

# 3GPP TR 38.825 V16.0.0 (2019-03)

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*Technical Report*

## **3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on NR Industrial Internet of Things (IoT); (Release 16)**



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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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- y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.
- z the third digit is incremented when editorial only changes have been incorporated in the document.

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# 1 Scope

The present document is related to Study on NR Industrial Internet of Things (IoT) with a scope as defined in [2].

The document describes NR enhancements to Ultra Reliable Low Latency Communications (URLLC) and Industrial Internet of Things, which were analysed as part of the study such as data duplication and multi-connectivity enhancements, solutions for UL/DL intra-UE prioritization/multiplexing and Time Sensitive Networking support (TSN) via accurate reference timing delivery, QoS/scheduling enhancements for TSN traffic types, Ethernet header compression. Technical Report captures also performance analysis of TSN requirements defined in [6].

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# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP RP-182090 "Revised SID: Study on NR Industrial Internet of Things (IoT)".
- [3] 3GPP TR 22.804: "Study on Communication for Automation in Vertical Domains".
- [4] 3GPP TR 23.725: "Study on enhancement of Ultra-Reliable Low-Latency Communication (URLLC) support in the 5G Core network (5GC)".
- [5] 3GPP TR 23.734: "Study on 5GS Enhanced support of Vertical and LAN Services".
- [6] 3GPP TS 22.104: "Service requirements for cyber-physical control applications in vertical domains".
- [7] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC) protocol specification".
- [8] 3GPP TR 38.824: "Study on physical layer enhancements for NR ultra-reliable and low latency case (URLLC)".
- [9] IEEE 802.1Q-2014 - IEEE Standard for Local and metropolitan area networks--Bridges and Bridged Networks.
- [10] 3GPP TS 23.501: "System architecture for the 5G System (5GS)".
- [11] 3GPP R2-1816689: "Ethernet Header Compression".
- [12] 3GPP R2-1817175: "Ethernet Header Compression".
- [13] 3GPP R2-1817572: "Discussion on the Ethernet header compression".
- [14] 3GPP TS 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".
- [15] 3GPP R2-1817913: "RoHC based Header Compression for TSN".
- [16] 3GPP R2-1816765: "Ethernet header compression".
- [17] 3GPP TS 36.323: "Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification".

- [18] IETF RFC 1951: "DEFLATE Compressed Data Format Specification".
- [19] 3GPP S2-189051: "LS on TSN integration in the 5G System".
- [20] 3GPP TR 37.910: "Study on self evaluation towards IMT-2020 submission".
- [21] 3GPP R1-1900156: "On evaluation of latency, reliability and TSN requirements".
- [22] 3GPP R1-1901334: "TSN evaluations for IIoT requirements".
- [23] 3GPP R1-1900935: "Discussion on the RAN2 LS on TSN requirements evaluation".
- [24] 3GPP R1-1901252: "Evaluation on TSN requirements".
- [25] 3GPP R1-1901470: "Reply LS on TSN requirements evaluation".
- [26] 3GPP R1-1900180: "Reliability and Latency Evaluation for Case I Factory Automation Scenario".
- [27] 3GPP R1-1901072: "Discussion on TSN requirements evaluation".
- [28] 3GPP R2-1816043: "LS on TSN requirements evaluation".
- [29] 3GPP R1-1901456: "Summary of evaluations on TSN reliability, latency and synchronization accuracy".
- [30] 3GPP R1-1900903: "Discussion on Timing Requirements for Industrial IoT".
- [31] 3GPP R1-1901353: "Analysis of Time Synchronization Accuracy over Uu Interface".

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## 3 Definitions, symbols and abbreviations

### 3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

### 3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

BWP	Bandwidth Part
CA	Carrier Aggregation
CG	Configured Grant
CSI	Channel State Indication
DC	Dual Connectivity
GM	Grand Master
gPTP	generalized Precision Time Protocol
HRP	High Reliability Protocol
IANA	Internet Assigned Numbers Authority
LCH	Logical Channel
LCP	Logical Channel Prioritisation
MTU	Maximum Transmission Unit
PMU	Phasor Measurement Unit
PTP	Precision Time Protocol
RG	Reliability Group
SCS	Sub-carrier Spacing
SPS	Semi-persistent Scheduling
SR	Scheduling Request

TE	Time Error
TRP	Transmission Reception Point
TSN	Time Sensitive Networking
UAV	Unmanned Aerial Vehicle
URLLC	Ultra Reliable Low Latency Communications

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## 4 Data duplication and multi-connectivity enhancements

### 4.1 General

This section focuses on PDCP duplication and higher layer multi-connectivity aspects such as assessment of gains of duplication with more than two copies, potential enhancements to achieve resource efficient PDCP duplication and captures RAN aspects of higher layer multi-connectivity solutions.

### 4.2 Enhancements to PDCP duplication

#### 4.2.1 Protocol aspects

In PDCP duplication, the PDCP entity delivers duplicate PDCP PDUs to more than one RLC entity.

The benefit in supporting up to four (4) copies can give the NW freedom, in certain architectural deployment scenarios, e.g. using CA or DC, to configure towards achieving consistent reliability using several concurrent radio links that dynamically vary in reliability and latency. Duplication increases overhead as well as protocol complexity and use of more than two copies is not expected to be a common configuration.

Multiple RLC entities/legs give better possibilities for varying link characteristics and selecting for which radio links duplication is active. This facilitates having duplicated PDUs transmitted, possibly dynamically, on selected radio link(s) in a subset of a total number of configured RLC entities/legs. For example, the active subset of configured RLC entity/leg and/or carriers can be dynamically switched to support flexible transmission of PDCP PDUs. In addition, supporting multiple configurable RLC entities/legs also supports different architectural deployments and combinations, e.g. DC in combination with CA or other.

RRC configuration can be used to initially configure UEs of a set of RLC entities or legs; for where the NW can dynamically control how configured RLC entities or legs are activated and used for duplicate transmission using signalling such as MAC CE. Dynamic selection of RLC entities or legs may possibly also be made using other methods, for example UE based.

PDCP duplication enhancements are applicable to CA, DC (NR only) and DC+CA (NR Only). LTE enhancements are not considered in this SI.

In this study, selective duplication in the form of that UE (PDCP) deciding on per packet basis if additional copies are needed, when a copy is delivered to another RLC entity/leg and on which RLC entity/leg a copy is transmitted have not been sufficiently evaluated. Details of selective duplication and possible benefits need more evaluation.

The current Rel-15 PDCP discard mechanism is deemed sufficient and benefits of an enhancement through a selective discard mechanism have been determined to be not needed.

Possible benefits in improving activation/deactivation of PDCP duplication could be to define UE based, configurable criteria or other to allow a more dynamic activation and deactivation of duplication for an RLC entity/leg or bearer. This would complement the extent to which the number of duplicates on active bearers are used. However, it is not clear from this study item if the benefit can be achieved within reasonable complexity increase.

In this study, it is assumed that the same RLC mode in all RLC entities per DRB are used. The RLC mode associated with a DRB is currently determined based on the service or services carried on that bearer.

Enhancements to LCH restriction or LCP, possibly with dynamic adaptation to improve e.g. radio resource efficiency may be beneficial but has not been studied in this SI.



## 4.2.2 Radio access network aspects

Packet duplication is regarded as an effective feature to meet the reliability requirements for URLLC services but at the cost of radio resources. Hence it is important to support efficient downlink packet duplication from a RAN architecture perspective. The current Rel-15 packet duplication functionality should be taken as the baseline. Optimizations to improve resource efficiency (e.g. Selective PDCP duplication upon transmission failure, PDCP discarding, Effective PDCP duplication) are discussed without full evaluation. Potential enhancements may be possible.

## 4.3 Higher layer multi-connectivity

### 4.3.1 Layer 2/3 protocol aspects

TR 23.725 [4] has introduced several possible solutions enabling higher-layer multi-connectivity. Some of the solutions were identified to have RAN impacts and this section captures layer 2/3 protocol aspects relating to Solutions #2, #3, #7, and #10 from [4], as summarised below.

#### **Aspects of Solutions based on Reliability Group (Solution #2 and Solution #10)**

To enable the realization of solutions based on reliability groups (RGs), wherein multiple UEs of a device are associating to distinct end-to-end connections to achieve diversity, broadcasting signalling (such as SIB) in the air interface could be applied for purposes of RG allocation (Solution #10). However, existing mechanisms (e.g., providing cell reselection priorities in dedicated signalling) can achieve the same functionality, and such an approach is preferable from RAN point of view.

#### **Aspects of Solutions based on PDCP/GTP-U Enhancement or HRP Protocol Layer (Solution #3)**

Option 1 of Solution #3 introduces dependency between the sequence number in GTP-U header and PDCP SN, in which PDCP SN could be assigned by the RAN nodes in accordance to the GTP-U header via mapping. Such approach could result in impacts in terms of PDCP SN resetting. In particular, the PDCP SN is used for ciphering, deciphering, and integrity protection, so it is extremely important that both PDCP transmitter and receiver have the same view of the SN of each of the PDCP PDUs. The PDCP SN is always set to zero when the PDCP is established. This can happen, for instance, when the entity is initially set up or when an RRC reconfiguration with the full configuration option is signalled. In this latter case (full configuration option), there is a risk of packet losses in PDCP. In addition, PDCP re-establishment also leads to PDCP SN reset to its initial value for UMD DRBs. PDCP (re-)establishment are also triggered by RRC.

On the other hand, Option 2 of Solution #3 introduces a new protocol layer dubbed HRP between UE and UPF to handle packet replication and elimination. Impacts to RAN are foreseeable as the knowledge regarding whether this new protocol layer exists (and hence the header), is required by the RAN to perform header compression/decompression at the PDCP. Moreover, as this option requires two N3 tunnels for DC-based architecture, two PDCP entities are needed at the RAN.

#### **Aspects of Solutions based on UPF Indication (Solution #7)**

In Solution #7, the UPF may indicate if a flow is utilized for redundant packet, and the lower layer should be instructed to treat the packets as uncorrelated as possible, in a bid to support reliable transmission via multi-connectivity. How the RAN should respond to such indication is an implementation issue and hence no specification impacts have been observed. UL transmission was not analysed in detail.

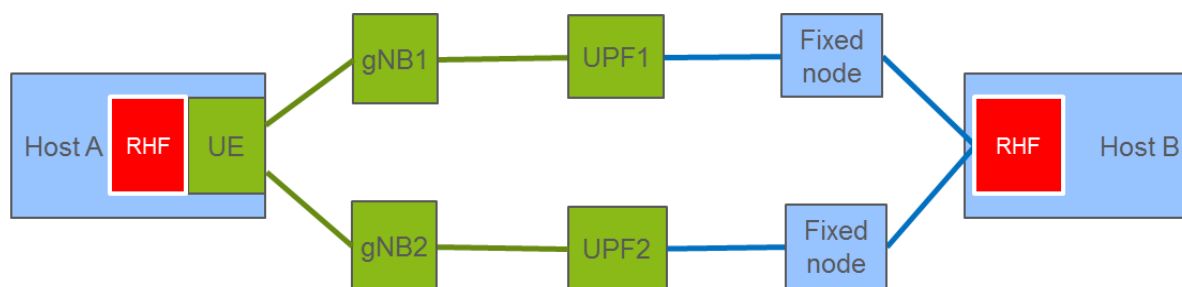
## 4.3.2 Radio access network aspects

### 4.3.2.1 Redundant user plane paths based on dual connectivity

#### 4.3.2.1.1 Overview

This is the solution of redundant user plane paths based on dual connectivity for Key Issue 1 captured in TR 23.725[4].

The solution will enable a terminal device to set up two redundant PDU Sessions over the 5G network, so that the network will attempt to make the paths of the two redundant PDU sessions independent whenever that is possible.



**Figure 4.3.2.1.1-1: Overview of redundant user plane paths based on dual connectivity approach**

#### 4.3.2.1.2 Impacts on RAN

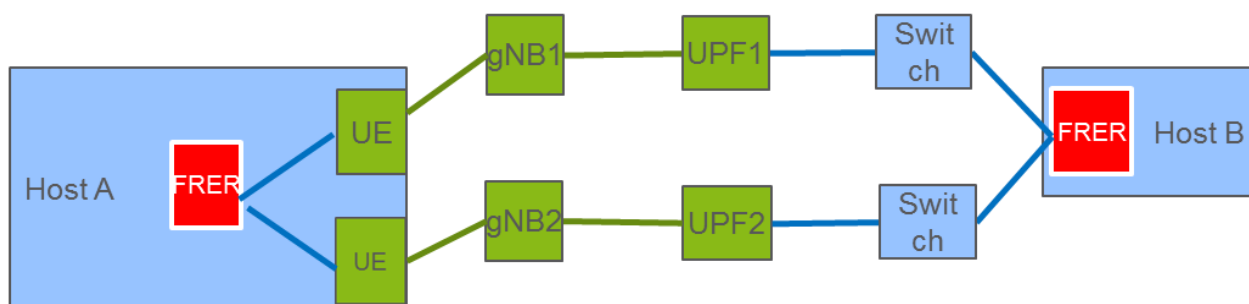
- Attempt to establish and maintain dual connectivity when the need for redundant user planes are indicated for a pair of PDU Sessions.
- Set up dual connectivity in such a way that both the MgNB and the SgNB have an independent PDCP entity for handling the two independent user plane paths. This is supported in the specification already.
- To achieve the use plane redundancy, one PDU session is setup as MN terminated MCG bearer, the other PDU session (of the pair) is setup as SN terminated SCG bearer.
- To ensure independent paths, the bearer type change of MN terminated MCG bearer to SCG bearer or split bearer may be disallowed. The bearer type change of the SN terminated SCG bearer to MCG bearer or split bearer may be disallowed.
- If the PDCP duplication is to be used, the lower layer resources should be ensured to be isolated, e.g. using other frequency.

#### 4.3.2.2 Multiple UEs per device for user plane

##### 4.3.2.2.1 Overview

This is the solution "Multiple UEs per device for user plane" for Key Issue 1 captured in TR 23.725[4].

The solution will enable a terminal device to set up multiple redundant PDU Sessions over the 5G network, so that the network will attempt to make the paths of the multiple redundant PDU sessions independent whenever that is possible.



**Figure 4.3.2.2.1-1: Overview of multiple UEs per device for user plane approach**

#### 4.3.2.2.2 Impacts on RAN

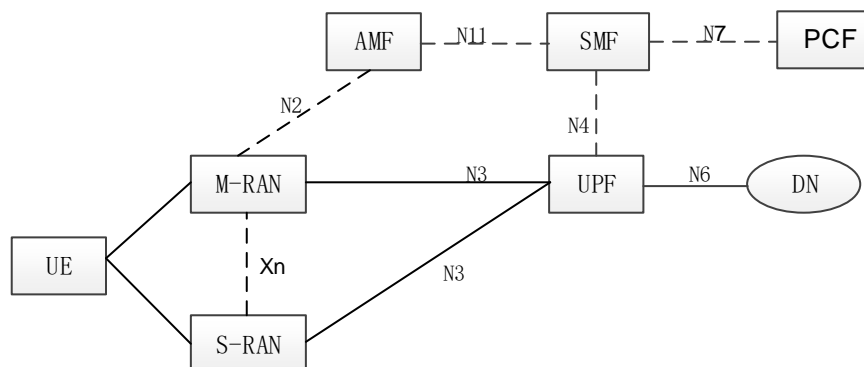
- O&M configuration of the RAN RGs on a per cell level.
- Prioritization of the handover of the UE to a cell whose RAN RG coincides with the UE RG, when such a suitable target cell is available.

### 4.3.2.3 Supporting redundant data transmission via single UPF and two RAN nodes

#### 4.3.2.3.1 Overview

This is the solution of "supporting redundant data transmission via single UPF and two RAN nodes" for Key Issue 1 captured in TR 23.725[4].

This solution realizes the reliability of user plane between UPF and UE while the QoS flow redundant transmission in the PDU session is decided by SMF.



**Figure 4.3.2.3.1-1: Overview of redundant data transmission via single UPF and two RAN nodes approach**

#### 4.3.2.3.2 Impacts on RAN

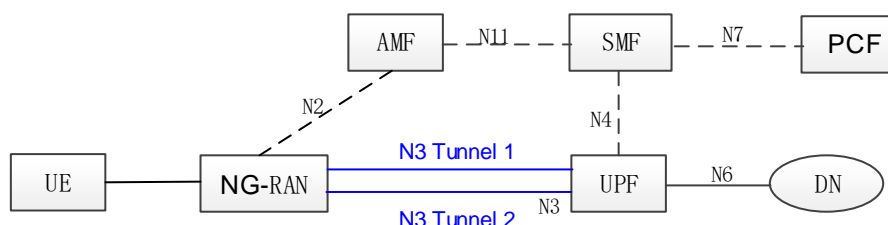
- The RAN node shall support redundant transmission via DC architecture with two N3 tunnels.
- In case protocol stack option 1 in TS 23.725[4] is adopted, RAN need to ensure there is only one QoS Flow per DRB.

### 4.3.2.4 Supporting redundant data transmission via single UPF and single RAN node

#### 4.3.2.4.1 Overview

This is the solution of "supporting redundant data transmission via single UPF and single RAN node" for Key Issue 1 captured in TR 23.725[4].

In this solution the redundant packets will be transferred between UPF and RAN via two independent N3 tunnels, which are associated with a single PDU Session, over different transport layer path to enhance the reliability of service.



**Figure 4.3.2.4.1-1: Overview of redundant data transmission via single UPF and single RAN node approach**

#### 4.3.2.4.2 Impacts on RAN

- The RAN shall be able to replicate the uplink packet per QOS flow and assign the same GTP-U sequence number to these packets, and send the duplicate packets to the two N3 tunnels.
- The RAN shall be able to eliminate the duplicate downlink packets based on the same GTP-U sequence number of these packets.

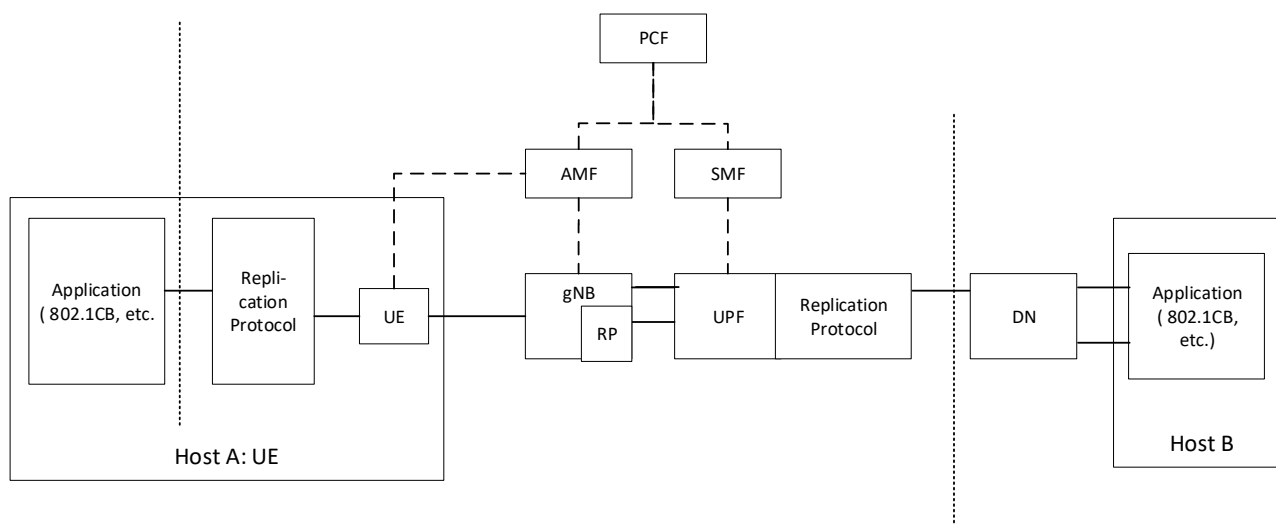
#### 4.3.2.5 Support replication framework in 3GPP System

##### 4.3.2.5.1 Overview

This is the solution of "Replication framework in 3GPP System" for Key Issue 1 captured in TR 23.725 [4].

This solution introduces a replicator that allows the 3GPP system to be aware (e.g. detect or have explicit information) that two or more "streams" of replicated packets belong together, and guide the lower layers to ensure these packets get an optimized treatment in the 3GPP system.

The Replicator functionality may be a part of the UPF (or collocated with the UPF) for user plane functionality and SMF for control plane functionality.



**Figure 4.3.2.5.1-1: Architecture with Replication Framework**

#### 4.3.2.5.2 Impacts on RAN

- Access to replicator functionality support. Replicator in the RAN has the capability to replicate packets over N3 and/or eliminate further replication of packets over Uu/N3.

## 5 Intra-UE prioritization/multiplexing

### 5.1 General

This section describes an aspect of intra-UE traffic prioritization and multiplexing considering data and control channels, different latency and reliability requirements and different types of resource allocations for both uplink and downlink directions.

## 5.2 Scenarios and use cases

### 5.2.1 Overview

Intra-UE prioritization/multiplexing considers the cases wherein a UE confronts with DL/UL radio resource conflict between control/data traffics associating to different QoS requirements. For example, a UAV at a smart factory may have to concurrently cope with eMBB traffics such as surveillance video and URLLC traffics such as motion control. The objective of this section is to describe several scenarios of Intra-UE prioritization that this SI has identified for further investigation.

### 5.2.2 Scenario 1: Intra-UE DL Prioritization

In this scenario, a UE has been scheduled to receive DL traffics with different priorities, corresponding to different DL assignments received sequentially, but over the radio resources overlapping in time.

### 5.2.3 Scenario 2: Intra-UE UL Prioritization: Resource Conflict between Configured and Dynamic Grants

In this scenario, a UE receives a dynamic grant for uplink transmission, the associated PUSCH of which overlaps in time with reserved uplink resources activated by either Type-1 or Type 2 configured grant. According to the priority rule defined in Rel-15, dynamic grant always overrides configured grant in situations of resource conflict between them. However, this may not be desirable in some cases as configured grants are typically used to cater URLLC traffics, and it may be problematic if URLLC can be punctured by another dynamic grant.

### 5.2.4 Scenario 3: Intra-UE UL Prioritization: Resource Conflict between Dynamic Grants

In this scenario, a UE sequentially receives two dynamic grants from the gNB for uplink transmission with overlapped PUSCH resources in time. For such cases, currently there is no existing mechanism or rules for the UE to determine how to handle prioritization of these two grants.

### 5.2.5 Scenario 4: Intra-UE UL Prioritization – Resource Conflict between Control Information and Control Information

In this scenario, a UE needs to conduct uplink transmission of control information such as SR, HARQ feedback and CSI associating to a prioritized traffic at the same time as the on-going uplink transmission of control information for other traffics with lower priority levels, to reduce the resultant latency.

### 5.2.6 Scenario 5: Intra-UE UL Prioritization – Resource Conflict between Control Information and Data

In this scenario, a UE needs to conduct uplink transmission of control information such as SR, HARQ feedback and CSI associating to a prioritized traffic at the same time as the on-going uplink transmission of data for other traffics with lower priority levels, to reduce the resultant latency.

## 5.3 Solutions for uplink intra-UE prioritization/multiplexing

### 5.3.1 Solutions for resource collision involving data only

Data-only intra-UE prioritization is applicable for resource conflicts between configured/configured, configured/dynamic, or dynamic/dynamic grants.

UE prioritization of a grant when there is at most one dynamic grant in the set of conflicting grants (scenario 2 and configured/configured grant collisions) shall be addressed. MAC specifies currently the UE prioritization of such cases, and modifications to MAC would be required.

RAN2 assumes that the later dynamic grant may always be prioritized over an earlier dynamic grant (scenario 3). One way to realize this is that MAC generates a PDU for each grant and lets L1 handle conflicting transmissions (to be confirmed following evaluation of physical layer aspects). Other solutions are not precluded.

For cases when MAC prioritizes a grant, MAC prioritizes the grant on which data of the highest priority can be transmitted according to LCP restrictions and priority configured for each logical channel.

### 5.3.2 Solutions for resource collision involving control information

This section describes the issues and possible solutions for intra-UE uplink resource collision cases corresponding to Scenario 4 and 5 listed in Section 5.2, where at least one colliding uplink resources are intended to be used for transmission of control information (e.g. SR, CSI, HARQ feedback and MAC CEs).

For resource collision between SR associating to high-priority traffic and uplink data of lower-priority traffic, the current specifications of Rel-15 refrains transmission of SR by always prioritizing UL-SCH, which may cause a delay for the SR transmission and may ultimately result in failure to meet the QoS requirement of high-priority traffic. Possible solutions include to define a prioritization handling rule to determine whether to transmit SR or PUSCH based on e.g. the priority of the LCH which triggers the SR and priorities of the data to be transmitted on the PUSCH resource.

### 5.3.3 Physical layer aspects

RAN1 has discussed the uplink intra-UE prioritization/multiplexing in scenarios 2, 3, 4 and 5 from PHY layer perspective.

For scenario 2, in case the collision between configured grant and dynamic grant occurs in physical layer, options to determine the prioritization between configured grant and dynamic grant include at least:

- Priority at PHY is determined by MAC layer for the purpose of PHY prioritization.
  - Note: this may or may not have any RAN1 impact
- Priority at PHY is determined via PHY channel(s)/signal(s)/parameters for the purpose of PHY prioritization.
- It is configurable as part of the configured grant configuration whether it should have higher priority than dynamic grant in case of conflict.
- Other options are not precluded.

RAN1 recommends to allow the prioritization of configured grant over dynamic grant under some conditions in case of collision in scenario 2.

For scenario 3, RAN1 recommends to support the handling of scenario 3.

For scenarios 4 and 5, RAN1 recommends to support enhancements for scenario 4 and 5. RAN1 recommends considering the prioritization and/or multiplexing behaviour among URLLC/eMBB HARQ-ACK/SR/CSI and URLLC/eMBB PUSCH, including the cases with UCI on PUCCH and UCI on PUSCH. Note that RAN1 has not concluded whether to support prioritization, or multiplexing, or both.

## 5.4 Solutions for downlink intra-UE prioritization/multiplexing

RAN1 has discussed the downlink intra-UE prioritization/multiplexing in scenario 1. RAN1 recommends to support the handling of scenario 1.

## 6 Time Sensitive Networking

### 6.1 General

This section contains explanation on what TSN networking is and how it can be supported using 5G/NR technologies as well as analysis of the potential TSN specific enhancements of NR such as accurate reference timing delivery, QoS/scheduling enhancements and Ethernet header compression. It also contains an evaluation of NR with respect to performance and synchronization accuracy requirements as defined in [3].

### 6.2 TSN use cases, scenarios and architectures

### 6.3 TSN performance evaluation

#### 6.3.1 Requirements

The following requirements extracted from [3] are the baseline for the TSN performance evaluation by RAN WGs:

**Table 6.3.1-1 Use cases and requirements considered for TSN requirements evaluation**

Case	#UE	Communications service availability	Transmit period	Allowed E2E latency	Survival time	Packet size	Service area	Traffic periodicity	Use case
I	20	99,9999% to 99,999999%	0.5 ms	$\leq$ Transmit period	Transmit period	50 bytes	15 m x 15 m x 3 m	Periodic	Motion control and control-to-control use cases
II	50	99,9999% to 99,999999%	1 ms	$\leq$ Transmit period	Transmit period	40 bytes	10 m x 5 m x 3 m	Periodic	Motion control and control-to-control use cases
III	100	99,9999% to 99,999999%	2 ms	$\leq$ Transmit period	Transmit period	20 bytes	100 m x 100 m x 30 m	Periodic	Motion control and control-to-control use cases

It should be noted that, after finalization of Technical Specification in [6], the requirements of various use cases as captured there take precedence over those captured in Table 6.3.1-1 and extracted from [3]. However, the differences for the use cases chosen for evaluation in RAN WGs concern communications service availability requirement (which was decreased) and service area and do not affect the outcome of the analysis as presented in this document.

Furthermore, the following assumptions are made with respect to TSN performance requirements analysis:

- reliability targets going beyond 99.9999% can be achieved by higher layer redundancy (e.g. PDCP duplication) and it is not required to analyse whether those can be met on PHY layer
- packet arrival jitter is not to be considered in performance evaluation (i.e. RAN-level analysis focuses on whether the maximum latency target can be met while de-jittering is handled by higher protocol layers)

The requirements for clock synchronization can be found in sections 5.6 of [6]. The evaluation should focus on the following clock synchronization performance requirements:

**Table 6.3.1-2 Clock synchronisation service performance requirement (source: 3GPP TS 22.104)**

Clock synchronicity accuracy level	Number of devices in one Communication group for clock synchronisation	Synchronisation clock synchronicity requirement	Service area	Scenario
1	Up to 300 UEs	< 1 $\mu$ s	$\leq 100 \times 100$ m	Motion control Control-to-control communication for industrial controller
2	Up to 10 UEs	< 10 $\mu$ s	$\leq 2500$ m <sup>2</sup>	High data rate video streaming
3	Up to 100 UEs	< 1 $\mu$ s	< 20 km <sup>2</sup>	Smart Grid: synchronicity between PMUs

The synchronicity requirement captured in Table 6.3.1-2 is meant for both intra- and inter-gNB cases. It is applicable to all UEs within the service area irrespective of the number of gNBs deployed within the area and the required precision is between the sync master and any device of the global time/working clock domain.

## 6.3.2 Physical layer aspects

### 6.3.2.1 General

Based on a request by SA2 in S2-189051 [19] and further request by RAN2 in R2-1816043 [28], RAN1 has performed analysis on latency, reliability and the achievable time synchronization accuracy over Uu interface to evaluate the TSN performance requirements for physical layer.

### 6.3.2.2 Latency

Based on the LS from RAN2 in R2-1816043 [19], a 0.5ms one-way (gNB-to-UE or UE-to-gNB) latency target is considered. One-way user plane latency analysis has been carried out for both DL and UL following the IMT-2020 evaluation methodology, which can be found in the TR 37.910 [20]. For UL, the grant-free PUSCH scheduling is considered. The considered duplexing schemes include both FDD and TDD.

For FDD, assuming UE processing time of capability 2 with PDCCH periodicity of 1 OFDM symbol, the one-way user plane latency from different sources are shown in Tables 6.3.2.2-1 and 6.3.2.2-2 for DL and UL, respectively.



**Table 6.3.2.2-1: Downlink user plane latency (in ms) for 1 (initial) transmission and 2 transmissions (initial and one retransmission) for different PDSCH durations in FDD.**

	PDSCH duration (symbols)	Num. Tx	Source R1-1900156 [21]	Source R1-1901334 [22]	Source R1-1900935 [23]	Source R1-1901252 [24]
15 kHz SCS	2	1 Tx	0.54	0.607		0.49
		2 Tx		1.464		
	4	1 Tx	0.71	0.893		0.66
		2 Tx		1.893		
	7	1 Tx	0.93	1.286		0.93
		2 Tx		2.429		
30 kHz SCS	2	1 Tx	0.31	0.339	0.357	0.29
		2 Tx		0.875	0.893	
	4	1 Tx	0.39	0.482	0.5	0.37
		2 Tx		1.089	1.107	
	7	1 Tx	0.5	0.679	0.679	0.51
		2 Tx		1.357	1.357	
60 kHz SCS	2	1 Tx	0.24	0.259	0.268	0.23
		2 Tx		0.688	0.696	
	4	1 Tx	0.28	0.33	0.339	0.27
		2 Tx		0.83	0.839	
	7	1 Tx	0.34	0.429	0.429	0.34
		2 Tx		0.929	0.929	

**Table 6.3.2.2-2: Uplink user plane latency (in ms) for 1 (initial) transmission and 2 transmissions (initial and one retransmission) for different PUSCH durations in FDD.**

	PUSCH duration (symbols)	Num. Tx	Source R1-1900156 [21]	Source R1-1901334 [22]	Source R1-1900935 [23]	Source R1-1901252 [24]
15 kHz SCS	2	1 Tx	0.5	0.571		0.52
		2 Tx		1.429		
	4	1 Tx	0.74	1.071		0.79
		2 Tx		2.071		
	7	1 Tx	1.04	1.286		1.02
		2 Tx		2.786		
30 kHz SCS	2	1 Tx	0.29	0.321	0.321	0.3
		2 Tx		0.821	0.821	
	4	1 Tx	0.41	0.571	0.465	0.43
		2 Tx		1.214	1.108	
	7	1 Tx	0.55	0.679	0.679	0.55
		2 Tx		1.429	1.429	
60 kHz SCS	2	1 Tx	0.23	0.250	0.25	0.24
		2 Tx		0.679	0.679	
	4	1 Tx	0.29	0.375	0.375	0.3
		2 Tx		0.875	0.875	
	7	1 Tx	0.37	0.429	0.429	0.36
		2 Tx		0.929	0.929	

For TDD, assuming UE processing time of capability 2 with PDCCH periodicity of 1 OFDM symbol, the one-way user plane latency from different sources are shown in Tables 6.3.2.2-3 and 6.3.2.2-4 for DL and UL, respectively. The slot patterns [7D,1S,6U] (R1-1900156 [21]) and [7D,7U] (R1-1901334 [22]) have been considered.

**Table 6.3.2.2-3: Downlink user plane latency (in ms) for 1 (initial) transmission and 2 transmissions (initial and one retransmission) for different PDSCH durations in TDD.**

	PDSCH duration (symbols)	Num. Tx	Source R1-1900156 [21] ([7D,1S,6U])	Source R1-1901334 [22] ([7D,7U])
15 kHz SCS	2	1 Tx	0.72	
		2 Tx		
	4	1 Tx	0.95	
		2 Tx		
	7	1 Tx	1.29	
		2 Tx		
30 kHz SCS	2	1 Tx	0.4	0.5893
		2 Tx		1.125
	4	1 Tx	0.51	0.7321
		2 Tx		1.3393
	7	1 Tx	0.68	0.9286
		2 Tx		1.6071
60 kHz SCS	2	1 Tx	0.29	0.3839
		2 Tx		0.8839
	4	1 Tx	0.35	0.4554
		2 Tx		1.0446
	7	1 Tx	0.43	0.5536
		2 Tx		1.1429

**Table 6.3.2.2-4: Uplink user plane latency (in ms) for 1 (initial) transmission and 2 transmissions (initial and one retransmission) for different PUSCH durations in TDD.**

	PUSCH duration (symbols)	Num. Tx	Source R1-1900156 [21] ([7D,1S,6U])	Source R1-1901334 [22] ([7D,7U])
15 kHz SCS	2	1 Tx	0.62	
		2 Tx		
	4	1 Tx	1.07	
		2 Tx		
30 kHz SCS	2	1 Tx	0.35	0.6071
		2 Tx		1.1071
	4	1 Tx	0.57	0.8214
		2 Tx		1.8214
	7	1 Tx		0.9286
		2 Tx		1.9286
60 kHz SCS	2	1 Tx	0.26	0.3929
		2 Tx		0.8929
	4	1 Tx	0.38	0.5
		2 Tx		1
	7	1 Tx		0.5536
		2 Tx		1.3036

Other sources (R1-1900180 [26], R1-1901072 [27]) also reported latency analysis in different ways, which also show that the 0.5ms latency target can be met. The latency analysis with other PDCCH periodicities and UE capability 1 have also been considered.

The 0.5 ms latency target analysis leads to the following RAN1 conclusions:

- For 15 kHz SCS, the 0.5ms one-way latency target cannot be achieved with Rel-15 NR.
- For FDD, the 0.5ms one-way latency target can be achieved for both DL and UL for 30kHz (and higher) SCS with Rel-15 NR for single shot transmission.
- For TDD:
  - For 30kHz SCS, some analysis shows the 0.5ms one-way latency target can be achieved with the respectively assumed UL/DL configuration, whereas other analysis indicates that it cannot be achieved with Rel-15 NR for the respectively assumed UL/DL configuration.
  - For 60kHz (and higher) SCS, the 0.5ms one-way latency target can be achieved with the respectively assumed UL/DL configuration for both DL and UL with Rel-15 NR for single-shot transmission.

### 6.3.2.3 Reliability

Based on the LS from RAN2 in R2-1816043 [28], the reliability targets of 99,99% (i.e.  $1e-4$ ) and 99,9999% (i.e.  $1e-6$ ) are considered as PDCP data duplication may be used to increase the reliability. The reliability analysis has been carried out for the following Case I in TR 22.804 V16.2.0 [3] using the IMT-2020 evaluation methodology:

Case	#UE	Communications service availability	Transmit period	Allowed E2E latency	Survival time	Packet size	Service area	Traffic periodicity	Use case
I	20	99,9999% to 99,999999%	0.5 ms	$\leq$ Transmit period	Transmit period	50 bytes	15 m x 15 m x 3 m	Periodic	Motion control and control-to-control use cases

Additionally, the updated Case I in TS 22.104 V16.0.0 [6] is also evaluated using the same methodology.

Case	#UE	Communications service availability	Transmit period	Allowed E2E latency	Survival time	Packet size	Service area	Traffic periodicity	Use case
I	20	99,999% to 99,99999%	0.5 ms	$\leq$ Transmit period	Transmit period	50 bytes	50 m x 10 m x 10 m	Periodic	Motion control and control-to-control use cases

On one hand, the SINR distribution for DL and UL channels with full-buffer traffic is determined using the system-level simulator to find the 5%-tile (one company reporting the 1%-tile, 1%-tile evaluation represents a more stringent requirement than 5%-tile evaluation). On the other hand, single UE link level simulation is performed to find the BLER performance versus SINR. The corresponding 5%-tile (and 1%-tile) SINR values are then used to check against the link level performance to see if the reliability of  $1e-4$  to  $1e-6$  can be achieved or not. The evaluation assumptions follow the link and system level evaluation assumptions for the Factory Automation use case described in TR 38.824 [8] with the following modifications:

- Modified system level evaluations assumption (on top of Table A.2.2-1 in Sec. A.2.2 of TR 38.824 [8]):
  - Network layout: A single cell placed in the middle of service area.
  - UE dropping: Uniformly dropped over the service area.
- Modified link level evaluations assumptions (on top of Table A.3-2 in Sec. A.3 of TR 38.824 [8]):

- Channel model: TDL-D 30ns.
- UE speed: 3km/h.
- Payload size for PDSCH/PUSCH: 50 bytes.
- PDCCH aggregation level: 16.

All sources that provided the analysis showed that the 5%-tile (and 1%-tile) SINR is adequate to achieve the reliability of  $1e-6$  with a large margin. The 5%-tile (and 1%-tile) SINR and the required SINR to achieve the reliability of  $1e-4$  and  $1e-6$  from different sources are shown in Table 6.3.2.3-1 for both DL and UL. Details on simulation results can be found in R1-1901456 [29].

**Table 6.3.2.3-1: The SINR (dB) at 5%-tile (and 1%-tile),  $1e-4$  and  $1e-6$  error rate for PDCCH, PDSCH and PUSCH from different sources.**

	Source R1-1900156 [21]			Source R1-1900180 [26]				Source R1-1900935 [23]			Source R1-1901072 [27]		
	1e-4	1e-6	5%- tile for Case I in TR 22.80 4 [3]	1e-4	1e-6	1%- tile for Case I in TR 22.80 4 [3]	1%- tile for Case I in TS 22.10 4 [6]	1e-4	1e-6	5%- tile for Case I in TR 22.80 4 [3]	1e-4	1e-6	5%- tile for Case I in TR 22.80 4 [3]
PDCCH	-9.4	-8.2	-3.38	-8.2	-7	-0.07	0.72	-0.5	3	59.7			8.84
PDSCH	-7.9	-6	-3.38	-4.1	-2.9	-0.07	0.72	-1	1.4	59.7			
PUSCH	-7.9	-6	-2.74	-4.1	-2.9	-0.75	0.06	-1	1.4	10.9	-7.2	-5.85	1.1

On reliability analysis using single UE link level evaluations, RAN1 makes the following conclusions:

- For the cases where the one-way latency target can be achieved, it was observed that the reliability target of  $1e-4$  to  $1e-6$  can be achieved with Rel-15 NR for the 5%-ile SINR geometry (e.g. cell-edge UE) in use case I based on the agreed methodology and assumptions from RAN1#95 (without PDCP duplication). It is RAN1 conclusion that PDCP duplication is not always available/applicable.

#### 6.3.2.4 Synchronization accuracy

Based on a request by SA2 in S2-189051 [19] and further clarification by RAN2 in R2-1816043 [28], RAN1 has performed analysis on the achievable time synchronization accuracy over Uu interface between a gNB and a single UE. The effects of the granularity and accuracy of the absolute timing indication information provided by the gNB are not considered. A range of service areas are considered.

RAN1 identified, that the achievable time synchronization accuracy is dependent on the maximum gNB-to-UE distance in case the UE would not compensate for the radio propagation delay between gNB and UE. Therefore, RAN1 evaluated the achievable accuracy for the case without UE propagation delay compensation for various gNB-to-gNB inter-site distances (ISD) as well as for the case with UE propagation delay compensation.

The evaluation results on maximum timing synchronization error for different inter-site distances without UE propagation delay compensation are summarized in Table 6.3.2.4-1, while the results on maximum timing synchronization error with UE propagation delay compensation are shown in Table 6.3.2.4-2.

**Table 6.3.2.4-1: Summary of maximum timing synchronization error results for different inter-site distances without UE propagation delay compensation.**

	15kHz SCS	30kHz SCS	60kHz SCS	120kHz SCS
Source R1-1900156 [21]	[-278ns,376ns]	[-147ns,245ns]		[-82ns,180ns]
Source R1-1900903 [30]	355ns (114m ISD)			
Source R1-1900935 [23]	215ns (20m ISD) 315ns (60m ISD)			
Source <sup>(1)</sup> R1-1901072 [27]	133ns (10m ISD)			
Source R1-1901252 [24]	506ns (20m ISD)	441ns (20m ISD)	343ns (20m ISD)	
Source R1-1901353 [31]	315ns (10m ISD) 350ns (20m ISD) 1080ns (250m ISD)			
Note (1): Half of the reported values of R1-1901072 [27] are included in this table, to align the results with the other sources and to only account for gNB-to-UE and not UE-to-UE synchronization accuracy.				

**Table 6.3.2.4-2: Summary of maximum timing synchronization error results with UE propagation delay compensation.**

	15kHz SCS	30kHz SCS	60kHz SCS
Source R1-1900156 [21]	488ns	357.5ns	276.5ns
Source R1-1901334 [22]	505ns	371ns	287.5ns
Source R1-1900935 [23]	472.5ns	338.5ns	
Source R1-1901252 [24]	536ns	438ns	357ns

Based on the evaluation results, the following has been observed:

- If a UE were not to apply propagation delay compensation, a gNB-to-UE timing synchronization accuracy of
  - 130 to 376ns for an ISD of 10m (3 sources)
  - 215 to 506ns for an ISD of 20m (3 sources)
  - 315 ns for an ISD of 60m (1 source)
  - 355ns for an ISD of 114m (1 source)
  - 1080ns for an ISD of 250m (1 source)

Based on the RAN1 agreed evaluation assumptions can be achieved for Rel-15 NR with 15kHz SCS. The achievable accuracy without propagation delay compensation becomes worse as the ISD increases. 2 out of 6 sources note that a better synchronization accuracy can be achieved for higher SCS (i.e. the higher the SCS, the better the accuracy).

- If a UE was to apply propagation delay compensation, a gNB-to-UE synchronization accuracy of 470ns to 540ns (from a total of 4 sources) for 15kHz SCS can be achieved independently of the ISD. The synchronization accuracy with propagation delay compensation improves for higher SCS (i.e. the higher the SCS, the better the accuracy).
- For small service areas with dense small cell deployments a propagation delay compensation by the UE is not required. The propagation delay compensation needs to be applied by the TSN UEs for larger service areas with more sparse cell deployments (inter-site distances >200m to achieve a synchronization accuracy better than 1us).

The related following conclusions of the physical layer aspects of the achievable timing synchronization accuracy have been informed to SA1, SA2, RAN2 and RAN3 in LS R1-1901470 [25]:

*A timing synchronization error between a gNB and a UE no worse than 540ns is achievable based on the RAN1 agreed evaluation assumptions for Rel-15 NR with 15kHz SCS. It is RAN1's conclusion, that the synchronization accuracy is improved when using higher SCS. For small service areas with dense small cell deployments a propagation delay compensation by the UE would not be required. The propagation delay compensation needs to be applied by the TSN UEs for larger service areas with more sparse cell deployments (e.g. for inter-site distances >200m the gNB-to-UE timing synchronization accuracy without propagation delay compensation may be worse than 1us).*

*Note that the RAN1 analysis does not contain the effects of the granularity & accuracy of the absolute timing indication information by the gNB, which are outside of the RAN1 study scope.*

### 6.3.3 Protocol aspects

With respect to different options of integrating TSN into 5G system, as captured in [5], from RAN perspective, it is preferential to reuse the current QoS framework and TSN integration options allowing that (e.g. "5G as a black box") are preferred.

Protocol aspects of accurate reference time provisioning are discussed in Section 6.4.

### 6.3.4 Radio access network aspects

#### 6.3.4.1 Time synchronization accuracy

Regarding the achievable time synchronization accuracy from the RAN perspective, the synchronization accuracy between the gNB and TSN GM clock can be much less than 1μs.

As examples, several options for delivery of TSN time information from the synchronization source were considered:

1. Local on-site GNSS receiver as TSN GM clock;
2. Local on-site TSN GM clock;
3. Remote TSN GM clock entity using cascaded PTP capable transport network connection.

The maximum absolute time error between the TSN GM clock and gNB for the above time synchronization options is summarized in Table 6.3.4.1-1.

**Table 6.3.4.1-1: Maximum absolute time error (TE) between TSN GM clock and gNB**

<b>Synchronization source</b>	<b>Synchronization accuracy</b>
Local on-site GNSS receiver (GPS is TSN GM clock)	$ TE  = 100 \text{ ns.}$
Local on-site TSN GM clock	TE is negligible.
Remote TSN GM clock entity using cascaded PTP capable transport network connections	$ TE  \sim N \cdot 40 \text{ ns,}$ where N is the number of PTP hops.

#### 6.3.4.2 Latency on network interfaces

The latency introduced by network interfaces depends on the backhaul type and network architecture. The latency can be negligible in certain scenarios, e.g. high quality backhaul and/or compact architecture (e.g. UPF collocated or very close to the gNB, no CU/DU split, etc). However, there are cases where the latency introduced on network interfaces is not negligible, e.g. when an operator wants to replace an existing wired TSN network with a full "in-building wireless solution" or when utilising wide area network deployment. In such scenarios, some delay budget needs to be available for the network interface out of the allowed E2E latency budget as specified in Table 6.3.1-1. This may also require 5GS QoS enhancements to be supported to deliver deterministic QoS on the links between the gNB and UPF, and at handover.

### 6.3.5 Overall synchronization accuracy analysis

The synchronization accuracy analysis is based on the following:

- Synchronization accuracy achievable over the Uu interface discussed in Section 6.3.2,

- Synchronization accuracy between TSN GM clock and gNB discussed in Section 6.3.4, and
- Granularity of signalled reference timing discussed in Section 6.4.2.

Considering the above and assuming 100 ns time error between TSN GM clock and gNB, as well as the sub-carrier spacing (SCS) of 15 kHz, the overall synchronization accuracy error between a clock source and UE clock would be equal to 665 ns (i.e. 540ns (air interface accuracy) + 100ns (network interface accuracy) + 25 ns (granularity/2)).

Some remarks about the above accuracy analysis:

- Most UEs will achieve smaller errors when the network configures higher SCSs.
- The above calculation assumes the propagation delay is either negligible (i.e. small service areas) or is compensated for in larger service areas.
- Without propagation delay compensation, for inter-site distances greater than 200m, the gNB-to-UE timing synchronization accuracy may be worse than 1 $\mu$ s.
- The synchronization accuracy analysis above is a generic analysis and does not assume any particular solution in [5].

## 6.4 Accurate reference timing provisioning

### 6.4.1 General

To meet clock synchronization requirements in clause 5.6 of TS 22.104 [6], accurate reference timing delivery by a gNB to UEs is used.

### 6.4.2 Realizing accurate reference timing delivery

Accurate reference timing delivery is carried out using broadcast and/or unicast RRC signalling (similar to E-UTRAN approach in [7]). Granularity of the signalled reference timing is at most 50 ns and determination of exact value needs further evaluation. Section 6.3.5 provides an analysis for synchronization accuracy achievable using accurate reference timing delivery.

## 6.5 QoS and scheduling enhancements

### 6.5.1 Overview of traffic characteristics in TSN use cases

In TSN use cases, e.g. in a future factory environment, the UEs need to handle a mixture of the following different traffic:

- multiple periodic streams, of different periodicities, of critical priority, for example multiple TSN streams coming from different applications;
- aperiodic critical priority traffic that is the result of critical events, like alarms, safety detectors that need to be informed about the occurrence of a critical event;
- best effort type of traffic such as eMBB traffic, internet traffic, or any other traffic supporting factory operations.

### 6.5.2 Issues and solutions related to TSN traffic support in NR

Table 6.5.2-1 presents TSN traffic characteristics, which may have impact on the current QoS/scheduling framework in NR. Potential approaches to resolve those impacts are also listed, which include solutions with both specifications impact and no specifications impact.

**Table 6.5.2-1: TSN traffic characteristics with potential issues and enhancements**



No.	TSN traffic characteristic	Description	Potential solutions and enhancements
1	Deterministic nature of TSN traffic	As captured in TS 22.104 [6], TSN traffic is often periodic, deterministic (meaning that the delay between transmission of a message and receipt of the message at the destination address needs to be stable (within bounds)) and with a message size which is fixed or in a specified range.	<p>Knowledge of TSN traffic pattern is useful for the gNB to allow it to more efficiently schedule either via CG/SPS or dynamic grants. It would be beneficial to provide the relevant information, e.g. upon QoS flow establishment. The provided information should at least include message periodicity, message size and reference time/offset. Additionally, such information as survival time could be considered, if deemed useful.</p> <p>The information could be provided either from the Core Network or from the UE, but since Core Network interacts directly with the TSN network and possesses all the required information, it is preferred for this information to be signaled from the Core Network.</p>
2	Short periodicities of TSN messages	As captured in section 6.3.1, the periodicity of the TSN flows, which need to be supported over NR can be as low as 0.5ms. Currently, configured grants can be set with the periodicity as low as 2 symbols, which spans between ~18us and ~143us depending on the subcarrier spacing. Therefore, in uplink direction, low periodicities of traffic can be supported. On the other hand, TSN communications is bi-directional while for DL direction, the minimum periodicity for SPS configuration is currently 10ms, which is not sufficient to support of periodic TSN traffic.	In order to support TSN traffic flows with very short periodicities in DL direction, it is beneficial to support additional, shorter SPS periodicities. Using SPS has an advantage over dynamic scheduling utilization, since it allows reducing PDCCH overhead and increasing reliability by avoiding control channel blocking.
3	Multiple TSN flows in a single TSN device	As captured in section 6.5.1, a single UE may need to handle "multiple periodic streams, of different periodicities, of critical priority, for example multiple TSN streams coming from different applications". Therefore, a solution to serve multiple TSN traffic flows in a single UE may be required.	In order to serve multiple TSN flows simultaneously, it is beneficial to support multiple Configured Grant as well as SPS configurations in the single UE, for a given Bandwidth Part of a serving cell.
4	TSN message periodicities with non-integer multiple of NR supported periodicities	In TSN use cases, the periodicity of data packets which are sent depends on application and in majority of the cases, it is not possible to modify it. There may be use cases where periodicity values are not multiple of NR slot or symbol period, which are used to configure CG/SPS periodicity. The severity of this issue depends on the traffic's latency requirement and the frequency of misalignment occurrences.	<p>The following solutions could potentially help in resolving or mitigating the issue:</p> <ul style="list-style-type: none"> <li>- Adjustment of SPS/CG resource by RRC reconfiguration (as per current specification)</li> <li>- Usage of short SPS/CG periodicities and/or multiple SPS/CG configurations and/or combination thereof (for SPS, support for shorter periodicities than those available in Rel-15 may be required)</li> <li>- More efficient adjustment of SPS/CG resource timing in the UE as compared to RRC reconfiguration, e.g. based on network configuration or dynamic network signalling and which could be based on knowledge of TSN traffic pattern</li> <li>- Applying de-jittering buffer at the edges of 5G system</li> </ul>

5	TSN system synchronized with external clock	As captured by SA1 requirements in section 5.6 of TS 22.104 [6], 5G system should support TSN services that are synchronized with external clocks. Such external clock may not be synchronized with clock used by NR, thus e.g., time offset and drift between the clocks may occur.	Even though the issue can potentially impact scheduling, it is at the moment understood that, if it occurs, it can be resolved outside of RAN, e.g. by using clocks with sufficient accuracy or adjusting the clocks without RAN involvement.  Therefore, work on dedicated solutions in RAN is not deemed required at the moment, although the solutions mentioned in row 4 of this table could be applicable.
6	Mobility of the UE serving deterministic TSN traffic flows	As captured in section 5.2 of TS 22.104 [6], in many factory automation use cases, the devices (and thus the UEs) are mobile, e.g. with speeds up to 75 km/h for a motion control use case. It is important to ensure that a UE which is serving periodic and deterministic traffic using CG or SPS configurations, after being handed over to a neighbouring cell, can still meet the service requirements in terms of delay/jitter and periodicity considering that the resources required to achieve that, can already be allocated for other UEs in the target cell.	The following solutions can address this issue: <ul style="list-style-type: none"> <li>- Coordination between the target node and source node on the resource pre-reservation, e.g. exchange of QoS and TSN traffic pattern information between source and target gNB during handover. Such information may be used by the target gNB to provide CG/SPS configuration already in the HO command.</li> <li>- Higher layer or physical layer duplications from both target node and source node until handover is successfully completed.</li> <li>- Other solutions, e.g. those developed as part of 3GPP work devoted to mobility enhancements, could also apply.</li> </ul>
7	Co-existence of deterministic and non-deterministic traffic	As captured in section 6.5.1, UEs need to be able to handle a mixture of periodic traffic with non-periodic high priority traffic as well as best-effort type of traffic. Due to the high requirements for TSN traffic (high number of users with very short periodicity traffic), a significant portion of available physical resources will be reserved to periodic high-priority TSN traffic. This may lead to inefficiencies in dynamic scheduling of other types of traffic.	The potential solutions to the issue include: <ul style="list-style-type: none"> <li>- Intra-UE or Inter-UE traffic multiplexing/prioritization or pre-emption, for example, using solutions described in TR 38.824 [8] or by allowing scheduling of non-adjacent resources with dynamic grants.</li> <li>- Deploying the network accordingly, e.g. via denser gNB or TRP placement (no specification impact)</li> </ul>

It should be noted that solutions for issues 2, 3, 4 and 7 may require modifications to physical layer specifications and the PHY layer impacts were not fully analysed.

## 6.6 Ethernet header compression

### 6.6.1 Scenario and benefits assessment

#### 6.6.1.1 General

Ethernet header compression is a means to reduce the overhead induced by transport of the Ethernet header. Ethernet frames may be transported over the 5G system in an Ethernet PDU session type. Header compression may especially be beneficial when payload sizes are relatively small compared to the overall size of the frame, which is typically the case in Industrial IoT networks based on Ethernet.

#### 6.6.1.2 Ethernet header fields

As an overview, IEEE 802.3 MAC Ethernet frame format is shown in IEEE 802.1Q, 2014, page 1703, "Figure G-1—Example of IEEE 802.3 MAC frame format" [9].

Some parts of the Ethernet frame do not need transmission over the 5G system, therefore TS 23.501 [10] states for the PDU session type:

*Ethernet Preamble and Start of Frame delimiter are not sent over 5GS:*

- *For UL traffic the UE strips the preamble and frame check sequence (FCS) from the Ethernet frame.*
- *For DL traffic the PDU Session Anchor strips the preamble and frame check sequence (FCS) from the Ethernet frame.*

Therefore, the fields PREAMBLE, SFD and FRAME CHECK SEQUENCE are not transmitted over the 5G system and can just be ignored in Ethernet header compression.

Furthermore, the DESTINATION ADDRESS (6 octets) and SOURCE ADDRESS (6 octets) fields provide the basic identifies of a station within the Ethernet layer. These fields may be static among subsequent packets, which can be exploited for compression.

The LENGTH/TYPE (2 octets) field may be used for length information or to define the 802.1QTagType, and can be used in compression. In most case where this is a TYPE-field the value would be static.

Tagging (Q-Tags) is widely used in Ethernet networks for traffic separation and marking. During forwarding various tags may be added to and removed from user data frames by the tag encoding and decoding functions of L2 nodes. The most common Q-Tags named explicitly for Ethernet header compression related contributions are:

- C-Tag: Tag Protocol Identifier (TPID) and Tag Control Information (TCI)
- S-Tag: Tag Protocol Identifier (TPID) + Tag Control Information (TCI)

These Q-Tags include not only a VLAN IDENTIFIER, but bits used for QoS purposes (e.g., PCP, DE) as well. Compression may not consider for example those QoS related bits.

Q-TAGs and all their sub-fields may be static, which can be used in compression.

There may be further fields within the Ethernet header for certain use-cases, which were determined not to be useful to be considered in structure-aware header compression.

### 6.6.1.3 Padding

The allowed minimum Ethernet frame length is 64 bytes. Any frame which is less than 64 bytes is illegal and dropped. Padding will be used to fill up the payload field of the Ethernet frame for payload data sizes smaller than the allowed field sizes. Padding is redundant, and furthermore, the 5G system transporting Ethernet frames does not expect Ethernet frame payload sizes of a certain defined length. Therefore, padding may either be removed, e.g. at PDU session level, or compressed as part of the header compression. Due to the absence of a length field in the Ethernet header indicating the actual payload size, additional complexity is required, when determining and compressing padding part of the payload field. The complexity property is related to the applied compression solution.

### 6.6.1.4 Benefit assessment

First of all, to analyse the gains, assumptions of the Ethernet payload sizes have to be considered. TS 22.104 ([6]) considers for example MTU sizes between 20 and 250 byte in several periodic deterministic communication service use-cases, and mentions also 1k-1.5k as payload size for certain use-cases in electrical power distribution and control-to-control motion control.

Given the minimum Ethernet frame size of 64byte, and assuming an Ethernet header size between 14byte and 22byte (considering SOURCE ADR, DESTINATION ADR, LENGTH/TYPE and potentially Q-TAGs), payload up to 40byte in the minimum Ethernet frame size can be considered. Padding would be used for lower actual payload sizes.

To estimate the benefit of header compression, an assumption needs to be taken to which size the header fields can be compressed. The following tables assume compression from 18 byte to 1, 3, 5 bytes respectively.

From R2-1816689 ([11]) relative gains in terms of reduction of overall frame size, assuming 1 byte compressed header:

**Table 6.6.1.4-1: Relative gains in terms of reduction of overall frame size, assuming 1 byte compressed header (Source: R2-1816689 ([11]))**

Header size without compression	Overall frame size without compression	Header size with compression	Overall frame size with compression	Relative reduction in overall frame size
18	64	1	47	27%
18	128	1	111	13%
18	1518	1	1507	1%

From R2-1817175 ([12]), relative gains in terms of reduction of overall frame size, assuming 3bytes and 5bytes compressed header (from 18byte uncompressed header):

Frame size (w/o FCS)	Gain with compression of header to 3 bytes (%) (src, dst, VID, E-type)	Frame size (w/o FCS)	Gain with compression of header to 5 bytes (%) (src, dst, VID, E-type)
64	23.44	64	20.31
128	11.72	128	10.16
256	5.86	256	5.08
512	2.93	512	2.54
1024	1.46	1024	1.27
1518	0.99	1518	0.86

**Figure 6.6.1.4-1: relative gains in terms of reduction of overall frame size, assuming 3bytes and 5bytes compressed header (from 18byte uncompressed header) (Source: R2-1817175 ([12]))**

Significant gains become obvious in the range of ~20-27% for frame sizes of 64byte, as well as ~10-13% for frame sizes of 128 byte, and moderate gains of ~5% for frame sizes of 256 bytes. For the maximum frame size of 1518 only marginal gains of around 1% are observed.

There is a trade-off between compression complexity and efficiency, i.e. to which minimum size the header can be compressed, with which effort e.g. in terms memory/cycle times. Given the analysis above showing high gains already for compression towards 3 or 5 bytes headers (instead of towards 1 byte), it appears sufficient to consider a simple solution only e.g. focusing on static header fields.

It is noted that potential additional gain in compressing/removing padding is not considered in above numbers. Also, compression schemes going beyond compressing the Ethernet header are not considered in the analysis above.

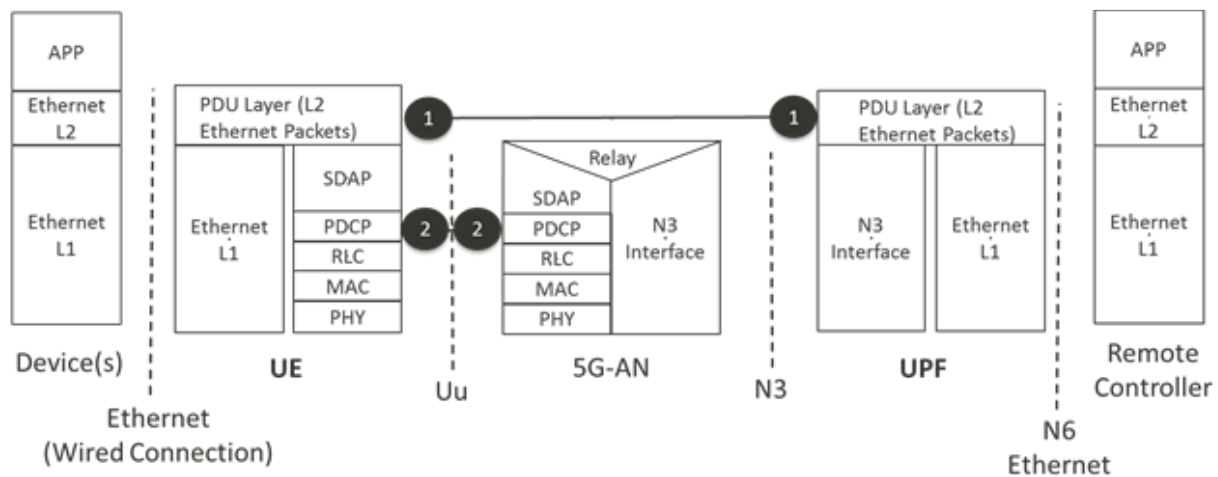
### 6.6.1.5 Industrial communication protocols using Ethernet

Beside support of generic Ethernet header compression, i.e. for IEEE 802.3 and/or IEEE 802.1Q, additional support for e.g. a wide range of industrial field-bus technologies building on those protocols, could potentially be considered, as discussed in R2-1817572 ([13]). It would require deep packet inspection to support many flavours of industrial protocols, leading to higher complexities.

## 6.6.2 Potential solutions

### 6.6.2.1 Protocol layer

One aspect of the solution development of the Ethernet header compression function is its placement, i.e. in terms of protocol layer as well as network protocol termination point. IP header compression today is done by Robust Header Compression (RoHC), which is part of PDCP, thus compression is done between UE and gNB [14]. Ethernet header compression could be anchored similarly on PDCP. See for example R2-1817913 ([15]) or R2-1816765 ([16]) for further details. An alternative option, mentioned in R2-1816689 ([11]), would be header compression between UE and UPF, where the (Ethernet) PDU session is terminated.



**Figure 6.6.2.1-1: Potential Ethernet header compression anchor points (Source: R2-1816689 ([11])).**

Overhead reduction resulting from Ethernet header compression may be only relevant over the radio interface Uu, assuming that the (wired) N3 interface has sufficient bandwidth. Therefore, Ethernet header compression between UE and gNB is the only relevant option (i.e. indicated as 2) in the figure. Furthermore, the natural protocol level choice is PDCP, as it is the layer that today provides ROHC functionality. As concluded from R2-1816765 ([16]), it would not be suitable to perform Ethernet header compression in MAC or RLC layer due to the encryption / integrity protection performed in PDCP layer. SDAP layer is not a suitable layer either. SDAP layer mainly maps QoS flows to DRBs. Adding Ethernet header compression functionality does not conform to the main functionality of SDAP layer. Lastly, adding a new layer on top of SDAP layer purely for Ethernet header compression is not justified. There is additional complexity when Ethernet header compression and ROHC are used together if Ethernet header compression is in a different layer other than PDCP. Given that ROHC is PDCP layer functionality and Ethernet header compression has the same motivation as ROHC, it is natural that Ethernet header compression functionality is in PDCP layer.

### 6.6.2.3 Relation to IP header compression

Ethernet may transport IP or non-IP traffic. This aspect is mentioned in e.g. R2-1817572 ([13]). IP header compression may be considered when Ethernet header compression is employed, in which case both independent/separate header compression solutions can be envisaged as well as a joint/integrated header compression of Ethernet and IP. Given the complexities inherent in a joint compression scheme, and the benefits of a modular approach, the developed structure-aware Ethernet header compression scheme should not consider IP header compression within a joint solution.

### 6.6.2.4 Design principles

Based on the analysis above, as a summary, the solution for header compression would build on the following principles:

- Preamble, SFD and FCS are ignored are not transmitted thus not considered in Ethernet header compression.
- Ethernet header compression considers the header fields DESTINATION ADDRESS, SOURCE ADDRESS, TYPE/LENGTH, Q-TAGs (including all sub-fields), but no further fields of the Ethernet header for structure-aware compression solution.
- Additional complexity of removing padding in Ethernet header compression must be justified.
- Further industrial protocols above Ethernet are not considered in structure-aware Ethernet header compression.
- The developed structure-aware Ethernet header compression scheme does not consider IP header compression within a joint solution.
- For structure-agnostic compression scheme, further fields, further industrial protocols above Ethernet, IP header are compressed together with Ethernet header.
- PDCP at gNB is the network anchor for Ethernet header compression.

### 6.6.2.5 Solution approaches

The following potential solution approaches were discussed in this study:

#### New PDCP solution

Ethernet header compression may be specified by RAN2 within a new solution integrated in PDCP. This study did not compare the performance in terms of complexity and compression ratio/gains between New PDCP solution and other solutions such as ROHC. The advantage of this approach would lie in the standardization process, i.e. a pure RAN2-based solution would avoid potential impact/dependencies to other specification groups or bodies.

#### ROHC-based solution

Ethernet header compression may build on the ROHC-framework, which is currently used for IP-header compression and applied on PDCP layer. A ROHC profile specific to the Ethernet header would need to be defined, meaning that the existing ROHC framework and features would be reused and do not need to be developed. R2-1817913 ([13]) analyses the benefits of this approach. For example, robustness of compression against packet losses and in-built handling for multiple flows. On the other hand, ROHC profiles are defined by IETF for TCP/UDP/RTP/IP protocols, and Ethernet is defined by IEEE. It is unclear how 3GPP can define a new ROHC profile and if/how IETF/IEEE adopts such new ROHC profile. In addition, ROHC profile identifiers may need registration with IANA. Such collaboration/liaison with other standard bodies may add uncertainties and could delay the work completion.

#### UDC-based solution

In LTE, Uplink Data Compression (UDC) [17] is defined in PDCP specification and based on IETF RFC 1951 (DEFLATE Compressed Data Format Specification) [18], and allows a generic compression of PDCP SDU data. It is unaware of the header structures of higher layer PDCP payload, i.e. Ethernet in this case. This way, also further headers of protocol layers above Ethernet including IP header, as well as padding and payload data, may be compressed. This study did not compare the performance in terms of complexity between UDC-based and other header-structure-aware schemes such as ROHC. An advantage of the UDC-based approach would also be that it is a pure RAN2 based solution without impacting to other specification groups or bodies.

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## 7 Conclusions

RAN WGs analysed various issues and solutions as per the objectives described in [2] and the conclusions and recommendations are provided below for each of these objectives respectively.

#### PDCP duplication enhancements

Various enhancements for PDCP duplication framework were analysed, as captured in section 4.2, and the following is concluded:

- For increased reliability, it is recommended to support PDCP duplication enhancement with up to 4 copies. To achieve that, it is recommended to specify the following enhancement:
  - Support of PDCP duplication with up to 4 RLC entities configured by RRC in architectural combinations including CA, and NR-DC in combination with CA. It is assumed that all RLC entities are configured with the same transmission mode.
  - Support of dynamic control of how a set or subset of configured RLC entities or legs are used by the UE for PDCP duplication, e.g. using MAC CE. Other methods of leg selection are not precluded.
- The solutions to increase resource efficiency when PDCP duplication is activated were analysed, including: per-packet selective duplication, selective discard mechanism, activation/deactivation of PDCP duplication enhancements. Based on the analysis in the SI, as captured in section 4.2.1, it is recommended to specify activation/deactivation of PDCP enhancements, e.g. MAC CE based or based on UE configurable criteria, provided that complexity increase is reasonable. Other solutions are not precluded, e.g. per-packet selective duplication. Enhancements for selective discard are not required.

Enhancements to improve resource efficiency in the downlink were discussed in RAN3. From RAN3 perspective, it is recommended that the Rel-15 PDCP duplication functionality should be taken as baseline, and enhancements for efficient DL PDCP duplication without impacting the UE may be specified, provided that gains can be confirmed with a reasonable complexity.

### Higher layer multi-connectivity impacts on RAN

RAN WGs have analysed higher layer multi-connectivity solutions as studied by SA2 and RAN impacts are explained in section 4.3. RAN impact analysis was communicated to SA2. Depending on further normative work in SA2, RAN2 and RAN3 may need to perform some specification work as well.

### Intra-UE prioritization and multiplexing

RAN 2 has analysed intra-UE prioritization and multiplexing for scenarios 1-5 as captured in section 5.2. It is deemed feasible to support enhanced prioritization between different traffic types and priorities as described by these scenarios. Additionally, a scenario where conflicts between multiple active configured grants occur should be addressed. In particular, based on the analysis, the following is recommended to be undertaken in the WI phase:

- Specification of enhancements to address scenario 2 and conflicts involving multiple CGs.
- Address scenario 3 under the assumption that the later dynamic grant may always be prioritized over an earlier dynamic grant, e.g. by MAC generating a PDU for each grant and letting physical layer to handle the conflicting transmissions (this solution requires further physical layer aspects evaluation). Other solutions may be considered.
- Specification of grant prioritization in MAC based on LCH priorities and LCP restrictions for the cases where MAC prioritizes the grant.
- Address a resource collision between SR associating to high-priority traffic and uplink data of lower-priority traffic, e.g. by specifying a prioritization handling rule to determine whether to transmit SR or PUSCH based on, e.g. the priority of the LCH which triggers the SR and priorities of the data to be transmitted on the PUSCH resource.

RAN1 has briefly discussed scenarios 1-5. RAN1 recommends to support the handling of scenarios 1 and 3, to allow the prioritization of configured grant over dynamic grant under some conditions in case of collision in scenario 2, and to support enhancements for scenario 4 and 5, following the guidelines and candidate solutions provided in section 5.3 and 5.4.

### Performance evaluation of TSN requirements

RAN WGs have analysed TSN requirements as captured in section 6.3.1 and it is concluded that NR, with some additional enhancements introduced in Rel-16, can meet the requirements in TS 22.104 with respect to latency, reliability and synchronization accuracy for some network configurations and deployments, but the performance depends on such aspects as utilized subcarrier spacing, FDD or TDD network type, backhaul type, cell density etc.

### Accurate reference time provisioning

In order to enable precise time synchronization using 5G/NR system, it is recommended to specify accurate reference timing delivery from gNB to UE using broadcast and/or unicast RRC signalling. The signalling specified in Rel-15 for E-UTRA can be used as a baseline, but the time information should have granularity no higher than 50 ns. The final design may also depend on SA2 decision with respect to overall synchronization solution.

### Enhancements (e.g. for scheduling) to satisfy QoS for wireless Ethernet when using TSN traffic patterns

Based on analysis of TSN traffic characteristics, the following enhancements are recommended for specification:

- Support of provisioning, from Core Network to RAN, of TSN traffic pattern related information such as message periodicity, message size, message arrival time at gNB (DL) and UE (UL).
- Support for multiple simultaneous active CG and SPS configurations for a given BWP of a UE.
- Support for shorter SPS periodicities than the existing ones

In addition, it is concluded that NR should address the following issues related to TSN traffic characteristics:

- Support TSN message periodicities with non-integer multiple of NR supported periodicities. Candidate solutions are captured in section 6.5.2. The choice and the details of the solution should be decided in WI phase.

It is noted that the scheduling enhancements related to TSN traffic patterns may have impact on physical layer and RAN1 needs to be involved in the related work in WI phase.

**Ethernet header compression**

With respect to Ethernet header compression, RAN2 concluded that it is beneficial in the context of Industrial IoT use cases. The solution for header compression should be built using the principles in Section 6.6.2.4.



## Annex A:

### Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
09/2018	RAN2#103 bis	R2-1814990				Skeleton	0.0.0
11/2018	RAN2#104	R2-1817266				Incorporates TP from R3-186254 on higher layer multi-connectivity.	0.0.1
02/2019	RAN2#105	R2-1900629				Sections on intra-UE prioritization/multiplexing, TSN performance evaluation and QoS scheduling and enhancements updated following the TPs agreed during RAN2#104 meeting.	0.0.2
02/2019	RAN2#105	R2-1900630				Clean version of V0.0.2 (without revision marks).	0.1.0
03/2019	RAN2#105	R2-1902776				Version includes TPs agreed during RAN1#96, RAN2#105 and RAN3#103 on PDCP duplication, higher layer multi-connectivity, intra-UE prioritization/multiplexing, TSN performance evaluation, accurate reference timing provisioning, QoS and scheduling enhancements, Ethernet header compression. It also includes the agreed conclusions of the Study Item. Additionally, editorial corrections, clean-up of the document, abbreviations added and removal of the unnecessary parts/sections of the TR.	0.1.1
03/2019	RAN2#105	R2-1902777				Clean version of V0.1.1 (without revision marks).	0.2.0
03/2019	RAN#83	RP-190189				Formatting corrections with respect to V0.2.0. Submitted to RAN#83 for approval.	1.0.0
03/2019	RAN#83					Approved and upgraded to version 16.0.0	16.0.0