MF.TR.156 V2.0.0 (2024-05)

Technical Report

Simplified Uni5G™ Technology Blueprints for 5G Industrial Devices and Ecosystem

Release 2.0

MFA

Postal address

5177 Brandin Court

Freemont, CA 94538 USA

Internet

https://www.mfa-tech.org/

Contents

Foreword

This Technical Report has been produced by the MFA.

The contents of the present document are subject to continuing work within the Technical Specification Group (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:

Version x.y.z,

where:

- x the first digit:
  - 1 presented to TSG for information
  - 2 presented to TSG for approval
  - 3 or greater indicates TSG approved document under change control.
- 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.

1 Scope

This document classifies selected 3GPP Rel-15 User Equipment (UE) feature groups [1] into functionalities for the purposes of identifying UE blueprints suitable for deployments in 5G private networks. The functionalities are further mapped to four specialized feature categories, defined to match the most relevant attributes for 5G NR private networks deployments.

Recommended UE blueprints indicate which of the four specialized feature categories are suitable for considered deployments and use cases. The focus of this document is Layer 1 features.

For each listed NR UE feature group, the corresponding field name of UE capability, as specified in TS 38.331 [2] is also captured in this document.

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 38.822: “User Equipment (UE) feature list”, v16.1.0 (2021-09)”.

[2] 3GPP TS 38.331: “NR; Radio Resource Control (RRC) protocol specification”.

[3] 3GPP TR 21.905: “Vocabulary for 3GPP Specifications”.

[4] mf2021.005.00: “Beecham research report”.

[5] mf2022.001.00: “Nokia – Proposals for blueprint examples”.

3 Definitions and Abbreviations

3.1 Definitions

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

example: text used to clarify abstract rules by applying them literally.

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [3] 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 [3].

Abbreviation	Definition
eMBB	Enhanced Mobile Broadband
FG	Feature Group
MCL	Maximum Coupling Loss
MFA	MulteFire Alliance
NR	New Radio
RWG	Radio Working Group
TSG	Technical Specification Group
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communications

4 Classification of UE Features

UE features suitable for 5G NR private network deployments may vary depending on the deployment type and specific use cases. To identify features suitable for 5G industrial devices and to help develop the corresponding device ecosystem, Beecham research has conducted a study by interviewing seven different sectors when deployment of 5G private networks is suitable. The interviewed sectors included hospitals, oil and gas, mining, agriculture, airport, warehouses, and ports, and the findings were summarized in [4].

Based on the findings in [4], and accounting for the eMBB service as a baseline, the RWG identified the following attributes as the most relevant for 5G private networks for industrial applications:

- Coverage
- Reliability
- Connection Density
- Latency

Each of these attributes is associated with a list of UE feature groups (FG)[1] [1], and mapping is based on the criteria given in Table 1.

The FGs are associated with the attributes if the following requirements are met:

- The FGs that improve UE performance with respect to associated attribute under most common deployment scenarios and use cases are included.
- The FGs that may improve performance under some scenarios and degrade performance under some others are not included.

[1] Unless indicated otherwise, FG index refers Layer 1 FG index.

Table 1: Criteria to Map Features to Attributes

Attribute	Criteria
Coverage	Feature groups that can support MCL larger than baseline eMBB
Reliability	Feature groups that can be used to achieve improved reliability than baseline eMBB
Connection Density	Feature groups that relieve control channels from being the performance bottleneck and that optimize UE performance for scenarios where pre-emption need to be utilized.
Latency	Feature groups that can be used to achieve lower latency than baseline eMBB

To ease the understanding of the categorized FGs, FGs are further grouped into feature categories based on the functionality they provide before being associated to the corresponding attribute. Each feature category can be mapped to multiple attributes. Table 2 lists the feature categories, the associated definition based on the functionality they provide, and associated FGs.

Table 2: Definitions of Feature Categories

Index	Name	Description	Associated FGs†
C1	Ultra-reliable CQI/MCS	CQI and MCS tables that facilitate ultra-reliable transmission of data where BLER target is several orders of magnitude lower than that of eMBB.	2-32c, 5-34, 5-34a, 5-34b, 5-34c
C2	Mini-slot	Minimum scheduling unit, smaller than regular slot; A “mini-slot” can start at any OFDM.	5-6, 5-6a, 5-11, 5-11a, 5-11b, 5-12, 5-12a, 5-12b
C3	PDCCH processing	Processing requirement for DCI reception at any OFDM symbol in a slot.	3-2, 3-5, 3-5b
C4	UL configured grant	UL configured grant enables UE to transmit periodic traffic without control signalling to request and grant UL resources.	5-19, 5-20, 3-6*
C5	DL semi-persistent scheduling	DL SPS enable gNB to transmit periodic low-rate traffic over pre-granted PDSCH resources to avoid transmitting DCI for DL data channel assignment.	5-18
C6	Repetition	PHY/MAC repetition schemes for duplication of critical data and control; duplication may be over different time-frequency resources.	5-14, 5-16, 5-17, 5-17a
C7	HARQ-ACK	To reduce round-trip time, HARQ-ACK is allowed to be piggyback on a PUSCH that is different from the starting OFDM symbol of PUCCH that HARQ-ACK would have been otherwise transmitted on.	4-28
C8	UE processing capability 2	A UE with processing capability 2 has reduced PDSCH and PUSCH processing time.	5-5a, 5-13, 5-13a, 5-13c, 5-5c, 5-13d, 5-13e, 5-13f
C9	PDCP duplication	PDCP duplication refers to implementation of parallel and redundant PDCP protocol, which diversifies transmission of data over multiple links to improve reliability.	1-6*
C10	Pre-emption indication	Pre-emption indication for DL.	5-21

Notes:
* Indicates Layer 2 FG index.
† Associated feature groups from 3GPP TR 38.822 [1].

Table 3 presents the association between feature categories and attributes. The current version of the technical report includes FGs defined in Release 16 of 3GPP specification [1].

Table 3: Association of Feature Categories and Attributes

Feature Category	Coverage	Reliability	Connection Density	Latency
Ultra-reliable CQI/MCS	X	X	–	–
Mini-slot	–	–	–	X
PDCCH processing	–	–	X	X
UL configured grant	–	–	X	X
DL semi-persistent scheduling	–	–	X	–
Repetition	X	X	–	–
HARQ-ACK	–	–	–	X
UE processing capability 2	–	–	–	X
PDCP duplication	–	X	–	–
Pre-emption indication	–	–	X	–

4.1 Ultra-reliable MCS

To adapt to dynamic radio link, 5G NR performs adaptive modulation and coding on DL with the assistance of a table of channel-quality-indicator (CQI) and that of modulation-and-coding-scheme (MCS). Specifically, UE reports a CQI pointing to an entry in the CQI table to assist gNB to adaptively select a MCS defined in the MCS table. For typical eMBB use cases, the two tables are designed to achieve block error rate (BLER) around 1e-2 with the end-to-end delay being of a few milliseconds.

To achieve higher reliability levels (say, BLER as low as to 1e-5) together with lower latency (say, <1 millisecond), Rel-15 specified an additional pair of tables ─the ultra-reliable CQI table including new entries for CQI report targeting at lower BLER, and the ultra-reliable MCS table including new entries supporting lower spectral efficiency, as illustrated in Figure 1.

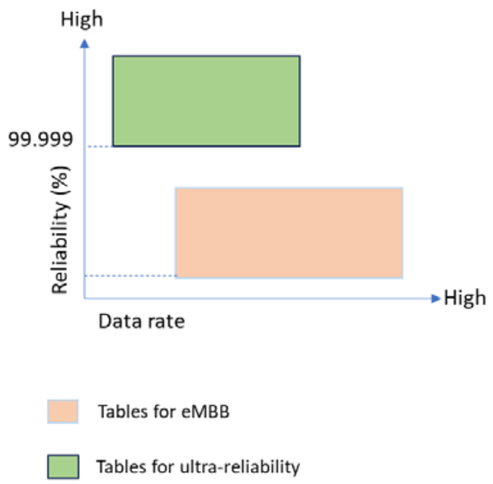


Figure 1: Separate MCS table and CQI table are introduced to facilitate ultra-reliability (say, 99.999%)

Ultra-reliable MCS enables operations-critical connectivity for industry verticals deploying applications that require coverage and reliability. Shipping ports encompass large indoor and outdoor environments, moving machinery, containers, supplies, and more. Reliable service is necessary to provide real-time video surveillance, remote control of crane and machine operations, container truck tracking, and drone inspection of port operations, among other activities.

4.2 Mini-slot

Rel-15 NR defines the slot size as 1ms, corresponding to 14 symbols under 15kHz subcarrier spacing (SCS) and normal cyclic prefix (CP). In order to meet the strict latency requirements of URLLC traffic, further reduced slot sizes have been defined, also called “mini-slots”. The supported mini-slot sizes are 2, 4, or 7 symbol duration. When transmission is scheduled in those mini-slots this is also called “non-slot-based scheduling”.

Support for PDSCH with 2, 4, or 7 symbol durations is optional for UEs, and they are indicated by separate UE capabilities. Similarly for PUSCH support is optional and indicated by separate UE capabilities for 2, 4, or 7 symbol duration mini-slots. For example, if the UE supports scheduling of up to 7 PDSCHs per slot in the same carrier, this means that gNB may schedule up to 7 PDSCH transmission of 2-symbol duration for that particular UE within the same slot. Please note the slot definition itself is not changed for UEs supporting mini-slots.

The mini-slot scheduling feature applied in a manufacturing setting enables lower latency and boosted scheduling efficiency. Providing enhanced operation management for demanding technical environments - including connected robots, autonomous guided vehicles, and more - mini-slot scheduling allows for more agile equipment control.

4.3 PDCCH processing

Rel-15 PDCCH Monitoring requires that the UE monitor across an NR slot (14 OFDM symbols) and process 1 downlink channel and up to 2 uplink channels for a typical industrial TDD configuration. In order to ease the blocking of these critical control channels, UEs can signal capability to monitor PDCCH candidates within 3 symbols and/or within short time gaps of PDCCH candidates. Rel-16 enhancements improve the latency of detecting and processing of the PDCCH but reducing the time span in which the PDCCH has to be monitored and when detected, processed. Time spans short as 2 OFDM symbols are supported thus reducing latency.

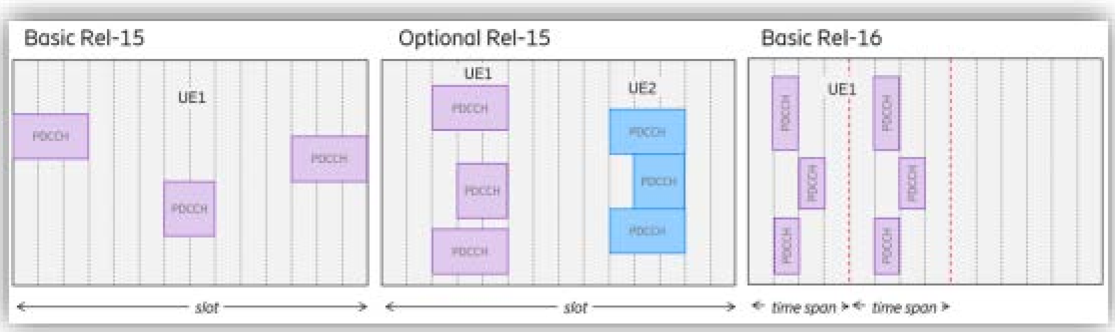


Figure 2: Enhanced PDCCH processing

In complex industrial scenarios with many UEs and varying data traffic, enhanced PDCCH monitoring reduces blocking probability of critical control channels by increasing the network's scheduling flexibility. For instance, in a manufacturing setting, PDCCH processing will enhance scheduling protocols and boost overall process efficiency for automated devices on the network; vital during critical and high-demand periods.

4.4 UL configured grant

Rel-15 introduced Uplink Configured Grants which allows the deterministic delivery of critical uplink data Figure 3. In Rel-16, this has been further enhanced to allow multiple configurations to be assigned to a UE. These configurations can be stored in the UE and up to 12 UL CG configurations can be simultaneously active. Furthermore, Rel-15 supported binary periodicities, and these are extended in Rel-16 to integer-multiples allowing further flexibility in scheduling uplink traffic.

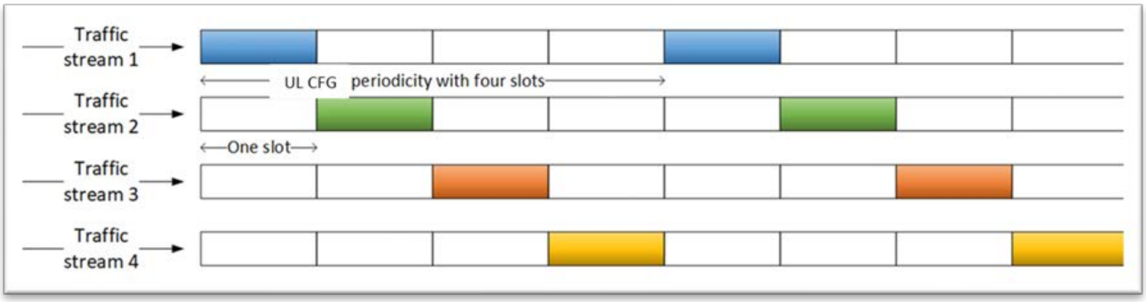


Figure 3: Enhanced Uplink Configured Grant

Control loops with feedback - or critical sensors such as IMUs and video cameras - are omnipresent in industrial scenarios. Modern video cameras support various coding rates and modes, which may require rapid switching and efficient signaling in the network. Industrial concentrators for sensors reduce cost/power consumption at the sensor and allow potentially heterogeneous traffic flows to be managed by the wireless network. An AGV also has a variety of sensors requiring various QoS levels, data rates, and periods feeding information to the network, where control functions reside. AGVs with multiple uplink configured grants, provides an efficient means of transporting critical data for industrial users.

4.5 DL semi-persistent scheduling

The concept of Downlink Semi-Persistent Scheduling (SPS) was already introduced in LTE 4G to handle Voice Over IP (VoIP) to improve efficiency. Voice was required by many users in the system and since the voice traffic was relatively low bit rates, control signalling became a larger part of the overhead and SPS dramatically reduced this overhead.

In 5G, critical industrial uses cases have similar profile to voice in that there is a steady flow of data at periodic intervals which may have small payloads per user but the 5G system is required to handle many users. Control signalling overhead can be reduced with the introduction of the SPS feature.

Rel-15 introduced Semi-Persistent Scheduling which is like Uplink Configured Grant but for the downlink. In Rel-16, this has been further enhanced to allow multiple configurations to be assigned to a UE. These configurations can be stored in the UE and up to 8 SPS configurations can be simultaneously active. Rel-15 supported binary periodicities, and these are extended in Rel-16 to support real-world values allowing further flexibility in precisely matching the packet size and rate of the industrial use case.

SPS usage in industrial settings results in improved process and AGV control. For example, process control can have a period of 20 ms and a small, fixed payload of 64 bytes – significantly increasing efficiency and response times. SPS can also be used for a human-machine interface (HMI) emergency button, where a watchdog supervision message is sent every 5 ms to the hosting device with an expectation of acknowledgement, increasing safety measures for equipment and staff.

4.6 Repetition

Repetition involves sending the same transport block multiple times to increases the chances of successful reception even if some copies are corrupted. It improves the reliability in a proactive way and, hence, as well reduces over-the-air (OTA) latency by not relying on feedback indication of data corruption.

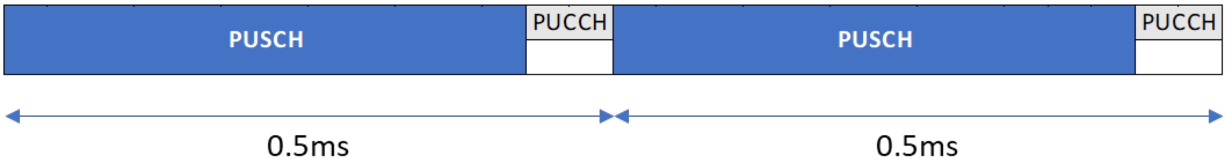
Rel-15 supported fixed number of repetitions over either PDSCH or PUSCH with static configurations over RRC. Rel-16 further specified new DCI field so that gNB can dynamically adapt the applied number of repetitions for different types of data flows with different reliability requirements. In addition, Rel-16 specified PUSCH repetition type B so that two-or-more PUSCH repetitions can be performed in one slot, or across a slot boundary in consecutive available slots, for benefit of low latency.

Automated manufacturing requires network reliability to maximize production and minimize downtime. In highly automated manufacturing environments, increased coverage and reliability is essential for maintaining operational requirements and staff safety. High availability is crucial in any manufacturing process for real-time operations such as connected manufacturing robots, autonomous guided vehicles, remote diagnostics, and inspection.

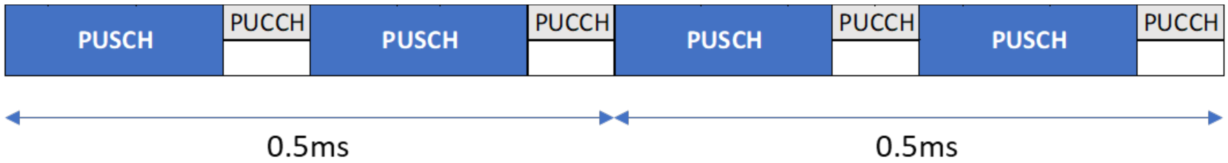
4.7 HARQ-ACK

HARQ operation has direct impact on round-trip time and thus on latency, especially in case of errors in the initial transmission. In Rel-15, one resource allocation scheme supporting URLLC-type of traffic is shown in Figure 2 (a), where a short PUCCH is allocated at the end of every slot, time multiplexed with PUSCH allocations.

Rel-16 further extended the HARQ framework to incorporate aspects of URLLC traffic. It introduces sub-slot based HARQ-ACK feedback to reduce delay for transmission of HARQ-ACK feedback in PUCCH, an example of which is shown in Figure 2 (b).



(a)



(b)

Figure 4: (a) Example resource allocation scheme to support URLLC-type of traffic in Rel-15. (b) 2 sub-slot PUSCH and 2 PUCCH allocations, possible only if UE indicates support to the corresponding UE capability. The examples assume 30kHz subcarrier spacing.

In addition, Rel-16 introduces support to two-HARQ codebooks, which improves reliability for service with higher priority (physical layer prioritization). The two-HARQ codebooks support slot-based or sub-slot-based transmissions, separate PUCCH configurations, and two priority levels for HARQ-ACK.

HARQ-ACK is a viable option for providing low latency to smart farms - particularly those located in rural environments. Farming equipment, including tractors and IoT sensors for irrigation systems, benefit from reliable connectivity by ensuring remote situational awareness of the entire farming and livestock operation.

4.8 UE processing capability 2

Another important tool for latency reduction defined in Rel-15 NR is the UE processing capability 2. UEs supporting the related UE capabilities support shorter processing time, hence resulting in faster turn-around for the corresponding HARQ processes. The baseline is UE processing capability 1, supported by all UEs, which defines the number of symbols a UE has to process a PDSCH. The exact value depends on subcarrier spacing (SCS), as defined in TS38.214 Tables 5.3-1 and 5.3-2. In concrete terms, for a typical case of 30kHz SCS, the processing times are as shown in Table 4.

Table 4: Processing time for UE processing capability 1 and 2

	Symbol duration	Processing time with UE processing capability 1 (default)	Processing time with UE processing capability 2 (optional)

FR1, 30kHz Subcarrier Spacing	~36µs	~360µs	~161µs

The UE can indicate support to the faster processing capability separately for each link direction (i.e. PUSCH or PDSCH) and for each supported transmission duration, including mini-slots. Please note this feature is supported only for Frequency Range 1.

Latency reduction and quick turnaround may be desirable for the deterministic transfer of data in industrial use cases within a cable-free environment. To further reduce latency, the UE processing capability 2 can be deployed to support automated devices on a factory floor.

4.9 PDCP duplication

PDCP duplication involves transmitting a single PDCP packet to two or more independent radio link entities, as illustrated in Figure 2 so that the PDCP packet can exploit diversity via being transmitted over different radio channels to achieve higher reliability and to reduce the time delay by eliminating need for retransmission.

PDCP duplication was first introduced in Rel-15, which basically supported duplication of a PDCP packet over two RLC entities for both user and control planes. Rel-16 further enhanced this feature with up to four RLC entities in architectural combinations including CA only and NR-DC in combination with CA. In addition, Rel-16 supports dynamic control of how a set or subset of configured RLC entities are used for PDCP duplication.

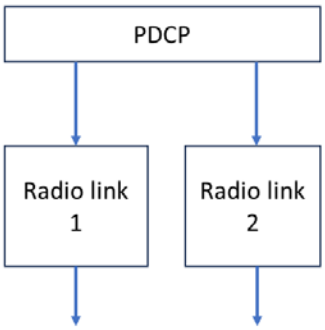


Figure 5: PDCP duplication enables a single PDCP packet to be transmit over at least two independent radio links.

Mining industries are turning toward smart solutions to improve worker safety, productivity, and autonomous operations. The reliability provided by a private wireless network ensures consistent connectivity to minimize interruption, driving increased employee and machine efficiency.

4.10 Pre-emption indication

Pre-emptive scheduling allows for gNB to schedule a mini-slot with URLLC-type of traffic that overwrites an ongoing eMBB-type of transmission of lower priority in the same slot. This avoids the need to wait for the conclusion of current slot before an URLLC transmission can be scheduled to the same UE.

Industrial operations requiring very low latency may deploy this feature to ensure certain applications and data transmissions are prioritized. For example, pre-emption indication can be used for robotics and AGVs to prioritize control information over data transfer in critical situations.

Annex A: Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2022-04-12						First version	1.0.0
2022-05-15						Second version	2.0.0