5G/5G-Advanced System for Supporting Deterministic Networking and Time-Sensitive Networks
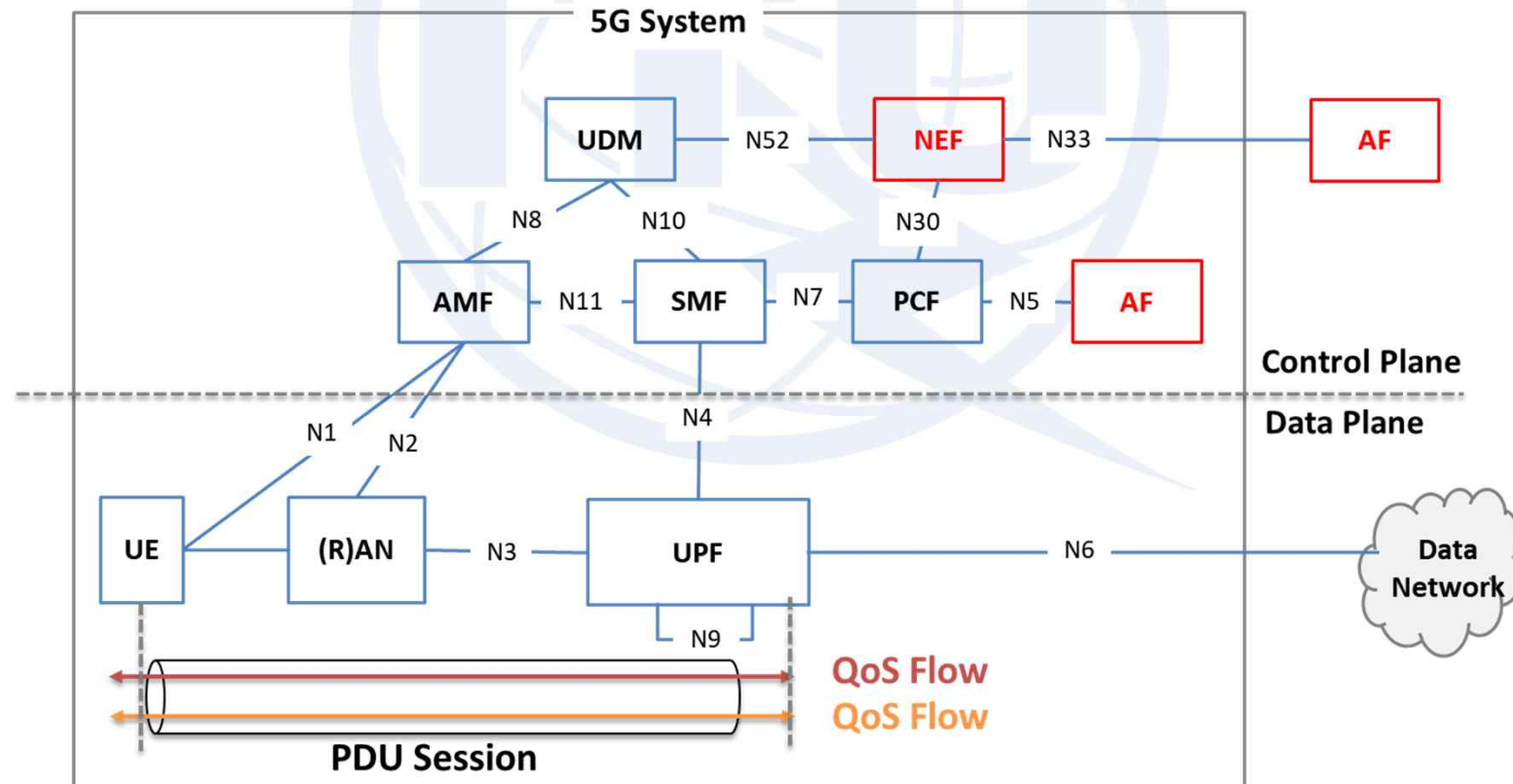
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5G System Overview

- **The 5G System architecture**
  - Separate the User Plane (UP) functions from the Control Plane (CP) functions
  - Support data connectivity and services

[3GPP TS 23.501]

Extension of the 5G System for Deterministic Networking and Time-Sensitive Networks

- **Rel 16 (5G System)**
  - Integrated with Time-Sensitive Networks
    - TSN-AF, Time sensitive translator (i.e., DS-TT, NW-TT)
    - Time Synchronization

- **Rel 17 (5G System)**
  - Extended and enhanced Feature for Time-Sensitive Communication (TSC)
    - Time-Sensitive Communication and Time Synchronization Function (TSCTSF)
    - TSCAI and Hold & Forward buffering mechanism
    - Uplink Time Synchronization (From UE to NW-TT)

- **Rel 18 (5G-Advanced System, ~ Current)**
  - 5GS Architecture to support IETF Deterministic Networking
 - TSN enabled Transport Network

5G System for Deterministic Networking and Time-Sensitive Networks

- **The 5G System can be extended to support the following:**
  - Integration of 5GS into a TSN data network (DN)
    - Integration as a bridge in an IEEE 802.1 Time Sensitive Networking (TSN). The 5GS bridge supports the Time sensitive communication as defined in IEEE 802.1 TSN standards.
  - Enablers for AF requested support of Time Synchronization and/or some aspects of Time Sensitive Communication.
  - Support for TSN enabled transport network (TN)
    - Enablers for interworking with TSN network deployed in the transport network. The interworking is applicable when the transport network deploys the fully centralized configuration model as defined in IEEE Std 802.1Qcc. In this scenario, a TSN TN is deployed to realize the N3 interface between (R)AN and UPF. From the perspective of the TSN TN, (R)AN and UPF act as End Stations of the TSN TN.
 - Integration as a router in a Deterministic Network as defined in IETF RFC 8655.

3GPP 5G Time Sensitive Networking

- **TSN Translator (TT) functionality for interoperation between TSN System and 5G System**
  - User plane: Device-side TSN Translator (DS-TT) & Network-side TSN Translator (NW-TT)
  - Control plane: TSN Application Function (TSN AF)
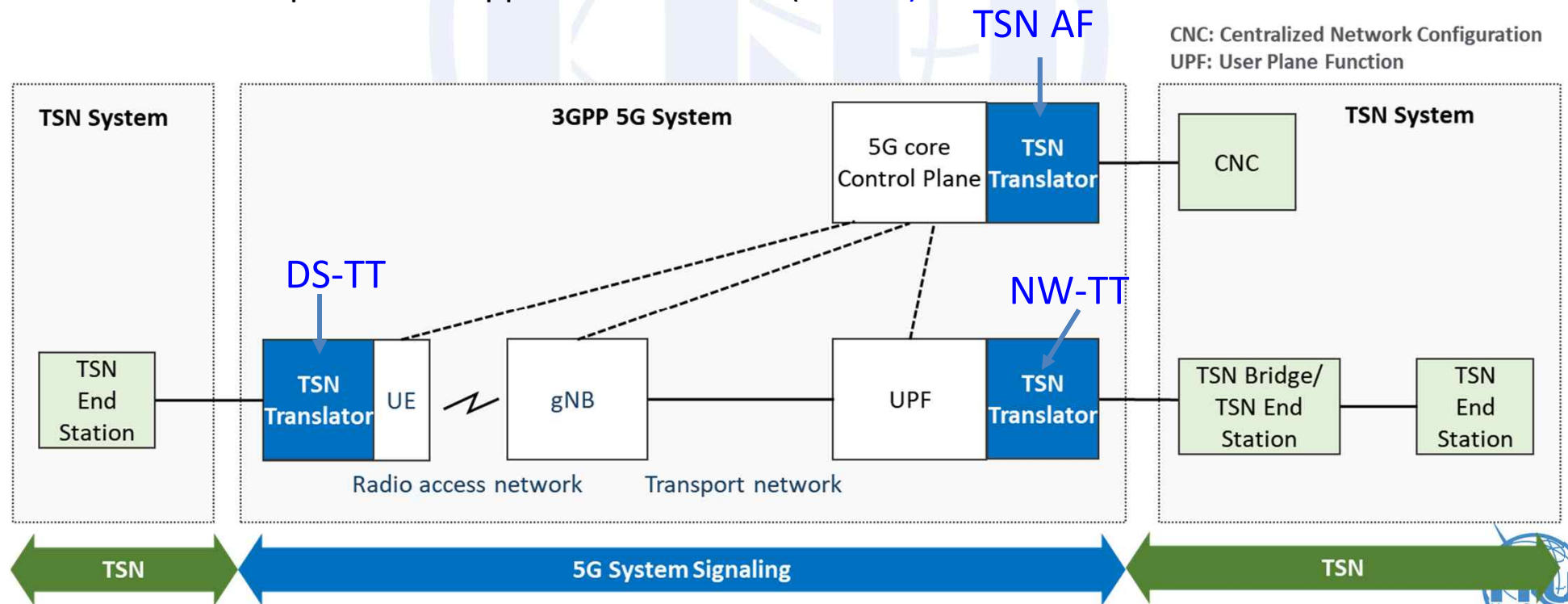
Architecture to support IEEE Time Sensitive Networking

- **The 5G System is integrated with the external network as a TSN bridge** (Rel.16)
  - This "logical" TSN bridge includes TSN Translator functionality for interoperation between TSN Systems and 5G System
    - 5GS TSN translator functionality consists of **Device-side TSN translator (DS-TT)** and **Network-side TSN translator (NW-TT)**
    - **The TSN AF** is part of 5GC and provides the control plane translator functionality for the integration of the 5GS with a TSN network, e.g. the interactions with the CNC
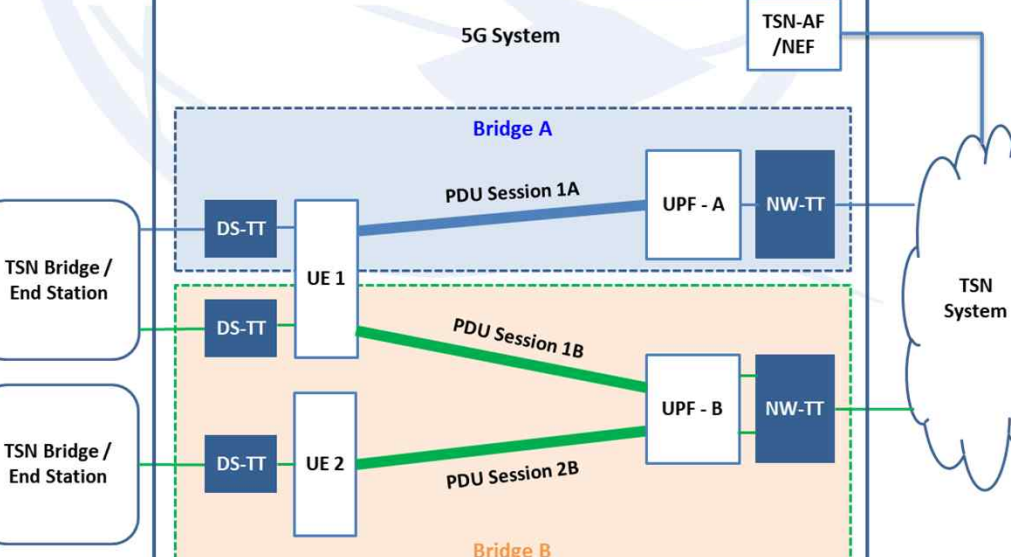

[3GPP TS 23.501]

5GS bridge for TSN DN
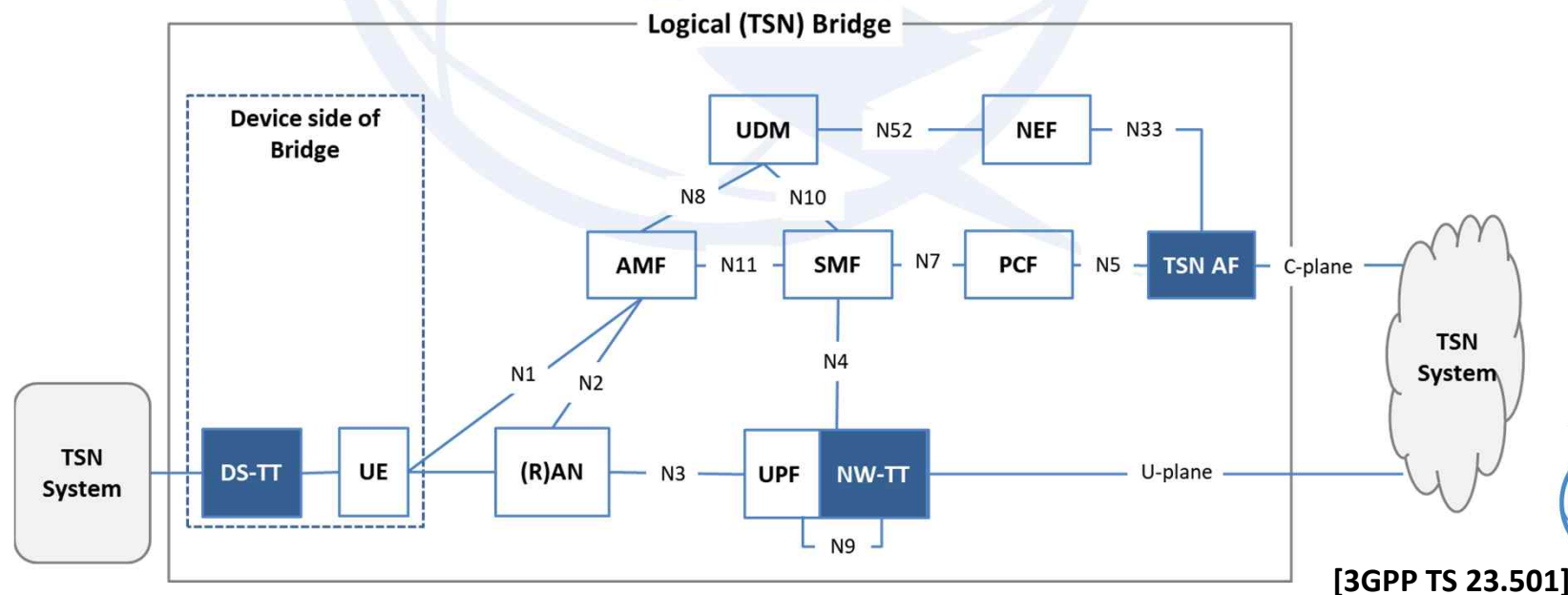
- **5GS acts as a Layer 2 Ethernet Bridge**
  - The 5GS Bridge is composed of the ports on a single UPF (i.e. PSA) side, the user plane tunnel between the UE and UPF, and the ports on the DS-TT side
    - The port on NW-TT support the connectivity to the TSN network, the ports on DS-TT side are associated to the PDU Session providing connectivity to the TSN network

Per UPF based 5GS bridge

[3GPP TS 23.501]

Architecture to support Time Sensitive Communication and Time Synchronization services

- **Support TSCTS service requested by AF (Rel.17 ~)**
  - TSCSTF controls the DS-TT(s) and NW-TT for the time synchronization service and supporting time sensitive communication
  - The NEF exposes 5GS capability related on time synchronization
  - Support Time Synchronization service **Ethernet or IP type PDU Sessions**
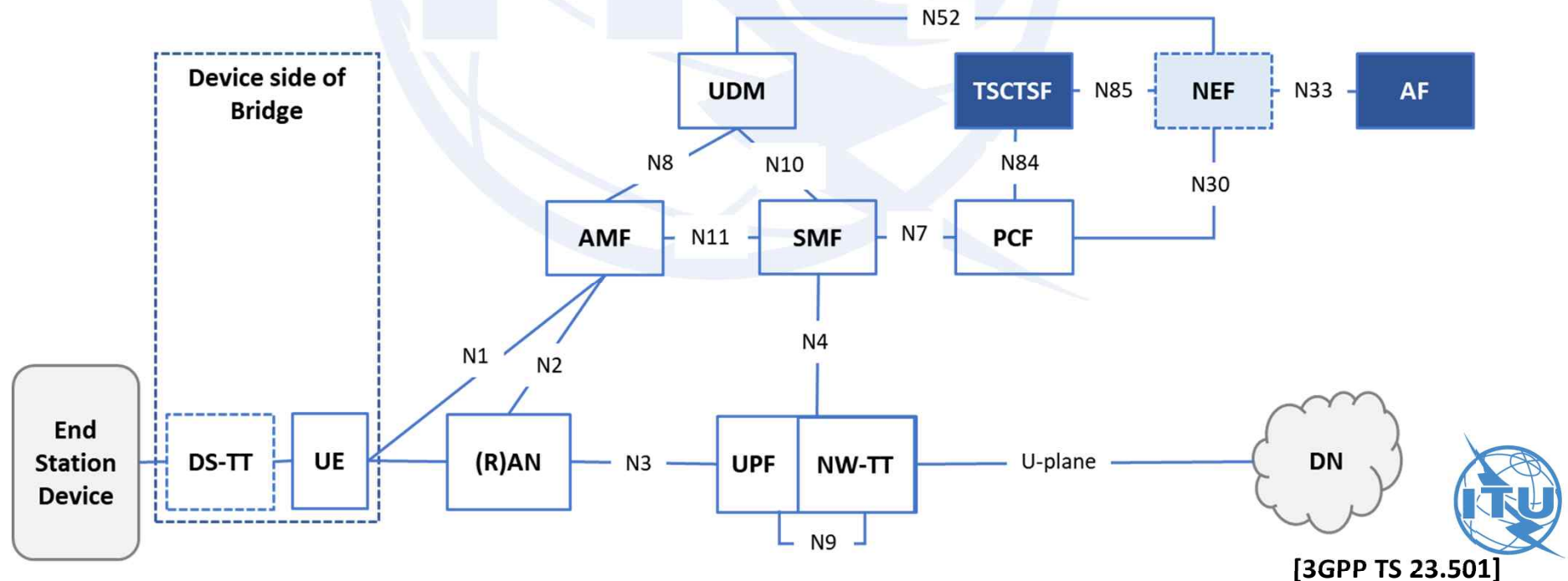
[3GPP TS 23.501]

Periodic deterministic communication

- **5GS Features to enable time sensitive networking, time-sensitive communication, time synchronization and deterministic networking**
  - Delay-critical GBR
  - A hold and forward mechanism to schedule traffic as defined in IEEE Std 802.1Q-2018 for Ethernet PDU Sessions in DS-TT and NW-TT to de-jitter flows that have traversed the 5G System if the 5G System is to participate transparently as a bridge in a TSN network
  - TSC Assistance Information: describes TSC flow traffic characteristics that may be provided optionally for use by the gNB, to allow more efficiently schedule radio resources for periodic traffic and applies to PDU Session type Ethernet and IP
  - Time Synchronization: describes how 5GS can operate as a PTP Relay (IEEE Std 802.1AS), as a Boundary Clock or as Transparent Clock (IEEE Std 1588) for PDU Session type Ethernet and IP and how 5GS can detect and report the status of the time synchronization.
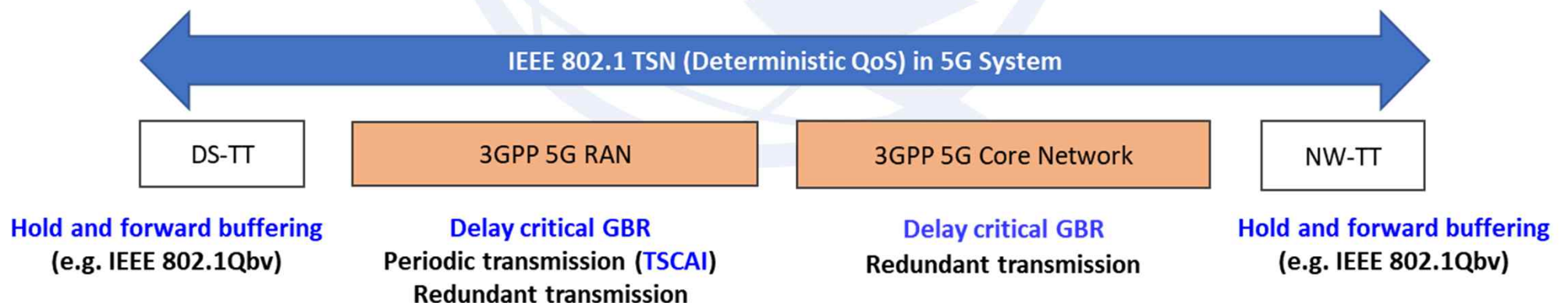
Periodic deterministic communication

- **5GS Features to enable time sensitive networking, time-sensitive communication, time synchronization and deterministic networking**
  - Delay-critical GBR
  - A hold and forward mechanism
  - TSC Assistance Information
  - Time Synchronization

IEEE 802.1 TSN (Deterministic QoS) in 5G System

| DS-TT | 3GPP 5G RAN | 3GPP 5G Core Network | NW-TT |

Hold and forward buffering
(e.g. IEEE 802.1Qbv)

Delay critical GBR
Periodic transmission (TSCAI)
Redundant transmission

Delay critical GBR
Redundant transmission

Hold and forward buffering
(e.g. IEEE 802.1Qbv)

TSC Assistance Information

- **TSC assistance information**
  - describes TSC traffic characteristics for use in the 5G System. The knowledge of TSN traffic pattern is useful for the gNB to allow it to more efficiently schedule periodic, deterministic traffic flows either via Configured Grants, Semi-Persistent Scheduling or with dynamic grants.

Assistance Information	Description
Flow Direction	The direction of the TSC flow (uplink or downlink).
Periodicity	It refers to the time period between start of two data bursts.
Burst Arrival time	The latest possible time when the first packet of the data burst arrives at either the ingress of the RAN (downlink flow direction) or the egress of the UE (uplink flow direction).
Survival Time	Survival Time, as defined in TS 22.261, refers to the time period an application can survive without any data burst
Burst Arrival Time Window	Indicates the acceptable earliest and latest arrival time of the first packet of the data burst at either the ingress of the RAN (downlink flow direction) or the egress of the UE (uplink flow direction).
Capability for BAT adaptation	Indicates that the AF will adjust the burst sending time according to the network provided Burst Arrival Time offset.
N6 Jitter Information	Jitter information associated with the Periodicity in downlink.
Periodicity Range	It indicates that the AF will adjust the periodicity and provides the acceptable range, formulated as lower bound and upper bound of the Periodicity.

TSC Assistance Information [3GPP TS 23.501]

TSC Assistance Container

- **TSC Assistance Container**
    - The TSCTSF determines the TSC Assistance Container based on information provided by an AF/NEF or a DetNet controller, or the TSN AF determines TSC Assistance Container
    - The PCF receives the TSC Assistance Container from the TSCTSF or the TSN AF and forwards it to the SMF and SMF uses the TSC Assistance Container to derive the TSCAI
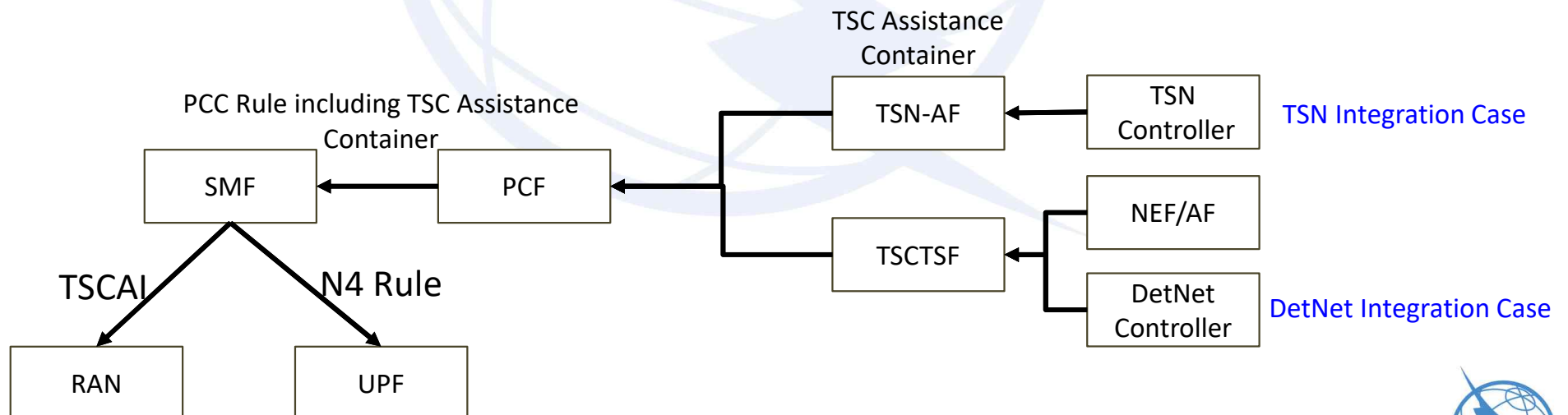
Time Synchronization

- **5G Clock synchronization and the (g)PTP domain synchronization**

    - **5G Access Stratum-based Time Distribution**: Used for NG RAN synchronization and also distributed to the UE. The 5G Access Stratum-based Time Distribution over the radio interface towards the UE is specified in TS 38.331. This method may be used to either further distribute the 5G timing to devices connected to a UE (using implementation-specific means) or to support the operation of the (g)PTP-based time distribution method.

    - **(g)PTP-based Time Distribution**: Provides timing among entities in a (g)PTP domain. This process follows the applicable profiles of IEEE Std 802.1AS or IEEE Std 1588. This method relies on the 5G access stratum-based time distribution method to synchronize the UE/DS-TT and on the 5GS time synchronization to synchronize the gNB (which, in turn, may synchronize the DS-TT) and the NW-TT.

Time Synchronization

- **For supporting time synchronization service, the 5GS is configured to operate in one or multiple PTP instances and to operate in one of the following modes (if supported) for each PTP instance:**

  a. as time-aware system as described in IEEE Std 802.1AS,

  b. as Boundary Clock as described in IEEE Std 1588, provisioned by the profiles supported by this 3GPP specification including SMPTE Profile for Use of IEEE Std 1588 Precision Time Protocol in Professional Broadcast Applications ST 2059-2:2015;

  c. as peer-to-peer Transparent Clock as described in IEEE Std 1588, provisioned by the profiles supported by this 3GPP specification including SMPTE Profile for Use of IEEE Std 1588 Precision Time Protocol in Professional Broadcast Applications ST 2059-2:2015; or

  d. as end-to-end Transparent Clock as described in IEEE Std 1588.
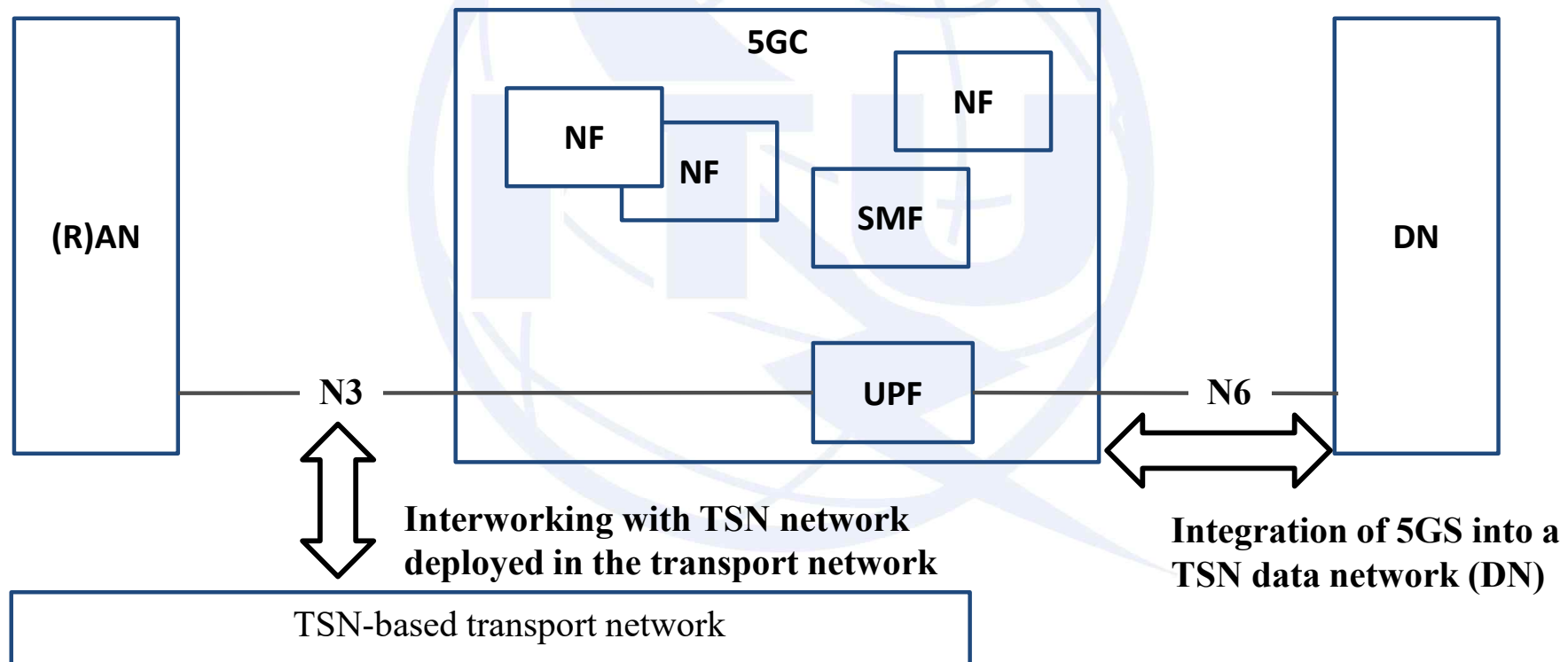
5GS as PTP instance for supporting time synchronization
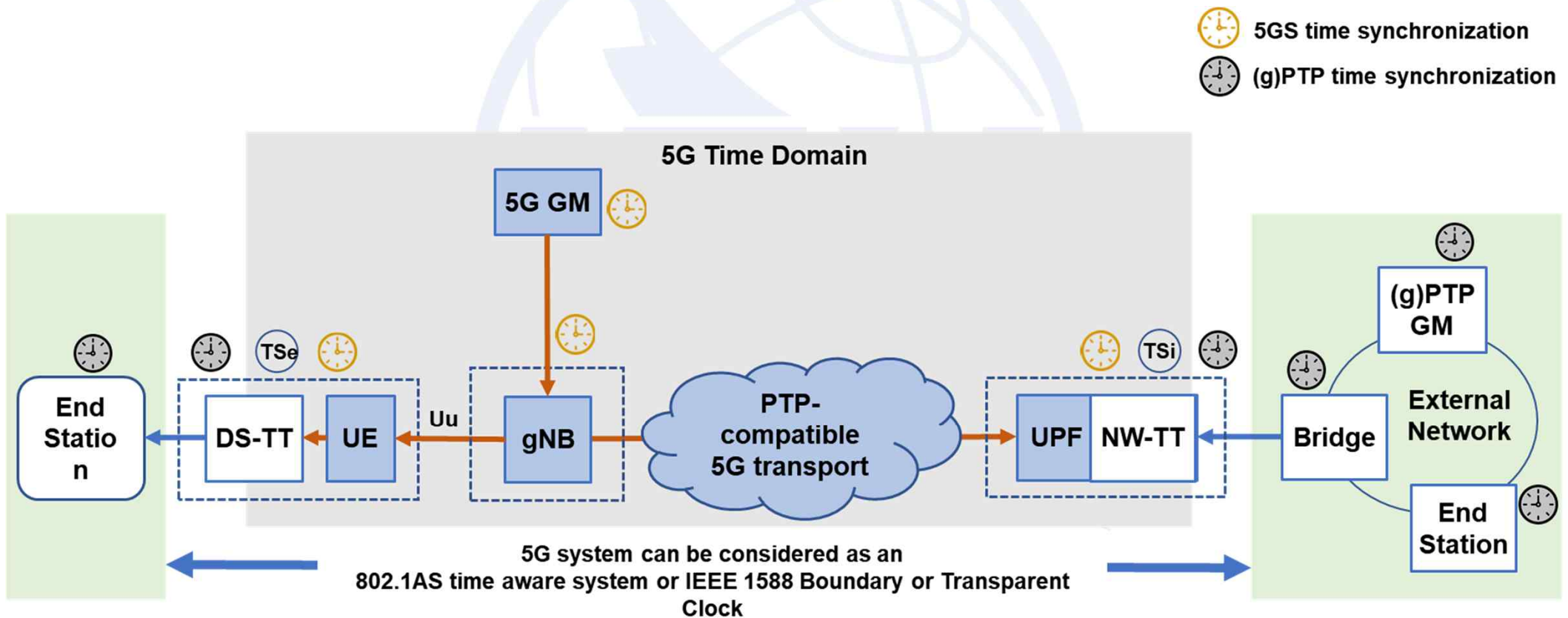
[3GPP TS 23.501]

TSN enabled Transport Network (Rel.18~)

TSN data network (DN): 5GS is deployed in a TSN DN to provide wireless connectivity. From the perspective of the TSN DN, the 5GS is modelled as a Layer 2 Ethernet Bridge of the TSN DN.

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(R)AN                    5GC                              DN

                  NF          NF
                      NF
                           SMF


N3 ────────────────── UPF ──────── N6
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Interworking with TSN network deployed in the transport network

Integration of 5GS into a TSN data network (DN)

TSN-based transport network

TSN enabled transport network (TN): a TSN TN is deployed to realize the N3 interface between (R)AN and UPF. From the perspective of the TSN TN, (R)AN and UPF act as End Stations of the TSN TN.

Interworking with TSN network deployed in the transport network

- **The CUC collocated with SMF interworks with the CNC in the transport network (TN CNC)**
  - The SMF/CUC provides the stream requirements on QoS Flow basis to the TN CNC
  - The TN CNC uses the stream requirements as input to configure respective path(s) and schedules in TN
  - The SMF/CUC can communicate with the AN-TL and CN-TL to configure the TSN-enabled Transport Network (N3)
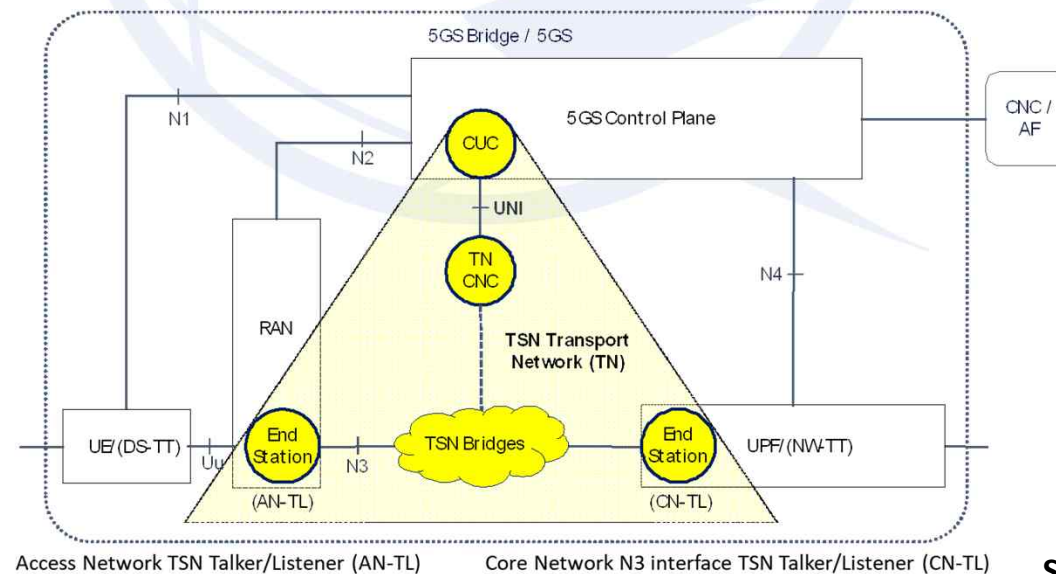
5GS Architecture to support IETF Deterministic Networking (Rel.18~)

- **The 5G System is integrated with the Deterministic Network as defined in IETF RFC 8655 as a logical DetNet transit router.**
  - The TSCTSF performs mapping in the control plane between the 5GS internal functions and the DetNet controller.
  - DetNet may be used in combination with time synchronization mechanisms.
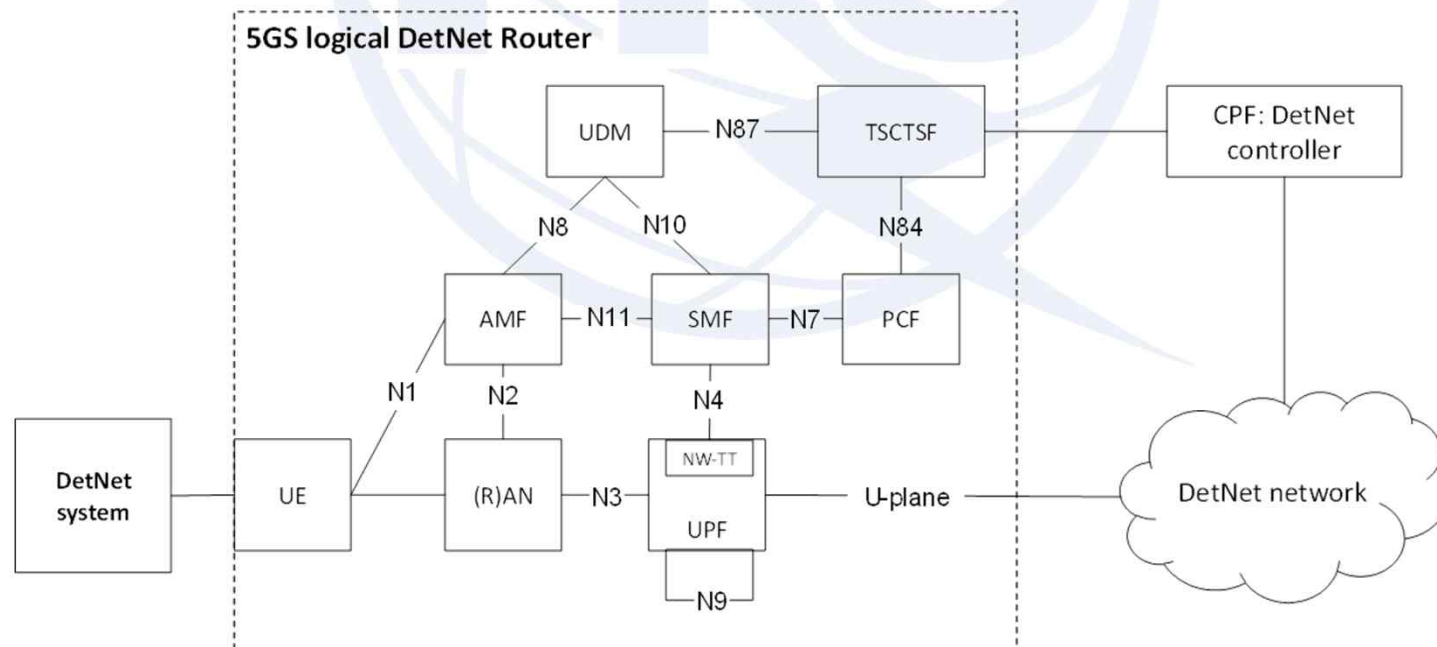
5GS bridge for DetNet Router

- **5GS acts as one or more DetNet routers**
  - A 5GS router is composed of the ports on a single UPF (i.e. PSA) network side, the user plane tunnel between the UE and UPF, and the ports on the device side
    - The ports on the network side and the ports on the device side that are associated with the PDU Sessions support connectivity to the deterministic network
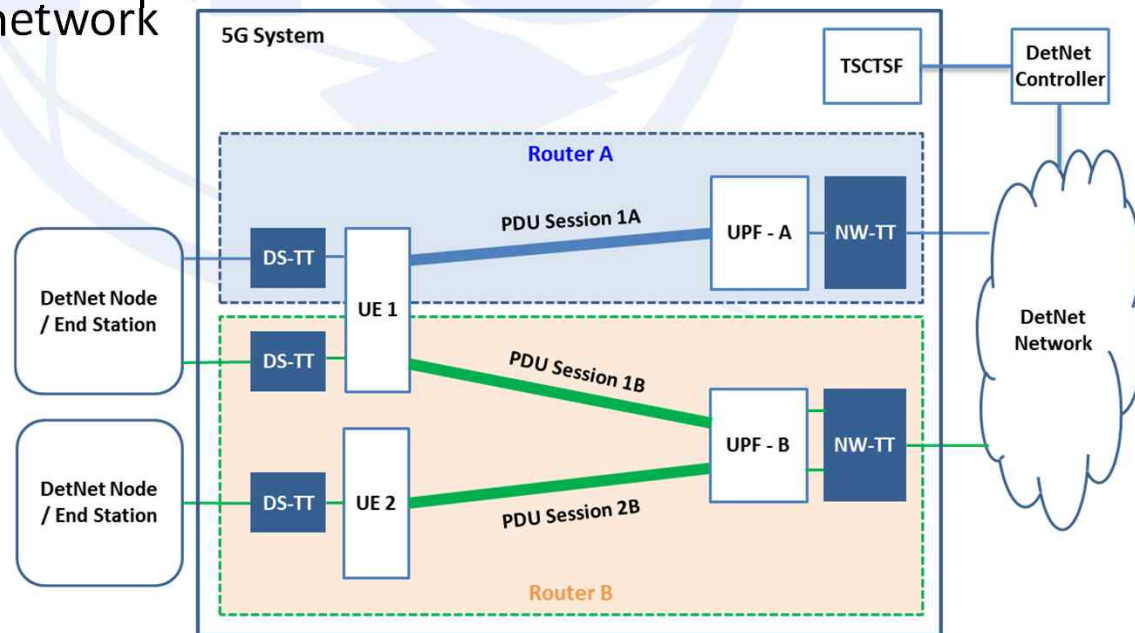
Per UPF based 5GS Router

Enhanced Features for Time Synchronization

- **Enhanced Features of 5G-Advance System (Rel.18 ~)**
  - Controlling time synchronization service based on the Subscription

  - Support for network timing synchronization status monitoring

  - Time synchronization service for a UE or a group of UEs in a specific geographical area (so called coverage area)

What is Next?

- **Future Steps of 3GPP SA2**

  – 3GPP almost finishes the standard works for rel. 18 (the first release of the 5G advanced system)

  – At this time, 3GPP SA2 is determining the new topic and new feature for the rel-19 5G-Advanced system

    - There are 10+ companies showing interest in TSC/URLLC-related topics