Time error analysis of 5G time synchronization solutions for time aware industrial networks

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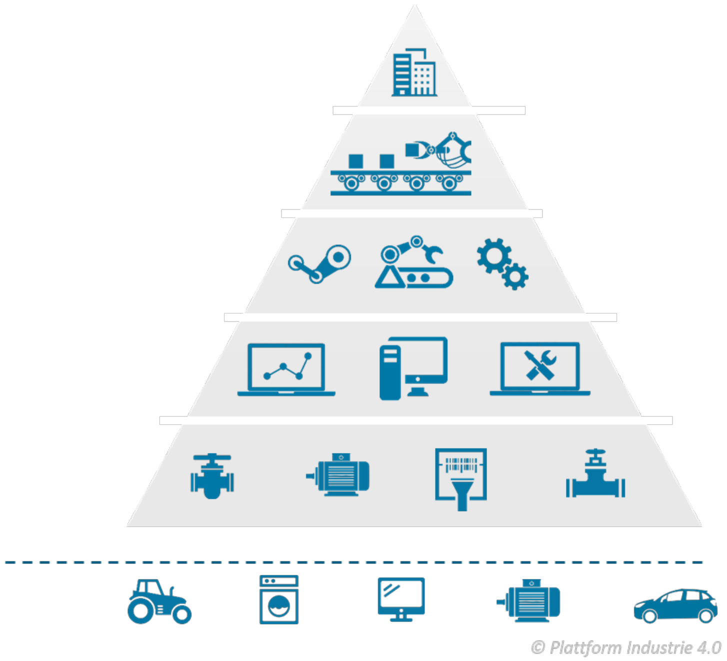
WSTS 2022

Agenda

- Introduction
- Role of 5G system to transport time synchronization packets
- Time error analysis
- Conclusion

Industry transformation

Industry 3.0



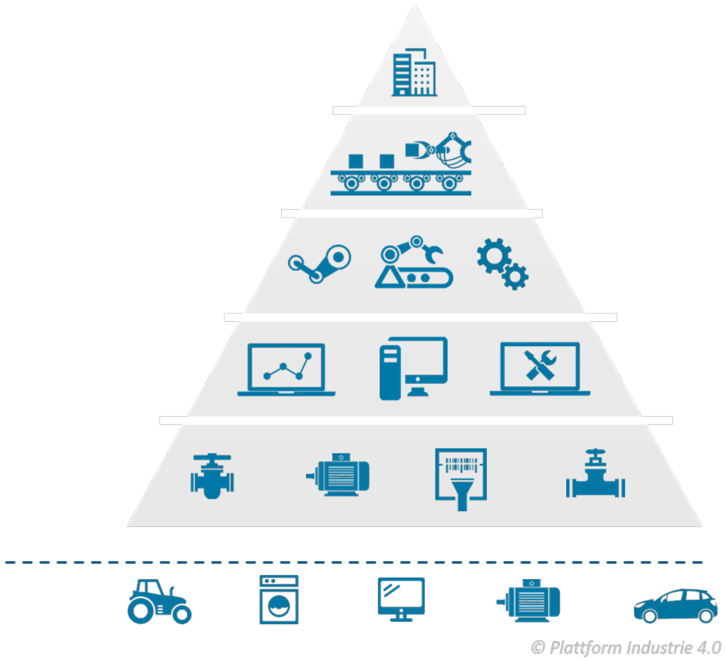
Hierarchical network design

Industry 4.0

Fully connected design

Industry transformation with 5G and Time Sensitive Networking (TSN) technology

Industry 3.0



Hierarchical network design

- Novel opportunities for Industrial IoT
  - Simplified, harmonized communication network for all services
  - Flexibility in network architecture and deployment
  - Transparency across all processes and assets always
  - Cloud computing, digital twins, AI/ML

Wired: TSN (multi-service incl. TSC)

Wireless: 5G (multi-service incl. TSC)

Industry 4.0

© Plattform Industrie 4.0

Fully connected design

TSC – time-sensitive communication

Need for time synchronization in smart manufacturing

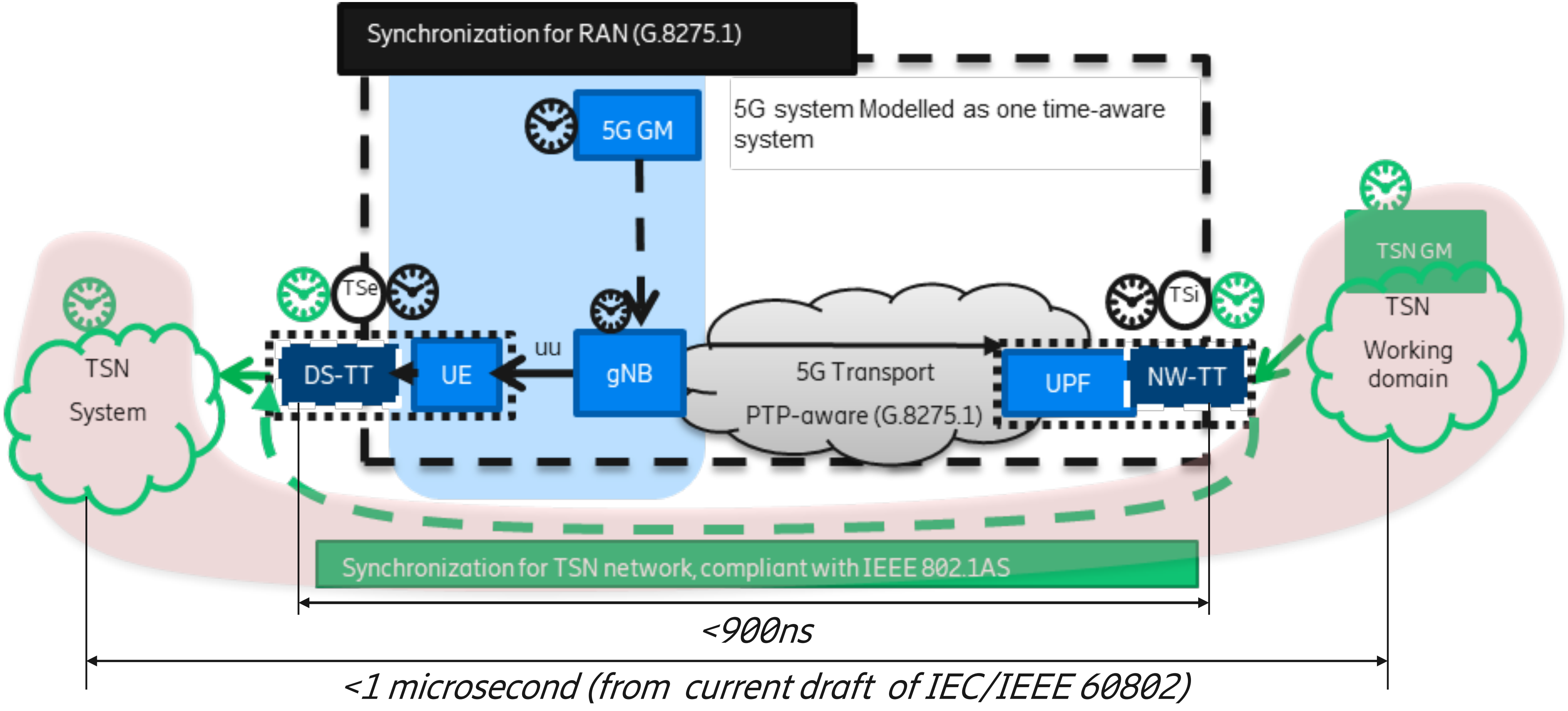
- Support for industrial control
  - Different devices need to perform coordinated tasks
  - Industrial controller coordinates different activities with regard to a common time reference

- Support industrial communication
  - TSN IEEE 802.1Qbv uses common time for all the TSN switches for time-aware scheduling

- Industrial measurements
  - Distributed measurement for joint analysis

Role of 5G system to transport time synchronization packets

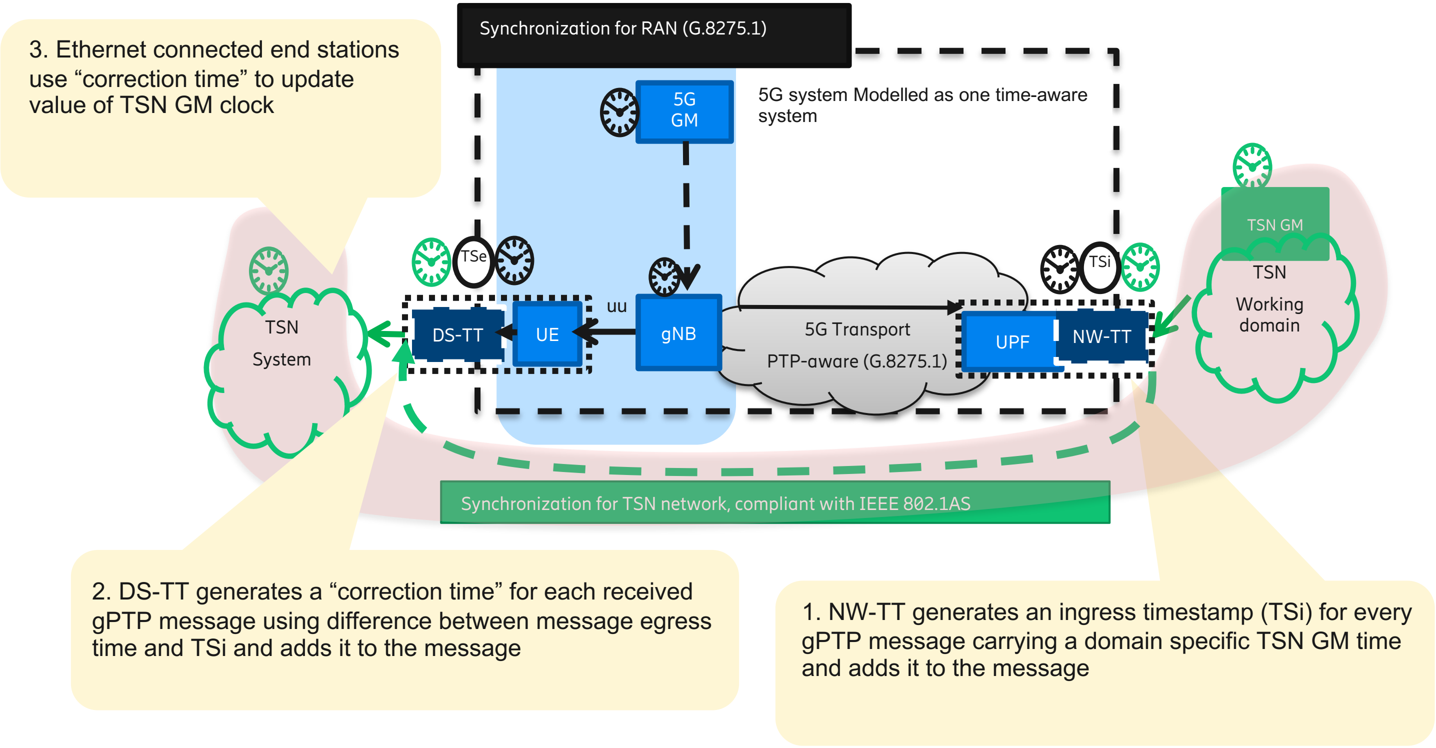
5G System can transport synchronization packets



- From SA1 working group 3GPP TS 22.104

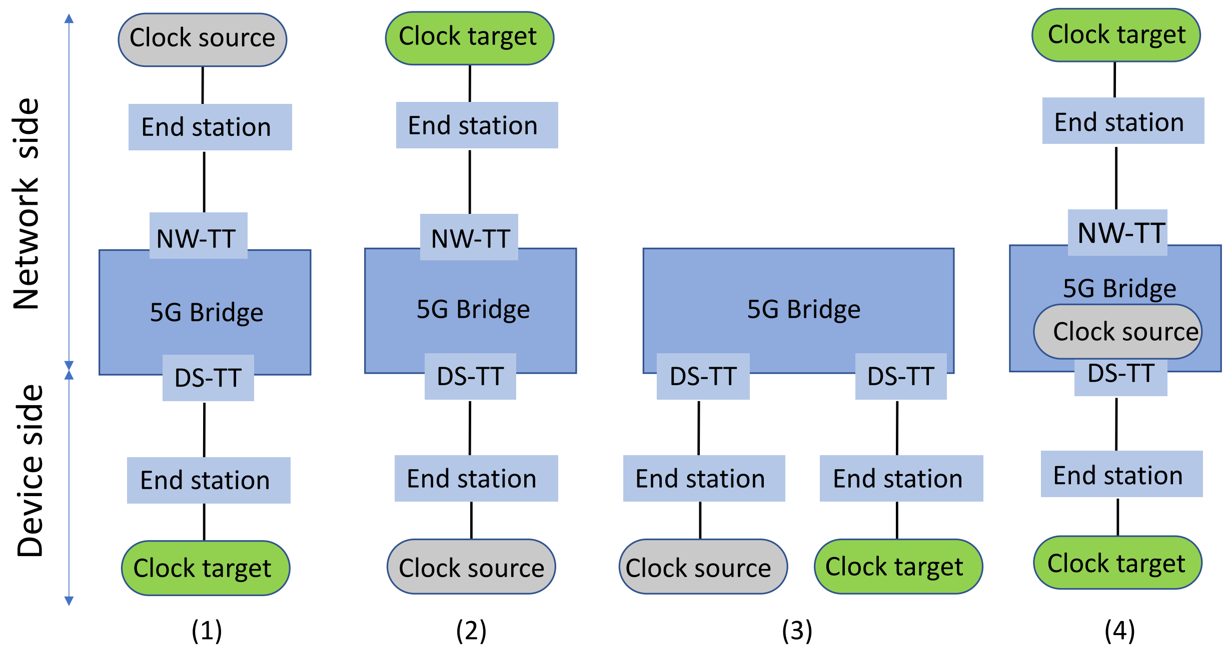
E2E time synchronization

- Two **independent synchronization processes:**
  - 5G reference time sync (for synchronizing gNB, UE, NW-TT, etc.)
  - TSN GM clock sync from the TSN GM towards TSN systems on the other end
- Timing within the 5G system typically distributed via IEEE1588 telecom profile (G.8275.1) over the 5G transport
- TSN sync., using IEEE 802.1AS gPTP via TSN transport (and across the 5GS user plane)
- 5GS acts as IEEE 802.1AS time-aware bridge
  - compliant with 1588 Boundary Clock (e.g., implements the BMCA)



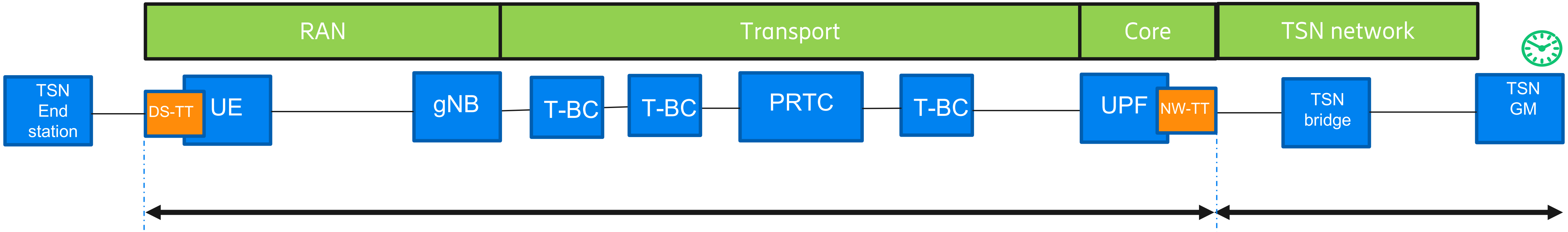
Time synchronization solutions from 5G

- For options 1, 2 and 3 in figure, internal 5G user plane nodes are synchronized to ensure precise calculation of the 5G System residence time
- For option 4, the 5G bridge acts as the clock source for the connected clock targets



Time error analysis

E2E Time synchronization chain
Typical smart manufacturing scenario (option- 1)



Time error budget $(Time\ error\ (transport) + Time\ error\ (RAN)\ ) \leq 900$ns

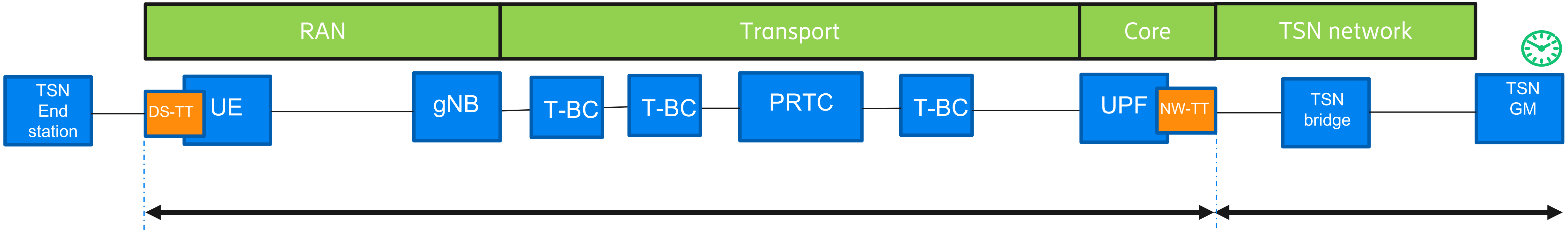
- For precise residence time calculation, time error between DS-TT and NW-TT should be below 900ns (now specified by 3GPP)
- Two main paths to consider
  - PRTC → UE/DS-TT (via gNB)
  - PRTC → NW-TT
- Recent exchange of liaisons between ITU-T and 3GPP (**TD 7/WP3**)

PRTC : primary reference time clock (5G GM)

T-BC : Telecom Boundary clock

gNB : End application clock

E2E Time synchronization chain
Typical smart manufacturing (option -1)



Time error budget ($Time\ error\ (transport) + Time\ error\ (RAN)$) ≤ 900ns

Time Error over RAN

- UE/DS-TT TE (e.g., 50/100 ns)
- TE during transmission of the 5G reference time (e.g., 275 ns)
- TE introduced due to accuracy of estimating propagation delay (e.g., 5 ns)

Time Error over Core/Transport network

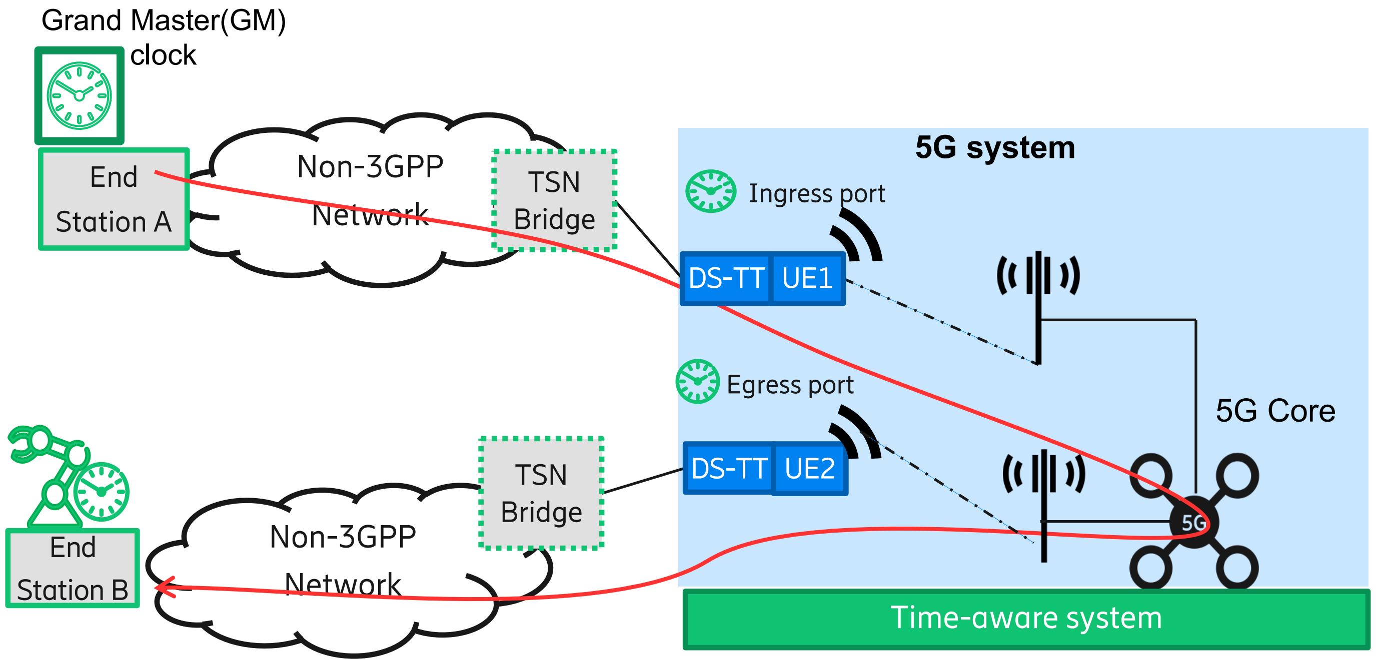
$$TE\ (transport) = Err_{T\_BC} + ErrFibre + Err_{gNB}$$

- Depends upon the class of the T-BC (class A, B, C) and number n of cascaded clocks ($n \times Err_{T\_BC}$)
- Additional Error due to gNB (Err_{gNB})
- Error from the fibers ($ErrFibre$)
- Network model defined in G.8271.1

- Worst total **RAN** time error is estimated around **380ns**
- This gives time error budget of **520** ns to core/transport network

- Note: above numbers are example of estimations and are not standardized

E2E time synchronization
Typical smart manufacturing scenario (option-3)



- TSN GM behind UE:
  - Two radio links in E2E time synchronization chain
  - RAN time error budget (twice as option 1) : **760ns**
  - Transport budget : **240ns**

- Note: above numbers are example of estimations and are not standardized

Conclusion

- Today 5G supports several options to realize time synchronization within TSN based industrial network
- New use cases emerge addressing time sync resiliency
- Time reference delivery over radio access network (RAN) is key component for E2E time sync solution
- The important factor in E2E time error budgeting is the uncertainty associated with estimating propagation delay between UE and gNB
- Time error analysis shows that 5G system is generally capable of meeting time error budget per 3GPP requirements

In collaboration with

The 5G-SMART project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857008.

Project website