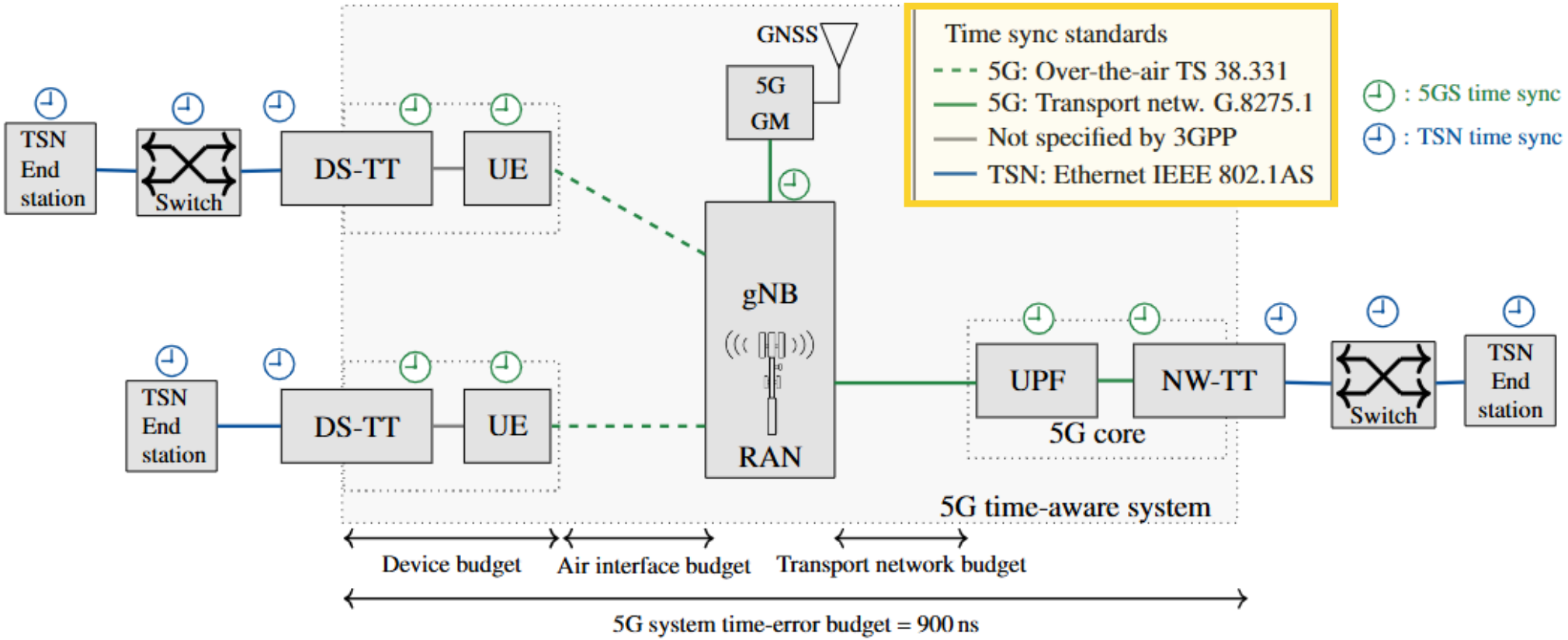
- A hot standby GM
- Static configuration
- BTCA disabled
- primarySecondaryOffset
- Split functionality




Also interesting to read: IEEE P802.1ASed – Byzantine Faults

Src: IEEE 802.1ASdm

# Time Synchronization for 5G-TSN Networks



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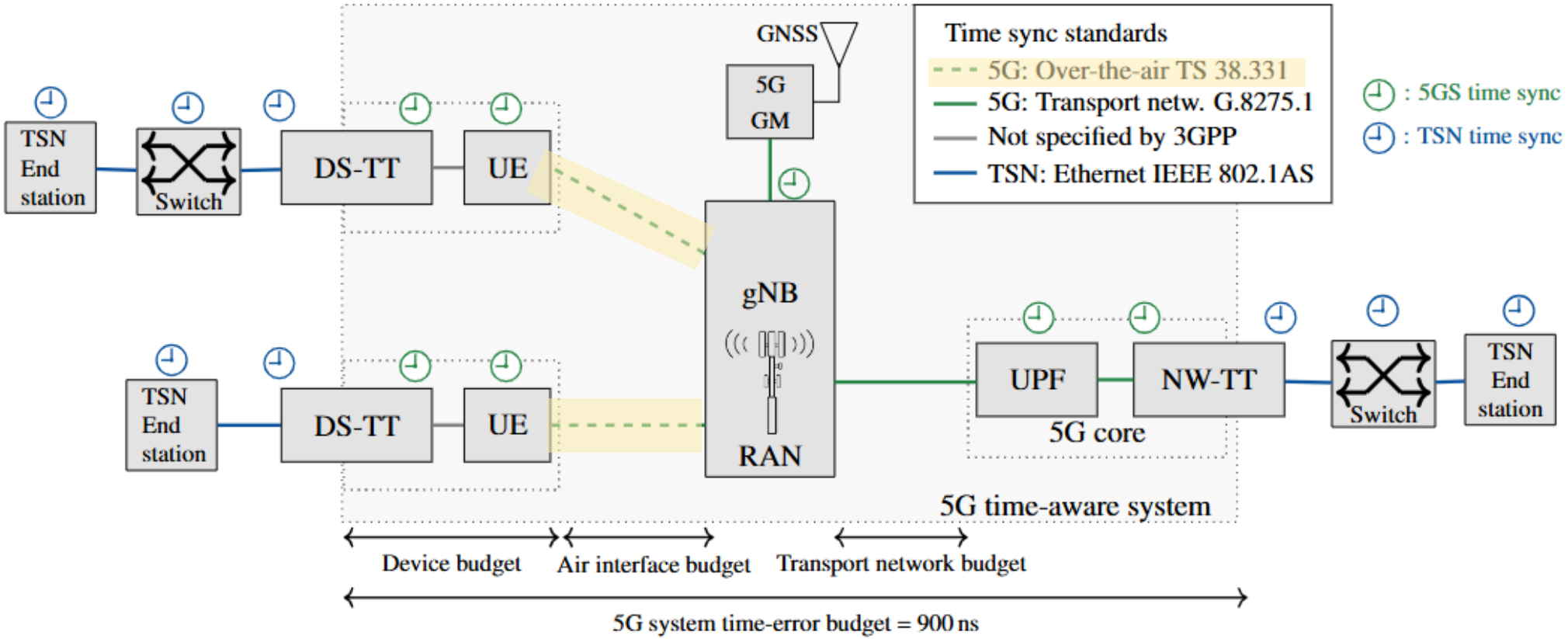

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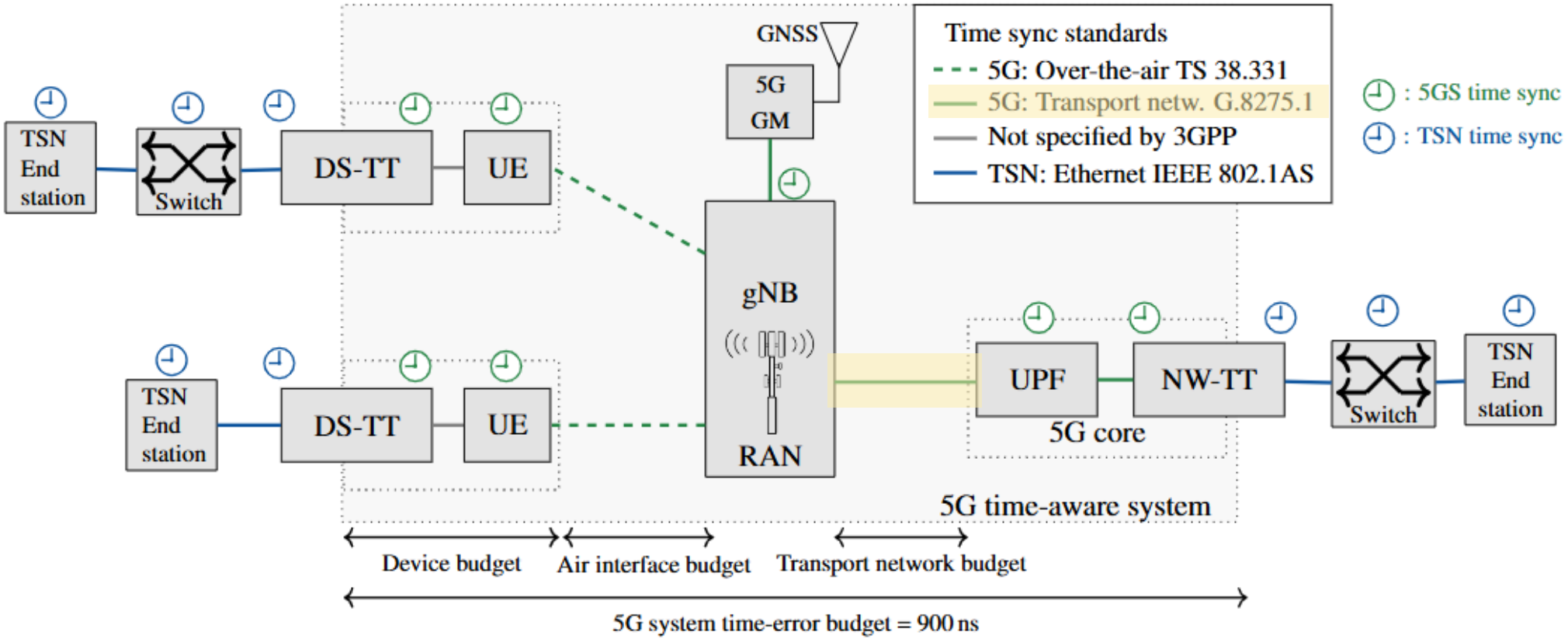

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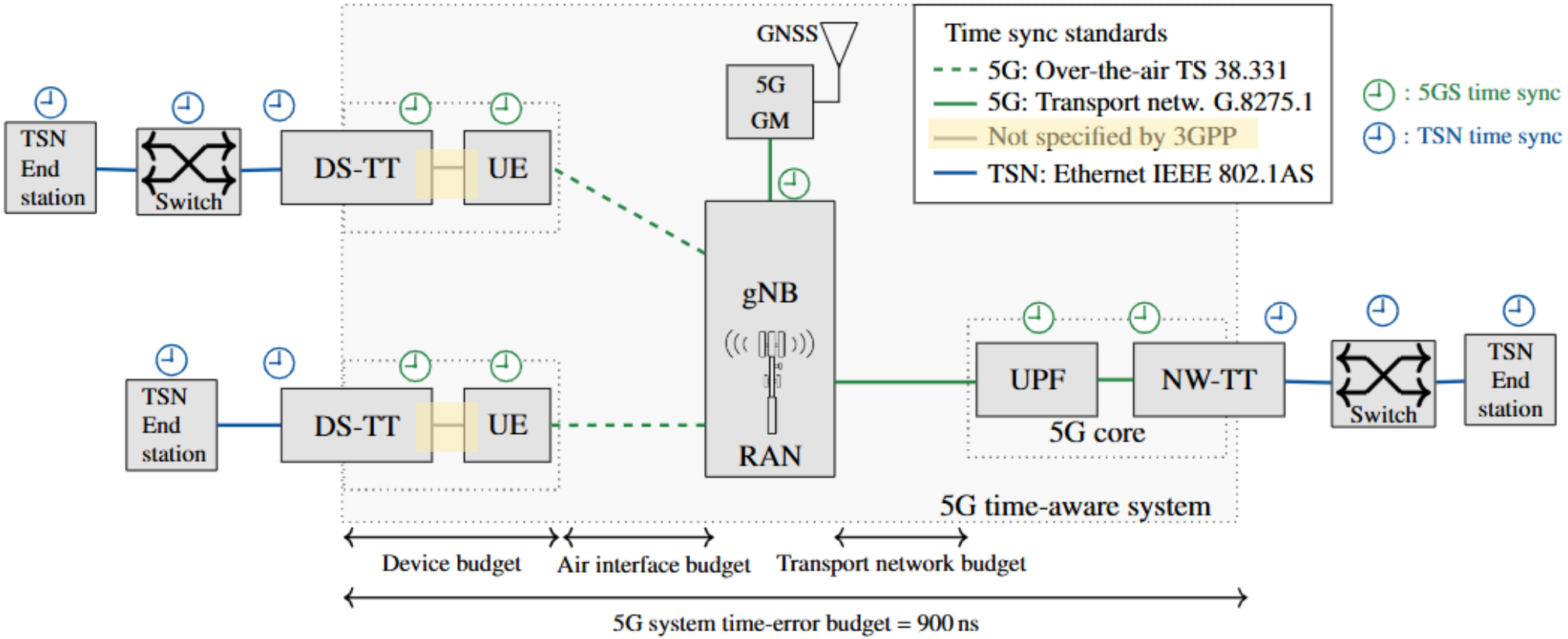

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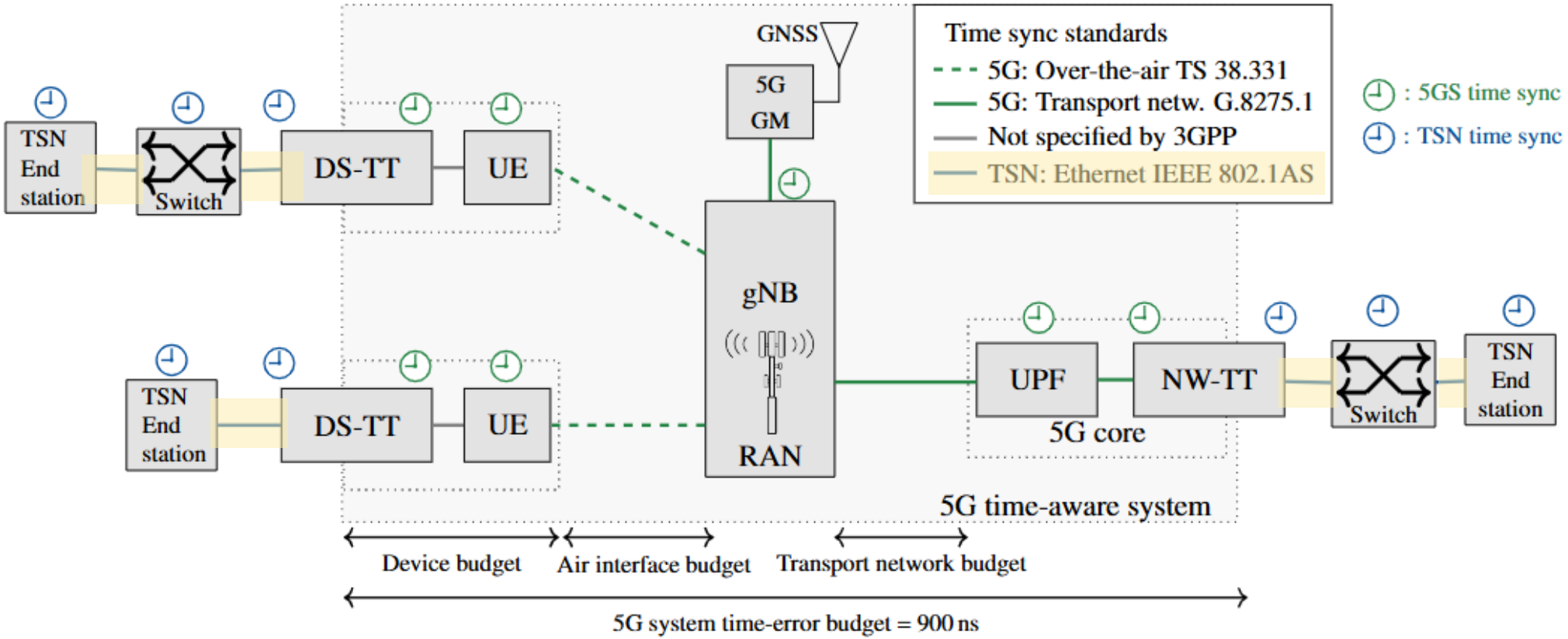

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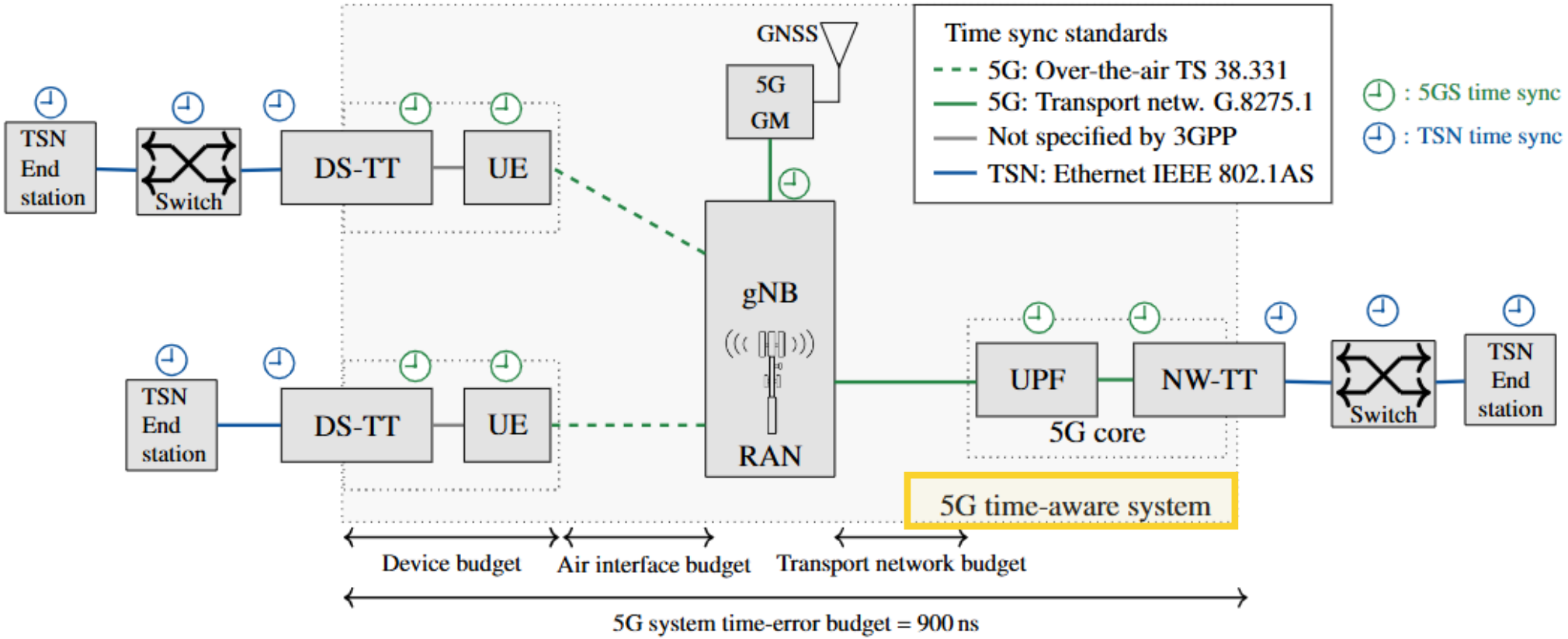

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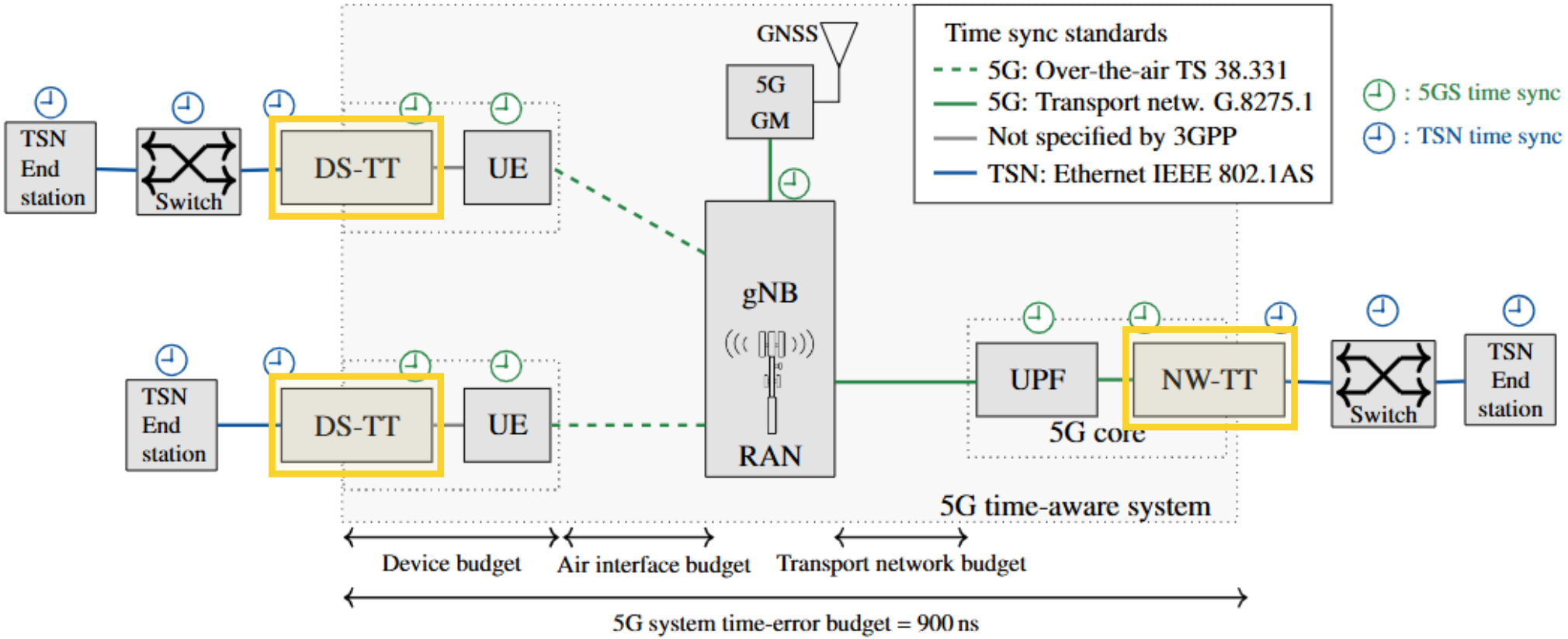

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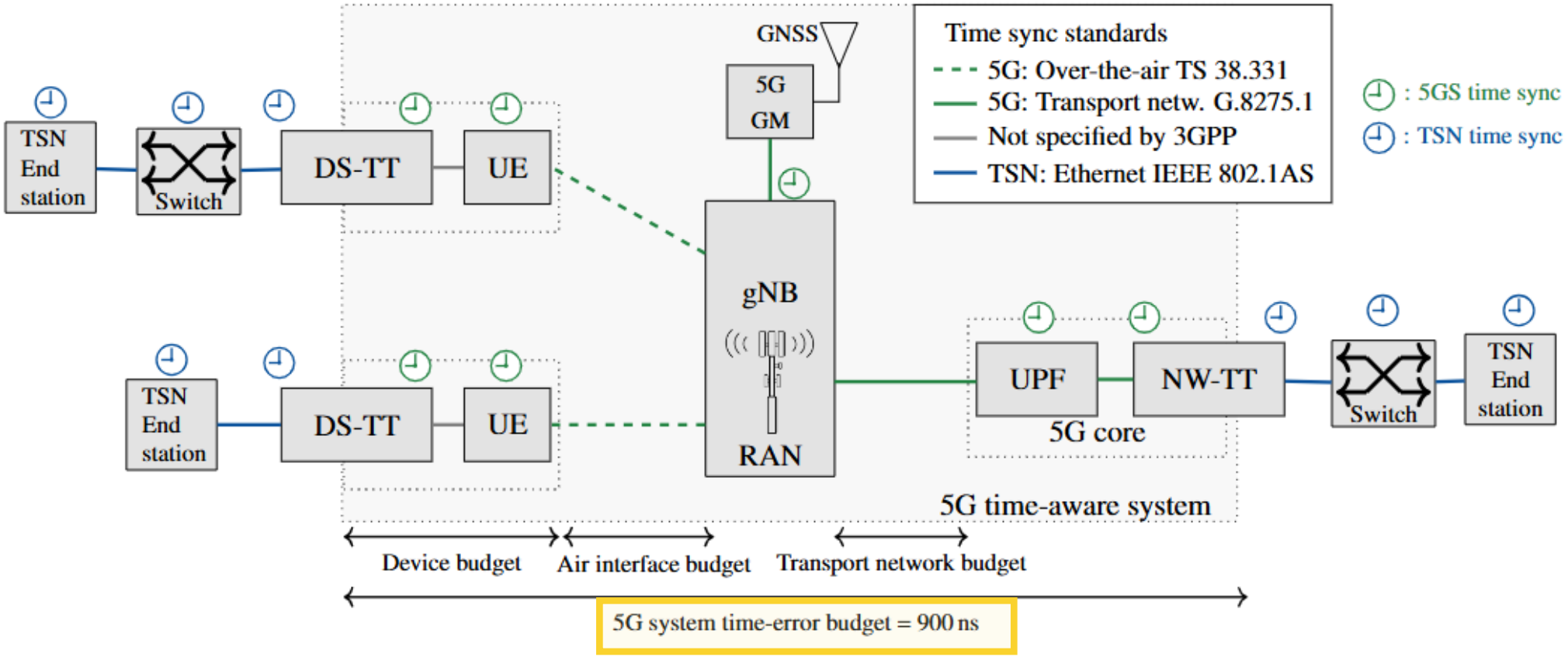

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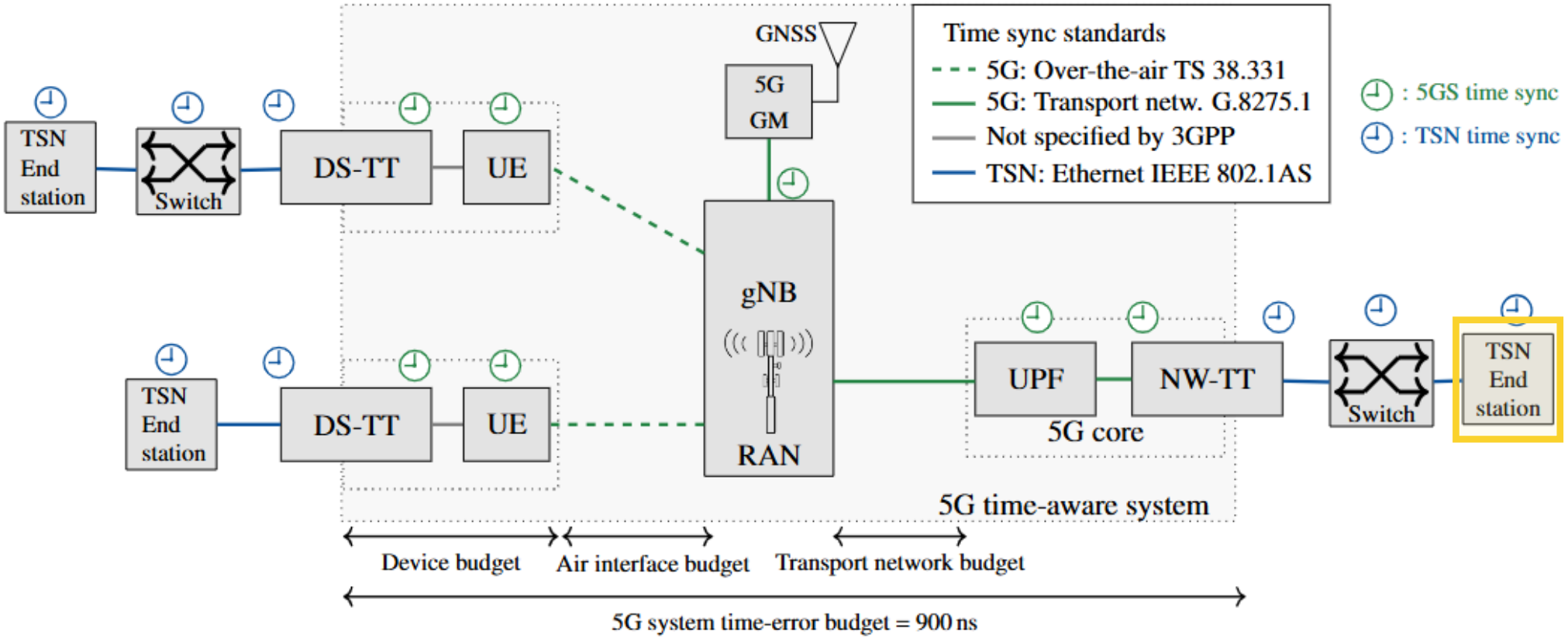

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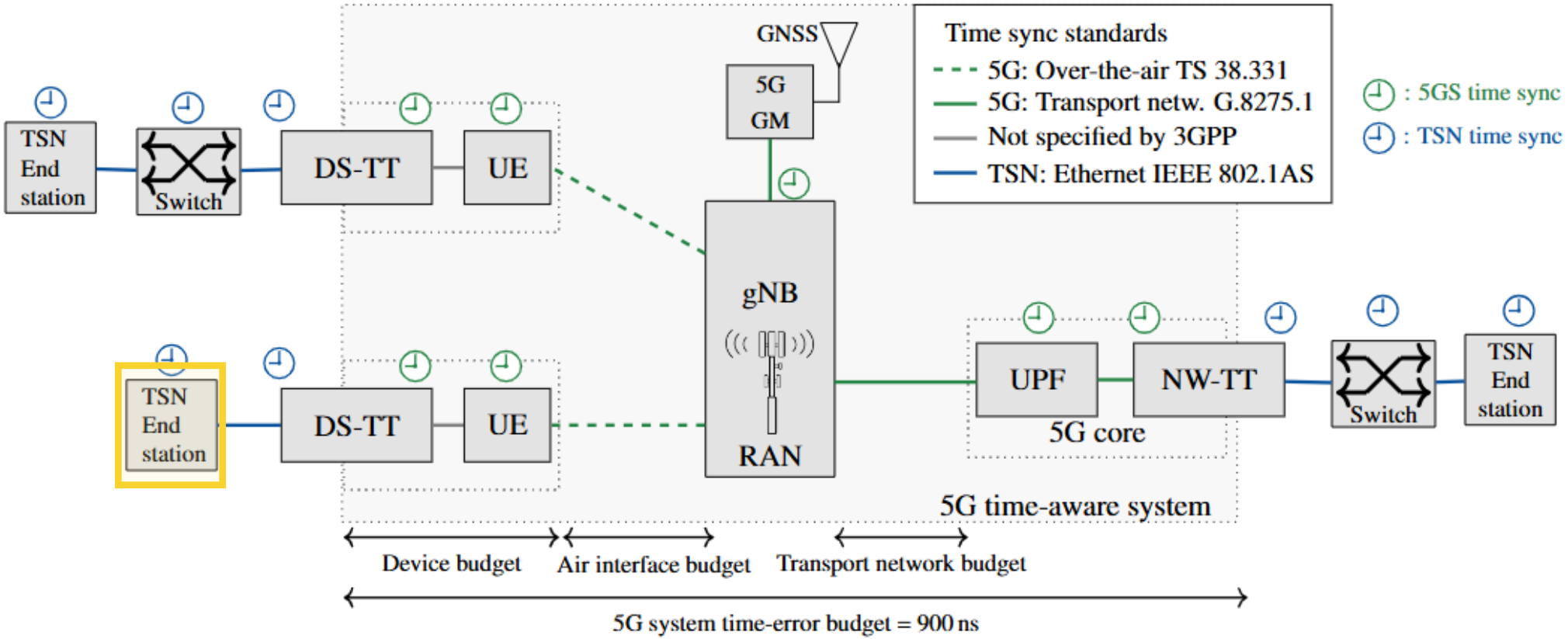

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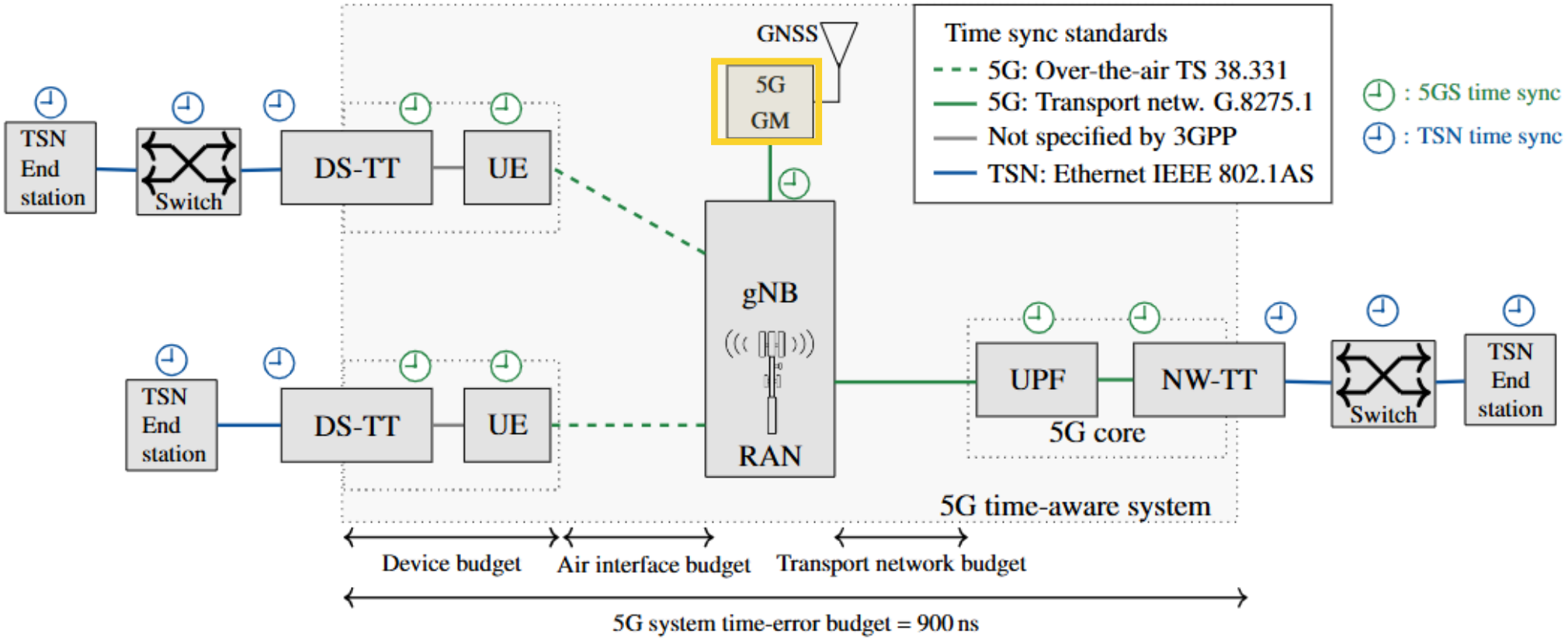
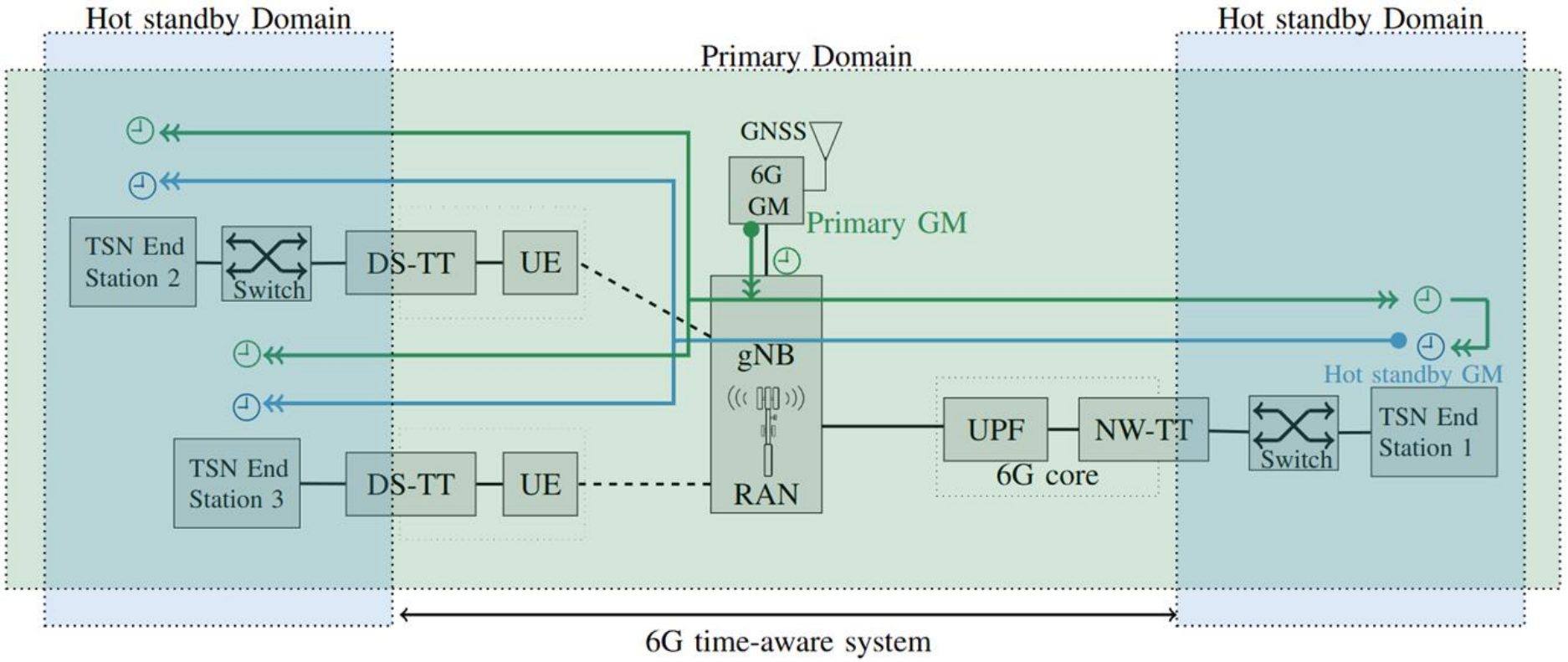


# Hot Standby in 6G-TSN Networks

- Important considerations[2]
  - 6G GM has a high quality clock
  - 6G GM does not synchronize to an external network
  - Disabling the optional split functionality
  - A network side GM helps keeping the time error low

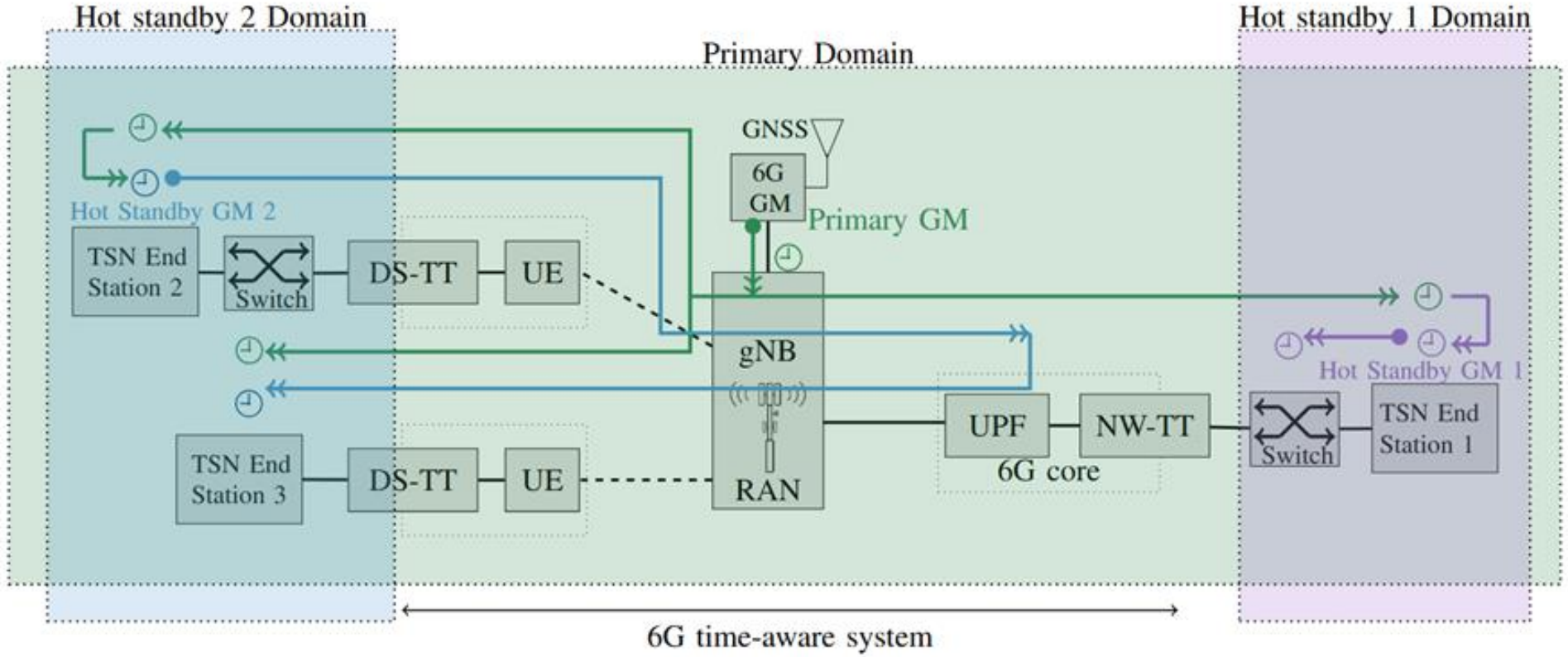
[2]Mahin Ahmed et al. ‘‘Resilient Time Synchronization in 6G Networks: A Hot Standby Solution”, IEEE Communication Standards Magazine, 2025

# Hot Standby in 6G – TSN Networks




6G GM as primary GM and network-side TSN end station as hot standby GM.

# Hot Standby in 6G – TSN Networks




6G GM as primary GM and one hot standby GM on device-side TSN end station and another hot standby GM on network-side TSN end station.

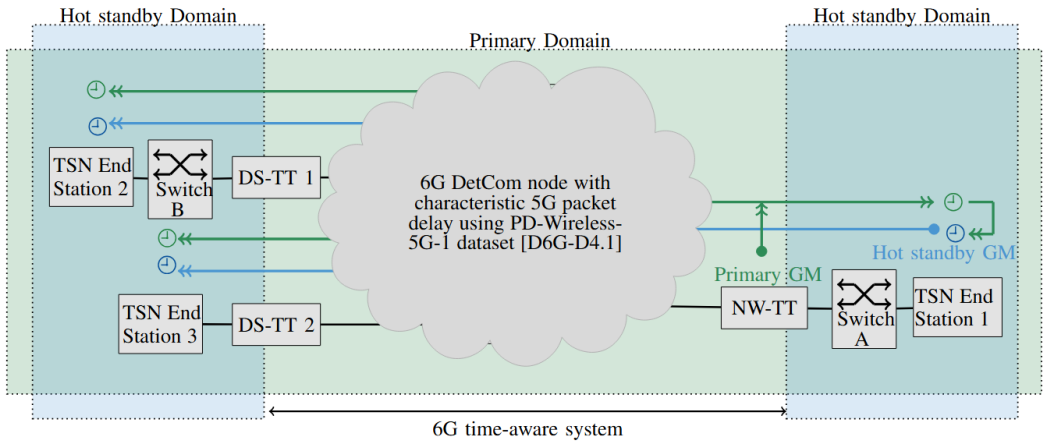
# Fault-Tolerance Analysis

- Time Synchronization Simulator in OMNeT++
  - TSN clocks are setup according to IEEE 802.1AS specifications
  - 6G clocks are setup as per 3GPP specifications
- Available opensource on GitHub[3]

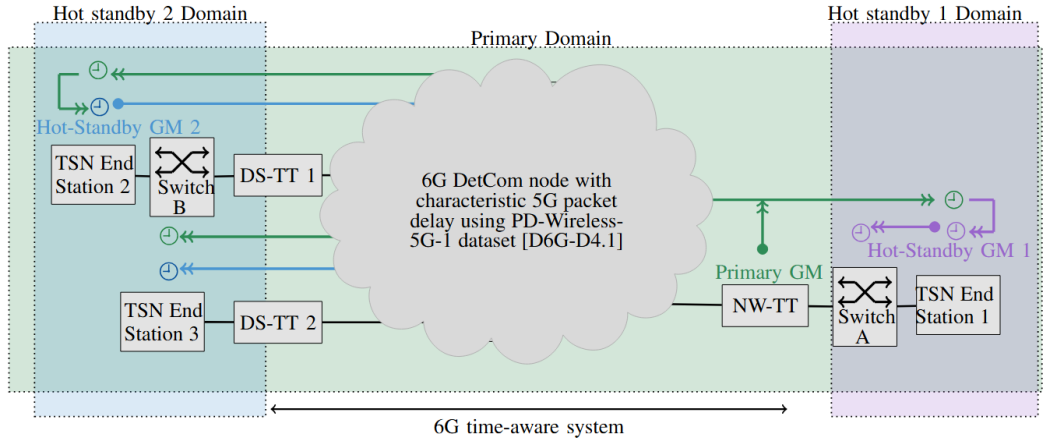
[3] https://github.com/DETERMINISTIC6G/6GDetCom_Simulator/

# Simulation Setup

- Failure cases
  - NW-TT loses access to 6G time
  - 6G network availability is compromised
  - Link between NW-TT and switch A is lost.




Hot standby scenario 1




Hot standby scenario 2

Mahin Ahmed et al. “Analysis of time synchronization for 6G-TSN networks with hot standby“, IEEE ICCCN 2025

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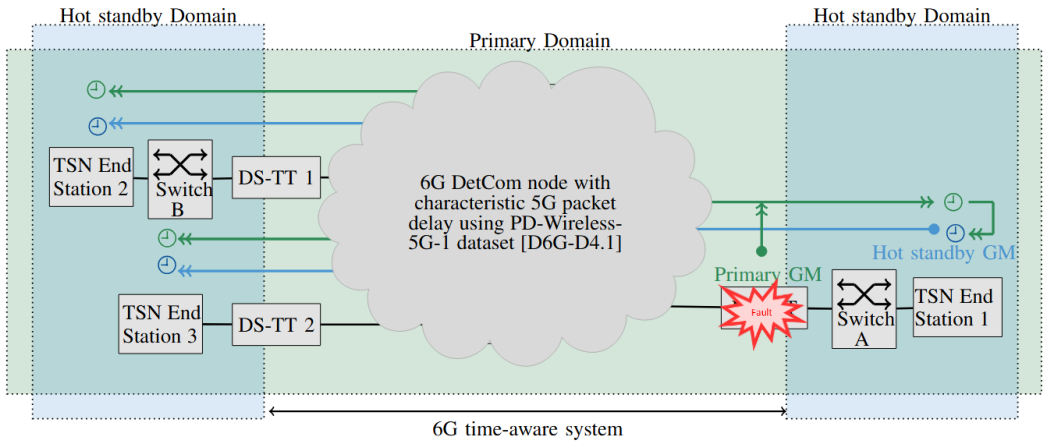


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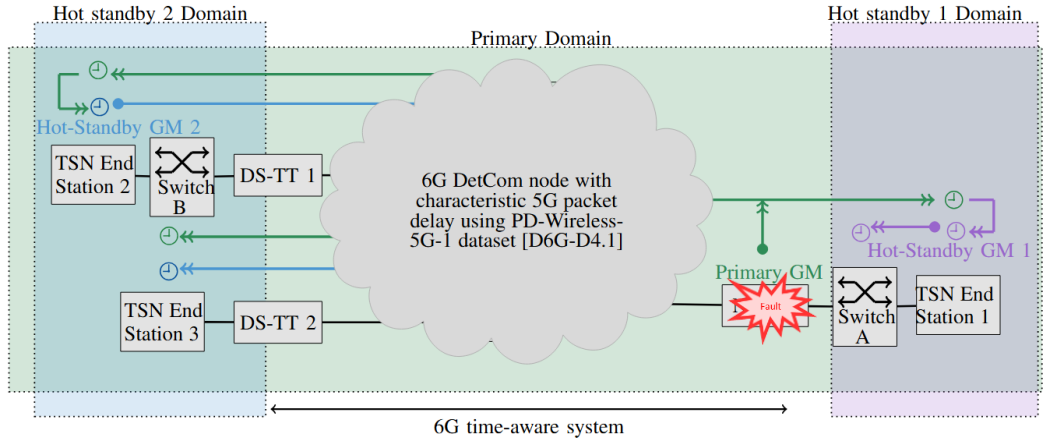


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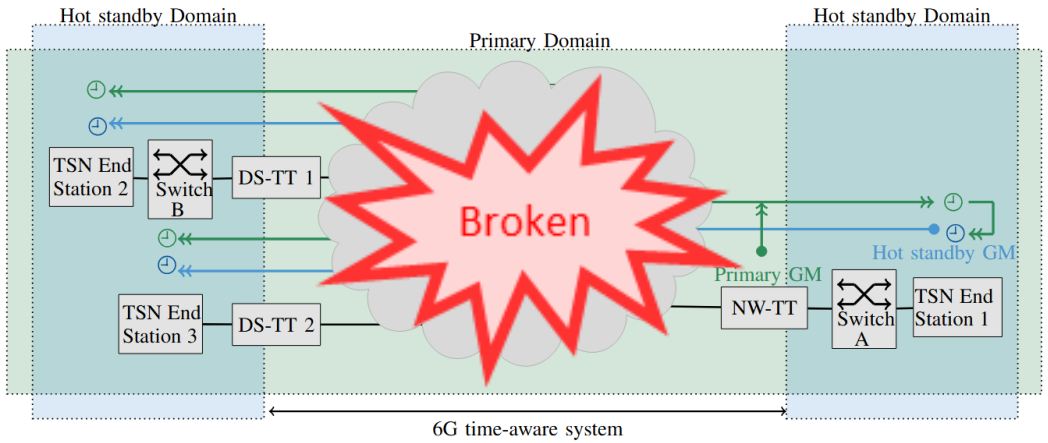


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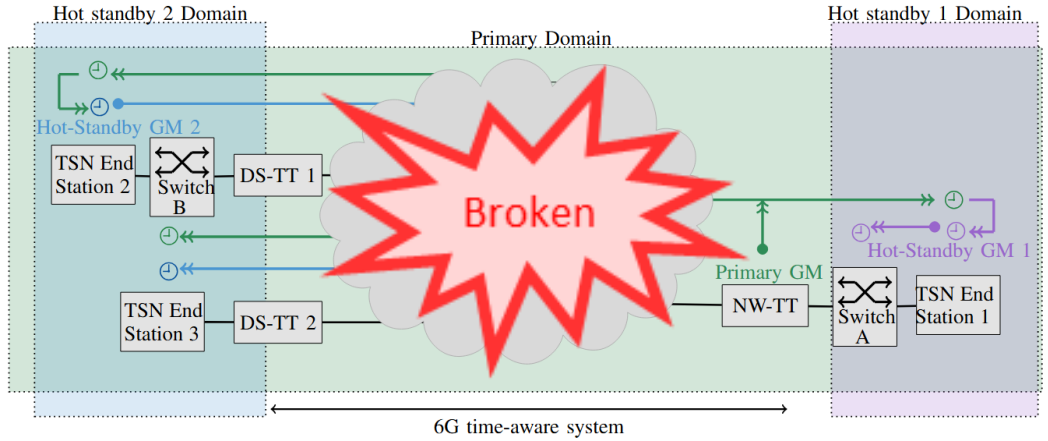


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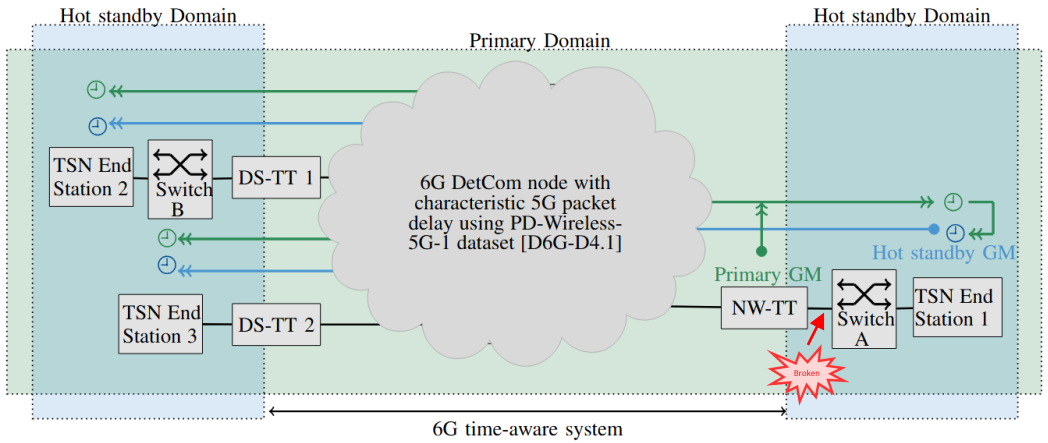


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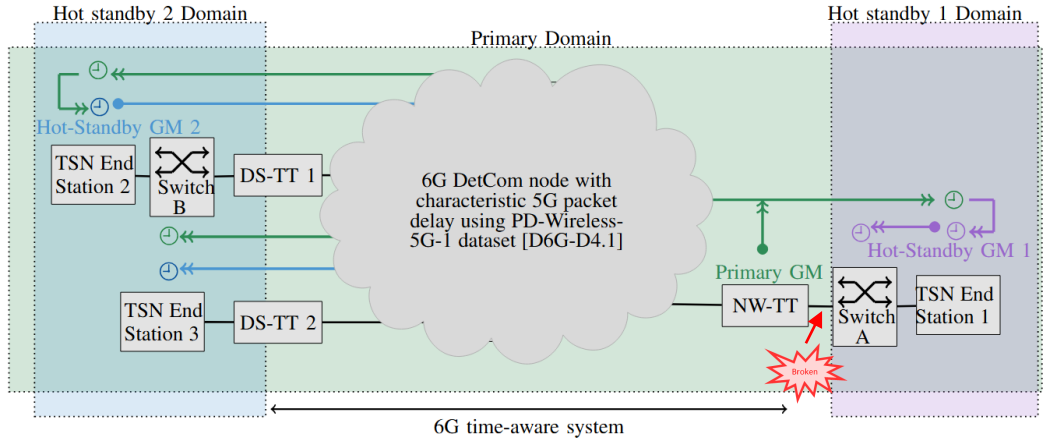
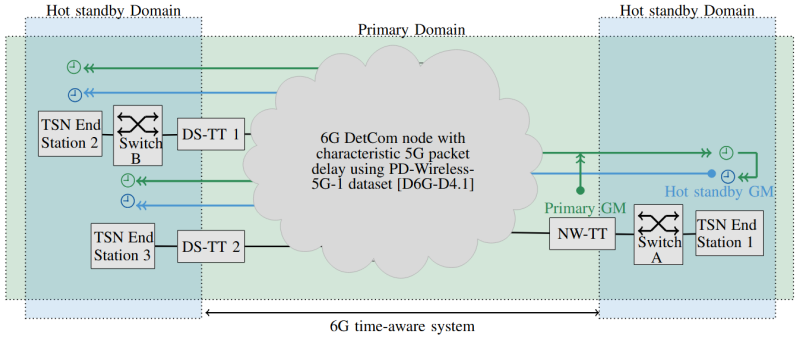
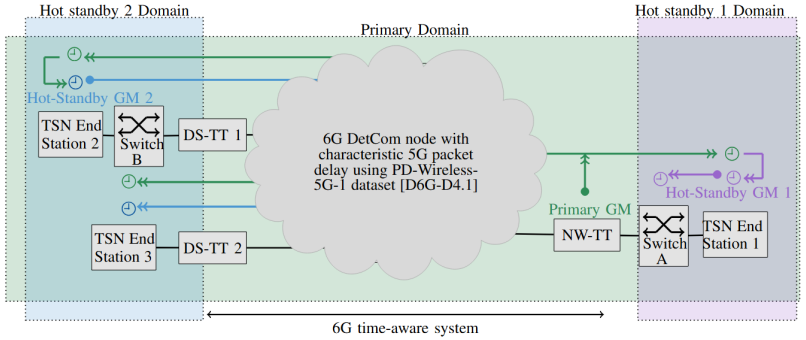



Hot standby scenario 2

Mahin Ahmed et al. “Analysis of time synchronization for 6G-TSN networks with hot standby“, IEEE ICCCN 2025

# Simulation Results: Adaptability to Failures

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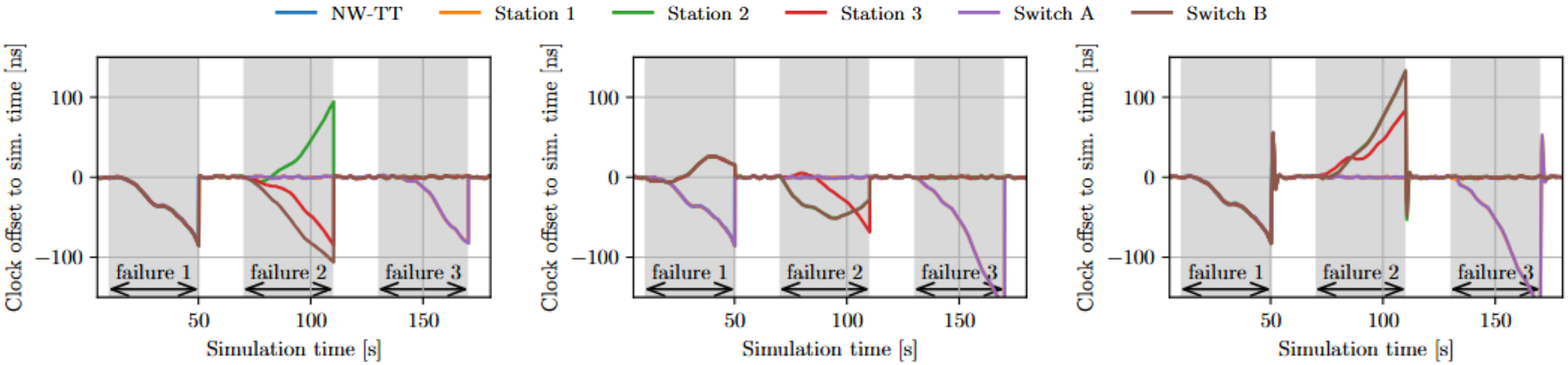


(a) Hot standby scenario 1

(b) Hot standby scenario 2

(c) BTCA scenario

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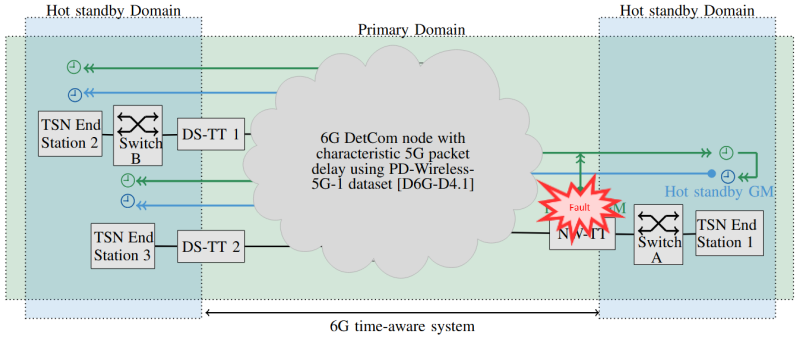


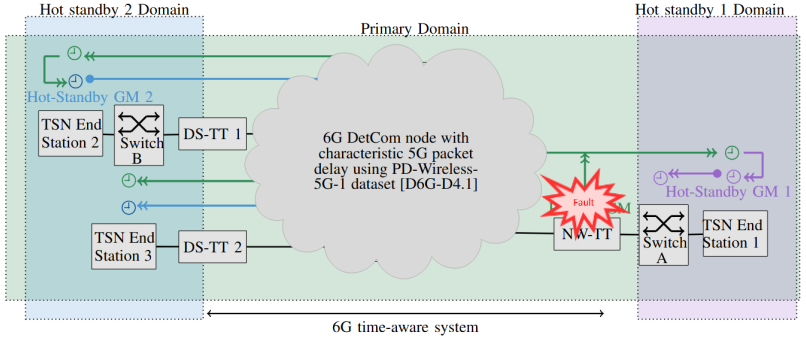


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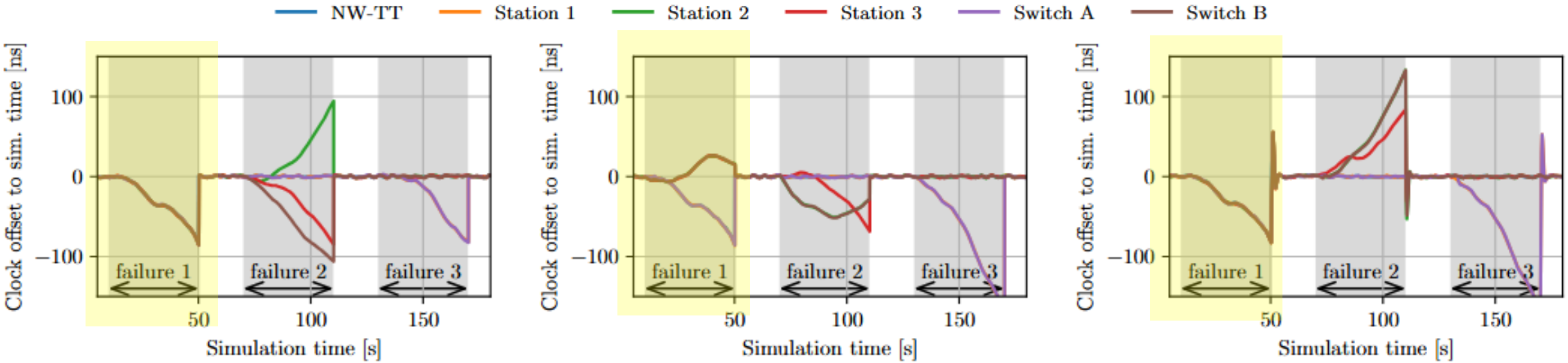


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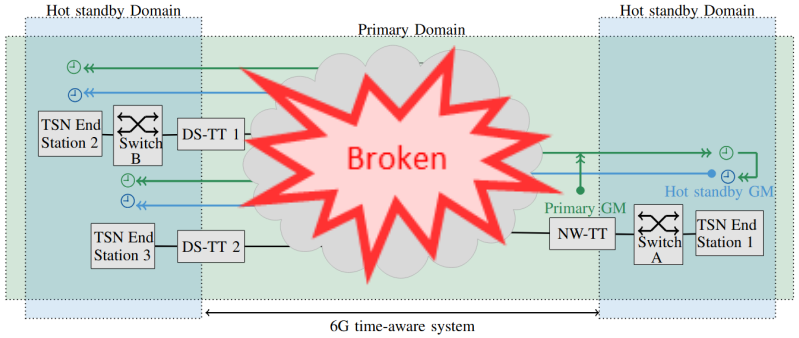


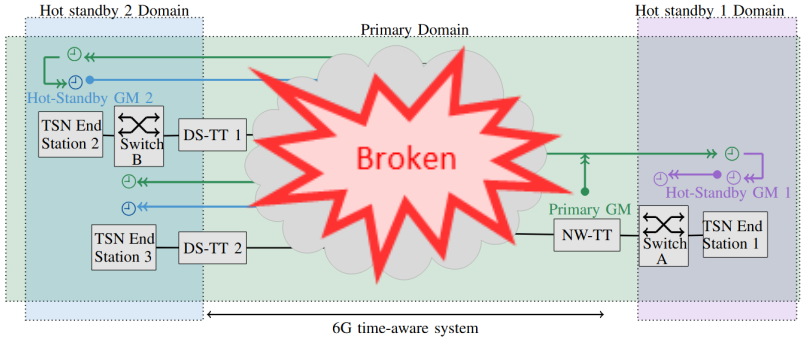


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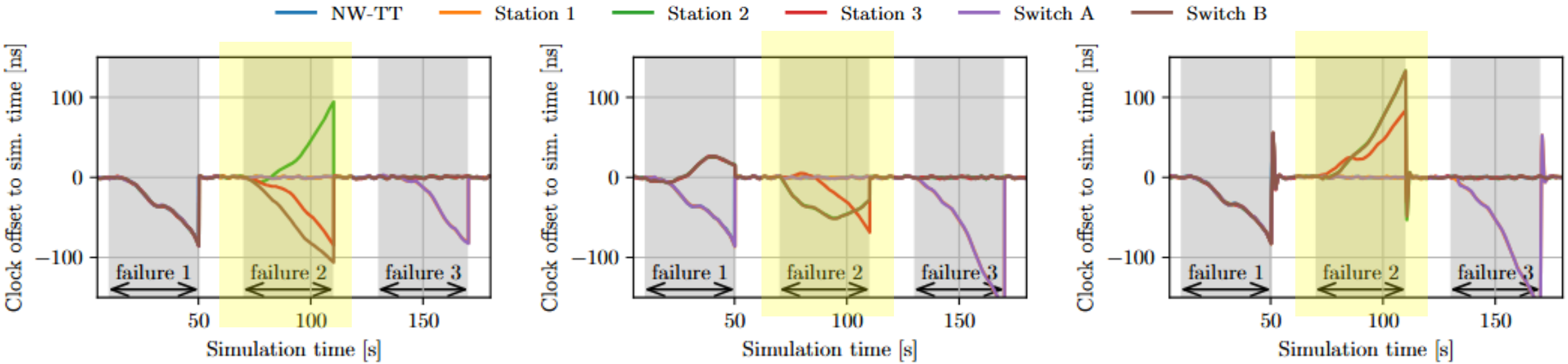


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Hot standby scenario 2

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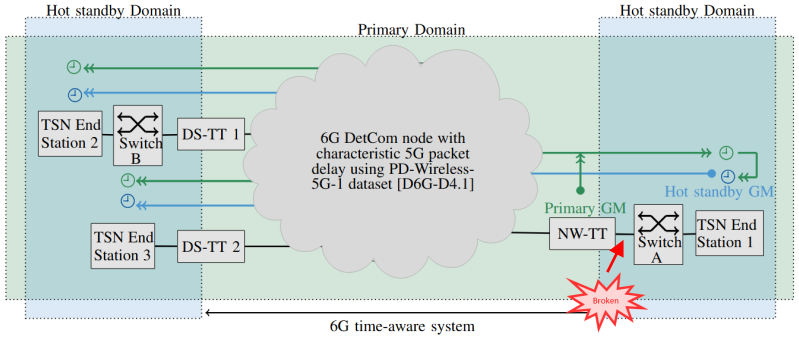


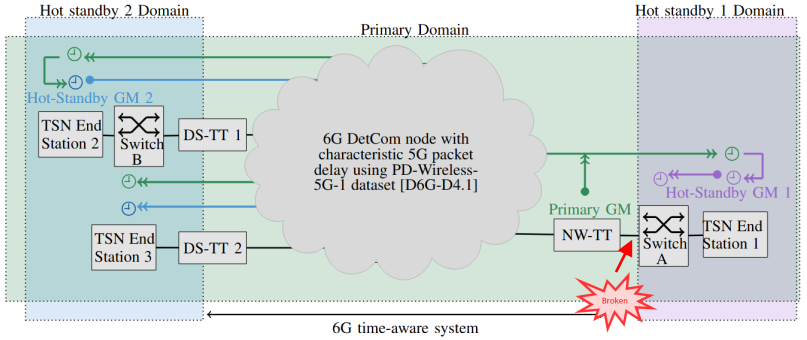


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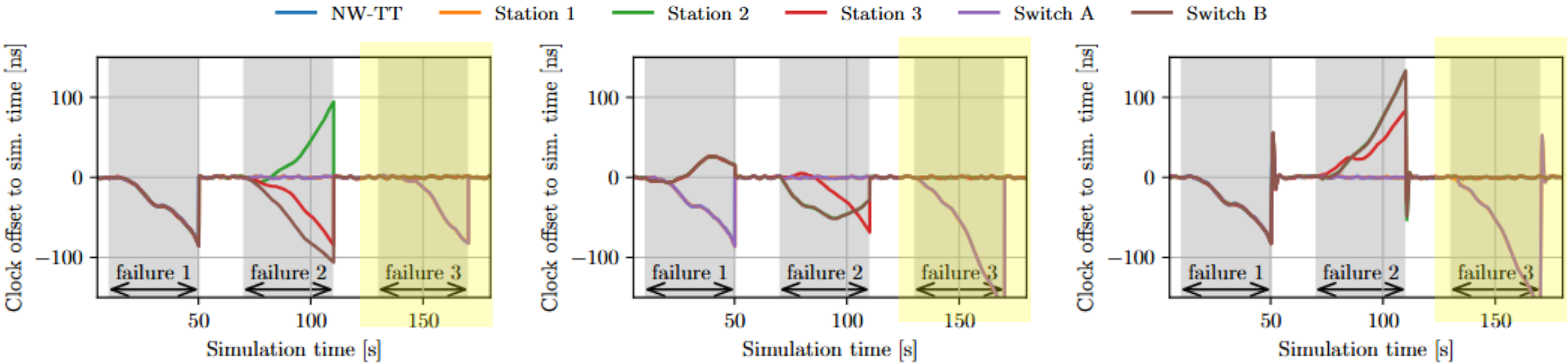


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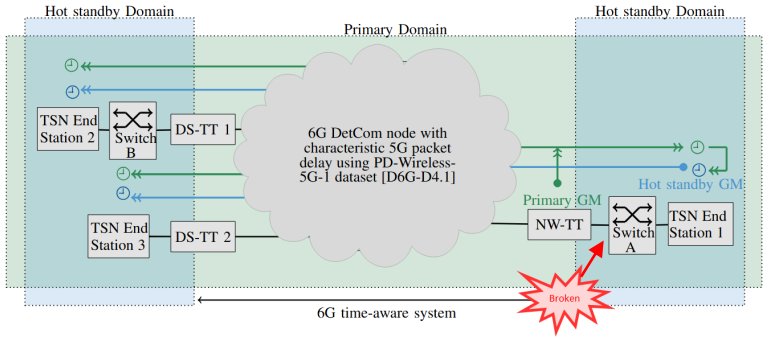
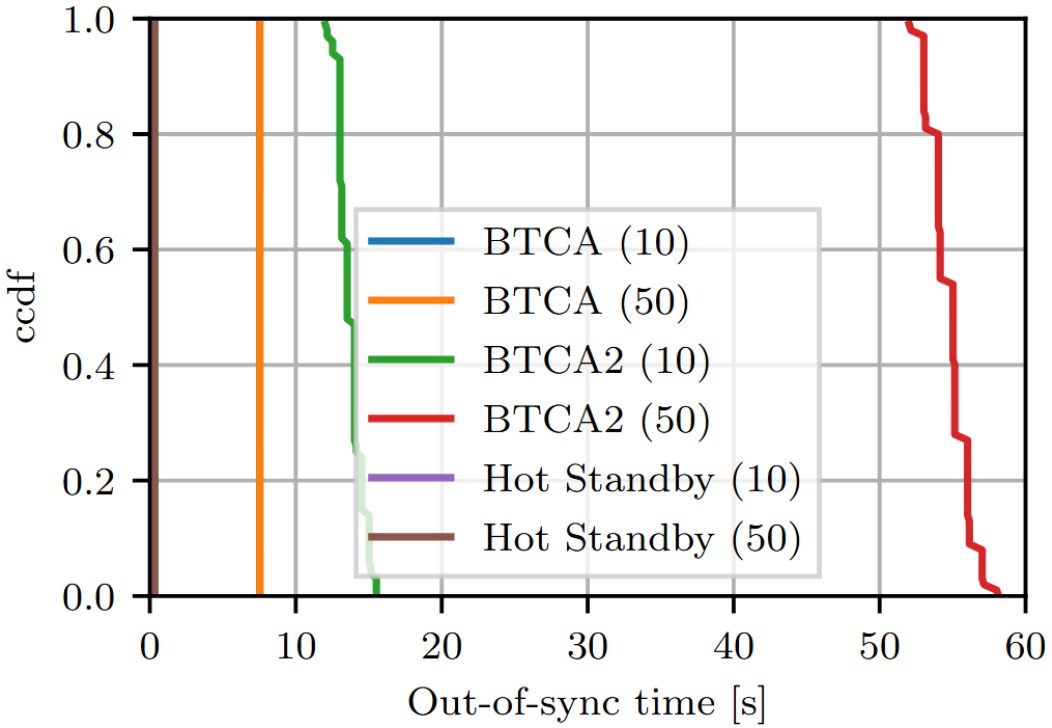
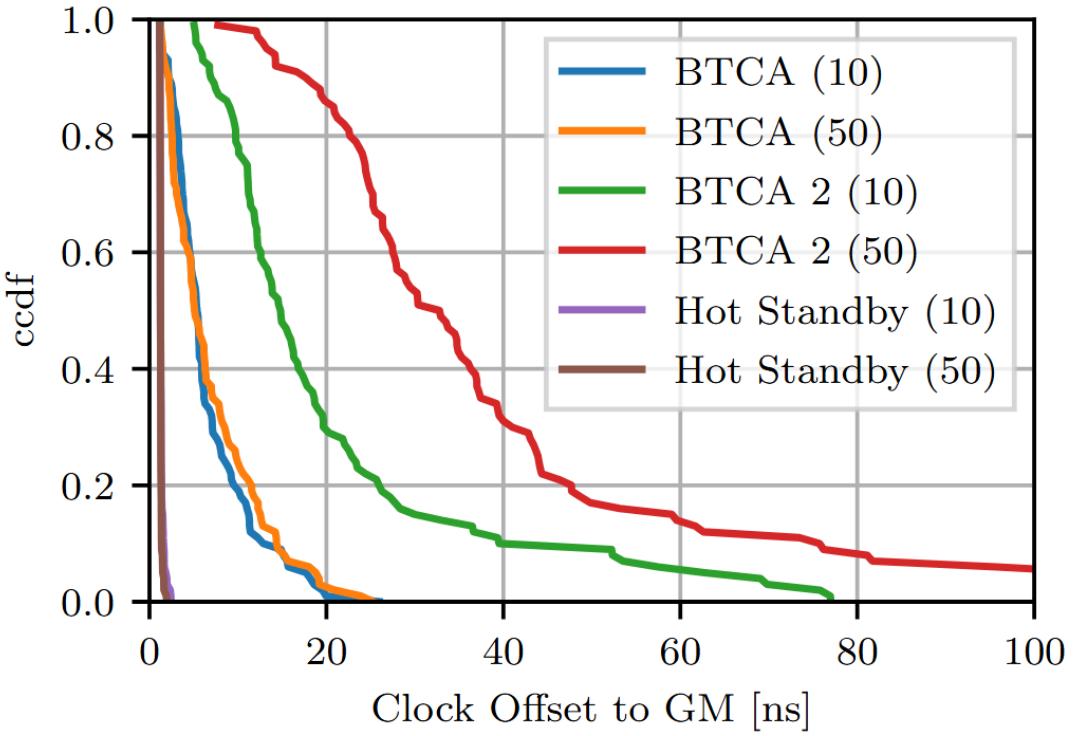
Hot standby scenario 2

# Simulation Results: Out-of-Sync Time




Hot standby scenario 1 with failure case 3 at switch A



# Conclusions

- Importance of continuous time synchronization
- Possibility of enabling hot standby GM in 6G-TSN Networks
- The decision to use a static GM configuration with hot standby or a dynamic GM configuration with BTCA should be based on the network topology and the presence of other redundancy measures, such as link redundancy.

# Important readings

- IEEE Std 1588-2019 – https://ieeexplore.ieee.org/document/4579760
- IEEE Std 802.1AS™-2020 – https://standards.ieee.org/ieee/802.1AS/7121/
- IEEE p802.1ASdm – d2.4 - https://1.ieee802.org/tsn/802-1asdm/
- 3GPP TS 23.501 “System architecture for the 5G System (5GS)”, clause 5.27.1, Annex K.2.2 https://www.3gpp.org/ftp/Specs/archive/23_series/23.501/23501-i00.zip

# DETERMINISTIC6G Grant Agreement No. 101096504

The DETERMINISTIC6G project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101096504.

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or visit: www.deterministic6g.eu

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