**Deliverable D4.2**  
5G Network Functionalities  
(first version)

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1 INTRODUCTION

This deliverable, being the first output of Task 4.2 ("5G network functionalities"), aims to describe the first version of the design and implementation of 5G functionalities required by the third pillar ("efficient, reliable and trustworthy computation & communication infrastructure") of the IntellIoT proposed framework. This pillar aims at addressing two of the 5 IntellIoT identified objectives.

**Objective 2:** Enable ultra-reliable low-latency communication over heterogeneous networks to enable tactile (real-time) and contextual (adaptive) interaction between IoT devices, humans, and services.

This deliverable will describe the state-of-art architecture and standard of 5G network, as well as preliminary results obtained to meet this objective. In particular, this deliverable will present the 5G network functions supporting URLL communications.

**Objective 5:** Development of a reference implementation of the IntellIoT framework, demonstrated and evaluated in the three use case areas: agriculture, healthcare and manufacturing.

This deliverable provides the description of the 5G architecture proposed to be developed for the IntellIoT framework, as well as the set of 5G network functions, which will be deployed in the different use cases.

As 3GPP is a constantly evolving set of specification, IntellIoT will develop its innovation based mostly on 5G NR rel. 15 and rel.16 for framework development and implementation, and anticipating future 5G NR rel.17 and rel.18 in its research and evaluation. The developments of the 5G network will be based on EURECOM's OpenAirInterface and Mosaic5G, where the required functions will be built upon existing NR & MEC/Edge functionalities.

From the Component perspectives, 5G Network Functions consists of the 5 components emphasized in red on Figure 1. First, private 5G Core and RAN will be developed to support private 5G NR radio access for IntellIoT functions, in particular URLL. Second, a 5G low latency MEC will be developed to deploy edge applications close to a 5G edge and therefore reduce the service latency. Finally, a 5G network monitoring and statistic component will be developed to provide 5G statistics and real-time performance to other components, in particular the Edge Orchestrator and the 5G Communication Resource Manager.
Figure 2 IntellIoT Component Architecture, with the 5G part highlighted

As it can be seen on the component architecture of Figure 2, the 5G components are expected to have a strong interaction with other components developed in different tasks and WPs. In particular, T4.2 will take input from Task 2.1 (“Use cases specification & Open Call definition”), Task 2.2 (“Technology analysis & requirements specification”), and Task 2.3 (“Architecture specification & interoperability”) related to the use case objectives, and required components.

Dedicated 5G Edge/MEC APIs will need to be provided for the MEC/Edge services from T4.1 (“IoT/edge infrastructure management”), and the 5G dynamic management solutions developed in Task 4.3 (“Dynamic network management”) will be integrated into the 5G architecture to meet the 3rd pillar requirements and optimize the use of the wireless resources. Finally, the output of Task 4.4 (“Trustworthy infrastructure by design”) will be considered in the design of the 5G network functions.

Finally, at the start of the IntellIoT 2nd Cycle, the outcome of the IntellIoT 1st Cycle in various WPs will be closely considered to enhance the 5G Network Functionalities to be developed in the 2nd Cycle. More details of the interplay between Task 4.2 and other tasks or WP are depicted on Figure 3.
Task 4.2 follows IntellIoT cycle-based development depicted in the figure below, which consists of two sequential cycles, coinciding with one Open Call. The Cycle-based prioritized developments of Task 4.2 are described below.

Task 4.2 is expected to contribute to reaching the following four key performance indicator (KPI).

**KPI 2.1:** Extending 5G network functionalities supporting URLL & eMBB for the needs of the 3 use cases.

In the 1st Cycle, Task 4.2 will first extend OAI and Mosaic5G to support a standalone 5G NR network for a frequency range < 6Ghz. It will develop and evaluate in a controlled environment enhanced 5G numerology matching URLL requirements. In the 2nd Cycle, Task 4.2 will extend the 5G NR network to millimeter wave spectrum (>20Ghz) and validate the new URLL numerology in the target environments at both frequency ranges. TRL 5 will be reached.

**KPI 2.2:** TSN functions integration in computation & communication infrastructure (combined with 5G)

In Task 4.2, the TSN extensions to 5G network in order to support an end-to-end TSN link will be considered only in the 2nd Cycle. A TRL level 3 is expected due to the prospective status of the 3GPP standards in that domain.

**KPI 2.3:** Enabling heterogeneous networking technologies: LTE, 5G NR, Cellular IoT, D2D

In the 1st Cycle, Task 4.2 will extend OAI 4G architecture to support 5G. Heterogeneous technologies will be reached by supporting two 5G architectures called non-standalone and standalone, where the former has heterogeneous
technology limited to the wireless part, while the latter extends the former with heterogeneous technologies on the network side. In the 2nd Cycle, Task 4.2 will add a D2D support and provide management functionalities to the underlying heterogeneous technologies.

**KPI 2.4: Enabling wireless TSN-grade D2D scheduler for decentralized computing in IoT context**

In the 1st Cycle, Task 4.2 will evaluate the performance of the state-of-art 5G NR V2X technology. In the 2nd Cycle, advanced mechanisms will be proposed to support TSN-grade D2D radio resource management in term of ultra-reliability and in term of guaranteed low delay.

This deliverable provides a description of the developments in the 1st Cycle, whereas the deliverable D4.6 ("Network Functionalities - Final") will include the developments completed during the 2nd Cycle.

### 1.1 Key 5G Innovations for 5G Infrastructures

If the general public considers 5G as providing only higher capacity on Radio Access Network (RAN), 5G provides significantly more new functionalities in terms of dynamic management and optimization of all 5G functions. We describe next the

- **5G Private Network** - This corresponds most likely to the biggest innovation of 5G in terms of enabling 5G not only being virtually operated but physically operated by various stakeholders. 5G Private Networks consist of being able to host and operate a 5G network in a particular location, and controlling all aspects of such network. First, 5G spectrum should not be commercial and be available to private 5G operators. Private spectra are gradually being defined in various EU countries. Second, it consists of operating a 5G network, therefore, hosting a 5G Core at the premises. Finally, it is to control data flow within the private 5G network, therefore, maintaining a strict privacy and accountability for data gathered by a particular stakeholder.

- **5G URLL** - The target objectives of 5G network are to reach the 1 ms RAN latency as well as >3 Gbps RAN capacity. Reaching a 1 ms RAN latency requires a more flexible radio resource numerology in order to avoid multi-subframe resource allocations. It also requires a larger bandwidth, which could be reached over millimetre wave spectra (a.k.a. FR2). It finally needs to have an optimal data-driven radio resource allocation entity, which could be capable of anticipating/predicting the required resources and reserve the ones providing the most reliable and lowest latency.

- **5G Edge/MEC** - Low latency must not only be guaranteed on the RAN links, but also in the back-end links. Accordingly, 5G applications and services should be deployed closer to the UE point of attachment. 5G edge/MEC architectures are another key 5G innovation, enabling applications to be deployed, managed and optimized at the network edge. Although MEC has been specified by ETSI, a harmonization between 3GPP edge and ETSI MEC specification is currently being done to propose a harmonized 5G architecture enabling web technology solutions to be fully integrated in 5G networks.

- **5G D2D** - while D2D communications have already been proposed in 4G, its limited functions or limited 4G links did not provide the expected success from such radical innovation. 5G D2D is being developed, with 5G V2X specification already being available, to benefit from the 5G RAN and Core innovations for D2D. For example, 5G D2D is expected to support URLL, slicing as well as decentralized edge applications.

- **5G TSN** - While TSN is critical in industrial networks, its availability in the wireless domain has so far been limited to sensor or WIFI technologies. With the development of Private 5G networks, TSN support becomes necessary to guaranty the successful deployment of private 5G networks in various industrial stakeholders and avoid technology segmentation within their industry. 3GPP proposes various architecture extensions to support TSN for 5G, with the objective at the same time to support TSN protocols within 3GPP networks and
through GTP tunnelling, to support time-controlled scheduling at the radio resource management and finally to keep TSN timing transparent over a 5G network.

Task 4.2 addresses all five key 5G innovations as function of the cycle-based development previously described. KPI 2.1 will propose a 5G Private Network supporting 5G URLLC, PKI2.3 will cover 5G Edge/MEC heterogenous managing functions, PKI2.2 will provide a TSN-compliant 5G network supporting TSN functions, while KPI2.4 will develop TSN-grade 5G D2D schedulers.

This deliverable describes the development in the 1st Cycle for KPI 2.1 and PKI2.3 in Chapter 3, while 1st Cycle achievements for KPI 2.4 are described in Chapter 4.

1.2 Relation to IntellIoT use cases

The 5G key innovations mentioned above play a central role in Next Generation IoT (NG-IoT), and therefore, in each of the IntellIoT use cases, as explained next.

OpenAirInterface (OAI) is the only open-source software project today delivering implementations of both 5G NSA and SA RAN (eNB, gNB, nrUE). Moreover, it achieves interoperability with OAI 4G and 5G Core networks considering standalone and non-standalone setup respectively as well as with COTS UE devices, spanning the full protocol stack of 3GPP standard and offering an end-to-end, native OpenAirInterface solution. This is feasible by running the OAI software on top of general purpose x86 processors. Accordingly, IntellIoT 5G network architecture will be built on top of OAI.

1.2.1 AGRICULTURE USE CASE (UC1)

Figure 4 depicts a schema of the NG-IoT services developed by IntellIoT for UC1. It also shows where 5G technologies play a major role. First, the IntellIoT will build a private 5G network supporting a 5G Edge/MEC for low latency service access. Second, the radio link between the tractor and the IntellIoT infrastructure will be based on 5G NR supporting URLLC communications mostly in DL in order to support remote controlling from a distant remote operator and transmit video feedback from the tractor to the operator. In order to further reduce latency, 5G NR in FR2 will be developed to provide increased capacity for URLLC traffic. Finally, considering the potential benefit of drones to provide extended perceptions or additional AI/ML management, V2X communication will be provided between a tractor to a drone, although, this function will be left to the OpenCall projects.

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1 OpenAirInterface - https://openairinterface.org/
1.2.2 HEALTHCARE USE CASE (UC2)

Figure 5 depicts a schema of the NG-IoT services developed by IntellIoT for UC2. It also shows where 5G technologies play a major role. Compared to UC1, the 5G challenges here are not low latency or reliable 5G communication, but massive IoT data to be transmitted between personal IoT devices and a 5G Edge/MEC platform. The 5G Edge/MEC platform not only plays a role to manage AI/ML mechanisms towards smart health recommendations, but also to store data in a private space, irrespectively if the 5G network is public or private. Considering IntellIoT’s proposal not to transmit patient data but AI/ML models, such private Edge/MEC is the guarantee by IntellIoT that highly sensitive patient health data remains confidential. Although 5G IoT technologies are currently being drafted by 3GPP, it is anticipated that they have to support massive amount of IoT data transmitted in UL. The current lack of 5G IoT devices or even prototypes, and the 3GPP postponing of 5G IoT to Rel.18 influenced IntellIoT not to fully rely on 5G IoT technologies but rather on improved 5G NR technologies. This should not be considered as a scale down option, first as the expected size of AI/ML models are not expected to fit to the current specification of 5G IoT (massive amount of small size), and second as the sensitivity of data transmitted between personal IoT devices and a 5G Edge/MEC are not expected to be massive locally. However, it is expected that massive AI/ML model exchanges between Edge/MEC might be required for cross-domain/cross site AI/ML federation, for which the IntellIoT project will develop a solution.

1.2.3 MANUFACTURING USE CASE (UC3)

Figure 6 depicts a schema of the NG-IoT services developed by IntellIoT for UC3. The 5G impact on this UC is similar to UC1 with the following major differences. First, unlike UC1, a wired TSN connection is expected between a robot and a 5G Edge/MEC, 5G URLL will be provided between the plant operator and the 5G Edge/MEC in AR. Accordingly, 5G URLL in that case will be more critical in UL rather than DL. Second, compared to UC1, this UC will test 5G in indoor instead
of outdoor scenarios. Indoor vs outdoor scenarios change the 5G capacity, in particular considering FR2. 5G V2X technologies are also envisioned in order first to enable a direct link between the plant operator and the robot when he is next to it, but also a multi-robot direct communication either for AI/ML direct exchange or to synchronize potential movements. 5G V2X aspects, however, are left to Open Calls.

![Diagram of 5G Edge/MEC, Plant Edge, 5G URLL, Robots & Machinery, Plant Operator, 5G V2X](image)

**Figure 6 Impact of 5G on the Manufacturing Use Case**

### 1.3 Deliverable Outline

To present the above 5G innovations and their applications to the three IntellIoT use cases, this deliverable is organised as follows:

- **Chapter 2** introduces 5G technology concepts as well as the development platform used for IntellIoT. It provides a description of the current standards for 5G networks as well as for Edge computing, both aspects being at the heart of 5G innovations for IntellIoT. Second, it describes the OpenAirInterface platform and its more recent architecture supporting 5G. This chapter finally describes the details of the applications of the described 5G innovations in each of the IntellIoT use cases.

- **Chapter 3** provides more details of the technical development on the OAI platform to support the availability of the targeted 5G innovations. In particular, it shows the first tests of 5G connectivity between OAI and a COST UE both in non-standalone and standalone step-ups. It then describes the new components developed on Mosaic5G to support dynamic management of 5G networks.

- **Chapter 4** provides details on the 5G D2D innovations, starting with a state-of-art overview of 5G Proximity Services and the differences between D2D and V2X mechanisms. Second, it presents simulation-based performance evaluation results of the capability of current 5G V2X technology and identify innovations to be carried in the 2nd Cycle.
2 5G NETWORKS AND PLATFORMS

We provide in this section the state-of-the-art of 5G Networks as well as a description of the OpenAirInterface Open5G platform, which will be used and extended in IntellIoT.

2.1 Brief Introduction to 3GPP Release-based Development

3GPP develop cellular technologies considering three denominations: generations, releases and commercial names.

The generations correspond approximately to 10–12 years of development. For example, as depicted the figure below, LTE appeared in 2008, while 5G appeared in 2018. The underlying specifications consisting to a particular ‘generation’ are called releases. A release (a.k.a. rel.) corresponds to a new release of the 3GPP specification including the addition of new functions developed for that release. This enables 3GPP to select and prioritize functions and components to be developed first, and leave other components to be included to later releases. For example, if enabling Proximity Services with LTE has been planned almost at the early phases of the 4G cycle (rel. 8), it has been defined only at the 12th release (rel.12), and applications to the automotive industry postponed to rel. 14. A release is said to be ‘frozen’ when its set of specifications is finalized and could be transferred to industrial stakeholders for production. A release is not bound to a cycle, as required modification for the 3G cycle may be added in a release currently being developed for the 5G cycle. Also, not all releases end up in productions. Accordingly, commercial names correspond to a full or partial compliancy to a particular release, which will be produced by industrial stakeholders. For example, LTE corresponds to full compliancy to the 8th release for LTE, and LTE Advanced Pro to partial compliancy to LTE Rel. 12 functions.

The 5th Generation (5G) cycle development started in 2016 with the first 5G NR rel. 16, but LTE continues to be extended even in rel.16 and rel. 17. The most recent 5G NR frozen release at the time of writing is 5G NR rel. 16, and IntellIoT will be based on 5G Network from rel. 15 to rel. 17.

2.2 5G Core & Radio Access Network

A brief introduction/overview of the key features of a 5G network according to the 16th release is provided in this section.

2.2.1 5GS REFERENCE ARCHITECTURE AND FUNCTIONS
The reference architecture of the 5GS is illustrated in Figure 7. If the UE, RAN and to some extend the DN entities are similar to an LTE architecture, the 5G core (5GC) significantly evolved. A brief description of each entity is provided below.

**5G NG RAN Functions:**

- **UE** – User Equipment, representing a 5G equipment capable of connecting to the 5G RAN.
- **RAN** – Radio Access Network, provides radio access to between a public/private network and UEs via radio links.
- **UPF** – User Plane Functions, support similar functionalities as L-GW and P-GW entities in LTE, enhanced to support network virtualization via Control and User Plane Separation (CUPS). It provides Packet routing & forwarding functions as well as IP address/prefix allocations, as well as the critical User Plane part of policy rule enforcement, e.g., Gating, Redirection or Traffic steering.
- **DN** – Data Network, IP or non-IP based network, outside of the scope of 3GPP, which can either correspond to the Internet or a private data network.

**Selected 5G Core Functions:**

- **AMF** – Access and Mobility Function, first entity connected to UE and RAN (gNB), which role is to provide various management tasks (registration, connection, reachability, mobility, access authentication and authorization). AMF is connected to the RAN and UE via the N2 and N1 reference point respectively.
- **SMF** – Session Management Function, provides session management (establishment, release, modification of sessions, tunnelling between a UE and UPF), IP address allocation, DHCP or ARP functions. The SMF is connected to the UPF via the N4 reference point.
- **PCF** – Policy Control Function, provides policy rules to Control Plane function(s) to enforce them.
- **NEF** – Network Exposure Function are critical to 5GS, as it enables to expose network functions to external entities without giving them access to the 5GS. Typical network functions exposed are network capabilities, secured provisioning of data from external networks, or translation between internal-external information.
- **NRF** – Network Repository Function maintains an up-to-date repository of network functions available in the 5G core. Network functions are key innovations of 5G and includes the previously described functions as well as MEC or D2D functions for instance.
• **UDM** – Unified Data Management handles several functions as generating AAA security credentials, access authorization, lawful interceptions etc...

• **AUSF** – Authentication Server Function deals with authentication mechanisms for 3GPP and untrusted non 3GPP entities.

• **AF** – Application Function interacts with other 5G core functions to support 3GPP services such as application influence over routing, time synchronization services. ProSe or V2X Application servers or TSN are typical illustration of AF.

• **NSSF** – Network Slide Selection Function, as its name indicates, deals with managing and selecting the appropriate network slice serving a UE and selecting the most appropriate AMF dealing with that slice.

Additional functions, such as NSSAAF, NSACF, further complete the multi-function 5G Core.

### 2.2.2 5G USER PLANE PROTOCOL STACK

Figure 8 depicts the 3GPP protocol stack for the User Plane for a PDU session. Independently to the end-to-end Application sessions (or even IP sessions), a PDU session must be initiated between a UE and its UPF function in the 5G core architecture. The PDU layer corresponds to the PDU carried between the UE and the DN over the PDU Session, as IPv4, IPv6 or ethernet. GTP-U is a useful ‘fossil’ from the GPRS time, which is designed to tunnel data packets between the 5G RAN and the corresponding UPF (i.e., tunnelling non 3GPP PDU within a 3GPP network). As it can also be seen, a key role of the 5G (R)AN is also to map the RAN-specific protocol stack (3GPP or non-3GPP) to the more traditional L1, L2 and IP stack.

![Figure 8 3GPP protocol stack for the User Plane](image)

### 2.2.3 5G QoS FLOW MANAGEMENT

A 5GS QoS model is based on 5G QoS Flows, which are defined by a QoS Flow ID (QFI) and a QoS Flow Profile (QFP), the latter depending mostly on two parameters:

- **5QI** – 5G QoS Indicator which is defined by a set of parameters, such as the resource type (GBR or non-GBR), the priority level, the packet delay budget or the target packet error rate.

- **ARP** – Allocation and Retention Priority, which defines the global priority level of the QFP in particular when flows need to either be dropped or pre-empted by more important flows in case of traffic congestions.

### 2.2.4 5G STANDALONE AND NON-STANDALONE SETUPS

The development potential product availabilities of 5G RAN and 5GC did not progress simultaneously, and in order not to delay 5G NR deployment, two 5G setups have been proposed:
• **5G non-standalone (NSA)** - It represents the situation where a 5GC is not available and 5G RAN needs to work with a 4G EPC. In that case, only 4G services may be provided, but benefiting from the increased capacity of 5G NR.

• **5G standalone (SA)** - In that configuration, a 5GC and 5G RAN are available and may operate without 4G. 5G services are provided, benefiting from the 5G NR increased capacity.

### 2.3 5G Edge

#### 2.3.1 EDGE COMPUTING ARCHITECTURE FOR 5GS

While Multi-access Edge Computing (MEC), also known as Mobile Edge Computing, has been defined by ETSI and is popular to enable innovative services close to the consumer, 3GPP also proposed an Edge architecture in its rel. 17 specification. The generic edge architecture in 5GS for non-roaming case is depicted in Figure 9.

![Figure 9 3GPP Edge architecture for a 5GS in non-roaming case](image)

While the central DN can be considered as the home location of global services, a local part of DN is hosted also close to the AN. The local part of DN hosts one or more Edge Application Servers (EAS), which can be reached by a session breakout triggered by the UPF. In other words, according to a 5G QFP or other 5G-specific configurable parameters, a 5G Flow can be re-routed to a local DN rather than a central DN.

As illustrated on Figure 9, considering the C-PSA UPF being the central session anchor point for the service hosted in the central DN, a second ‘intermediate’ UPF function creates a breakout point according to an UL classifier (UL CL) and re-direct the selected flows to a third UPF, hosting the local session anchor point for the service hosted in the local DN. From a 3GPP perspective, an EAS is hosted on a DN, so its specification is out of the scope of 3GPP, but 3GPP provides edge functions and flow classifiers (UL CL) to re-direct traffic transparently to an EAS. As it can also be seen on Figure 9, UPF being user plane functions, the SMF hosts the control plane functions determining the re-routing parameters and triggering the local breakout according to various authorization, security and billing options.

3GPP defines three types of connectivity models for Edge Computing as depicted on Figure 10:

- **Distributed Anchor point** – a distance service supports distributed databases and processing, which are located at the edge. Accordingly, the UPF represents a distributed PDU session anchor point and connects the UE to the EAS hosted in the local DN.
• **Session Breakout** – according to 5G QFP and a UL classifier controlled by a 5G Core SMF, selected traffic can be re-directed to an EAS located on a local DN. Accordingly, a local UPF in charge of the breakout point and act as a local anchor point.

• **Multiple PDU sessions** – in that configuration, different PDU sessions are created to either reach the central DN or the local DN.

![Diagram of Distributed Anchor Point, Session Breakout, and Multiple PDU Sessions]

**Figure 10: 3GPP Edge Computing Connectivity Models**

### 2.3.2 **EDGE COMPUTING DISCOVERY PROCEDURE**

Edge Computing enables operator and 3rd party services to be hosted in EAS close to the UE’s point of attachment. The traffic to EAS can be routed based on the UE position and EAS availability “near to” that position.

3GPP defines 4 procedures to enable and manage edge computing on a 5GS. The most important one is the EAS discovery/re-discovery procedure, enabling a UE to discover the existence of a EAS close to its point of attachment.

EAS Discovery is the procedure by which a UE discovers the IP address(es) of a suitable Edge Application Server(s) using Domain Name System (DNS). EAS Re-discovery is the EAS Discovery procedure that takes place when the previously discovered Edge Application Server cannot be used or may have become non-optimal (e.g., at edge relocation). Accordingly, DNS service should be available to a 5GS both in local (L-DNS) and global (G-DNS) configuration. The L-DNS service can be reached through anycast addressing, and will resolve the current IP address of the local EAS.

### 2.4 **OpenAirInterface 5G Platform**

OpenAirInterface (OAI) is an Open5G Software Defined Radio (SDR) platform gathering a community of developers from around the world, who work together to build wireless cellular Radio Access Network (RAN) and Core Network (CN) technologies. Initially developed by EURECOM as platform for SDR research on cellular technologies since 2.5G, OAI evolved to a major community-based software alliance led by EURECOM to enable open research and development of 5G wireless technologies. OAI is composed of three main projects.

#### 2.4.1 **OAI 5G RAN**

The scope of the OAI 5G RAN project is to develop and deliver a 5G software stack under the OAI Public Licence V1.1. Figure 11 depicts the general architecture targeted by the OAI 5G RAN for both non-standalone and standalone modes.
2.4.1.1 OAI RAN SOFTWARE ARCHITECTURE

The OAI 5G NR software is depicted on Figure 12, both for the gNB and NR-UE case. The NGAP function connects to the 5GC AMF, whereas the N3 function connects to the 5GC UPF. The SDAP layer is an addition to the 5GS stack compared to the LTE stack. The SDAP (Service Data Adaptation Protocol) handles the QoS mapping and adaptation to radio resources and radio bearers.

![Figure 12 OAI NR RAN software architecture](image)

The roadmap for the OAI 5G RAN is to test and prove components from Figure 13, in particular adding SDAP functionalities and provide support for FR2.

2.4.2 OAI 5G CORE

The OAI 5G Core architecture is depicted on Figure 14. It shows the evolution of OAI 4G EPC towards 5GC, where old EPC functions are in white and new 5GC functions are in orange. This figure also allows to better understand the architectural difference between a 4G EPC and a 5GC.
OAI is actively working to develop a fully functional 5G C. The current development status is depicted on Figure 16, which a roadmap planned to add the remaining functionalities during 2022.

2.4.3 MOSAIC5G

Mosaic5G represents the architecture of the various flexible management functions of a 5GS. As depicted on Figure 17, Mosaic5G is built on top of OAI 5G-RAN and 5GC and has two main layers:

- **FlexRIC** - Flexible RAN Intelligent Control (RIC) providing dynamic control over RAN parameters (e.g., radio bearer configuration, QoS handling, slice parameters).
- **FlexCN** - Flexible Core Network (CN) mechanisms to support edge application servers (EAS) as well as dynamic low latency edge services, such as PDU local breakout points, as well as API supporting ETSI MEC functions.
- **Trirematics** - This layer represents the orchestration and management of the underlying layers. It provides components for controlling and monitoring resources, handling AI as well as storage of ready-to-use optimisation functions.
Mosaic5G 5G architecture is currently being developed as replacement of the 4G architecture according to the current roadmap depicted on Figure 18.

2.5 5G Architecture in IntellIoT use cases

5G functions will be deployed in all three IntellIoT use cases, although not similar in the different use cases. We describe below the proposed 5G architecture for each use case.

2.5.1 Use Case 1

The 5G architecture proposed for the Agriculture use case is depicted on Figure 19. As it may be observed, the main 5G functions previously described are deployed. First, the tractor will be connected over a 5G NR radio link to a 5G gNB. The link is expected to support URLL in order to enable remote control of the tractor from a distant operator. A 5G Core entity will also be deployed next to the 5G gNB and the 5G Edge/MEC entities for control and monitoring.

An Edge architecture is also described, which can be split in two parts:

- **Radio edge** – a Mosaic5G based FlexRIC, and Flex CN entities will be deployed, which objectives are to configure and control 5G slices and perform PDU session breakout for tractor edge apps to reach the 5G edge apps rather than the central apps.

- **Application edge** – an Edge controller will deploy required edge apps from a local database when required. These Edge Apps will support ETSI MEC API to interact with the CN & RIC controllers.

Together, the 5G gNB, 5G Core and the 5G Edge/MEC entities are locally stored at the tractor operator premise, providing a fully functional Private 5G architecture.
2.5.2 Use Case 2

The 5G architecture proposed for the Healthcare use case is depicted on Figure 20. Considering that it is not possible to deploy a non-commercial 5G network at the UC2 demonstration site, a commercial 5G operator will be used for 5G RAN and Core functionalities. It is yet not a major issue, as the main 5G functions to be tested in the Healthcare use cases are the cooperative IoT/Trusted mechanisms, for which a commercial/existing 5G RAN may already be sufficient in terms of delay and throughput (no remote control or AR/VR requirements). Critical to this use case is to maintain data privacy, which will be provided by an Edge platform, responsible to host and manage the edge applications as if they were located on a private 5G network. Edge applications and central applications will both be able to interface with the edge applications, and data transfer between patient, edge and central entities will be encrypted to maintain privacy. The Edge platform architecture will be built to respect as much as possible 3GPP and ETSI APIs in order to facilitate their integration in a non-commercial Private 5G network outside of the scope of the demonstrator.
2.5.3 Use Case 3

The 5G architecture proposed for the Manufacturing use case is depicted on Figure 22. The architecture is similar to the 5G architecture for UC1, with the main difference being, that the required 5G NR radio link is required between the AR control and not on the VR control used by tractor side. Moreover, a TSN architecture will also be deployed between the robot, the private central and edge networks. It will, however, not impact the 5G network, as TSN end-to-end link between the AR control is not planned for the demonstration. A TSN extension to the Private 5G architecture will, however, be discussed to support such end-to-end TSN link, would this solution become necessary.
Figure 22 5G architecture for Smart Manufacturing
3 IMPLEMENTATION OF OPENAIRINTERFACE 5G COMPONENTS

This section provides a technical description of the 5G-related components described before. It also provides initial performance and validation tests.

3.1 OAI Based E2E 5G NSA Network (4G/5G RAN & 4G EPC)

We provide here the extension of OAI for NSA developments and preliminary results obtained for Cycle 1.

3.1.1 BACKGROUND

For the 1st Cycle of IntellIoT, an NSA setup based on OAI EPC, gNB and UE components has been completed. In a first development round, there is no Core Network and eNB, and all required configurations that would normally take place over the LTE links to establish a 5G connection are preconfigured, so that data plane IP traffic over the 5G NR stack could be demonstrated.

On a second Development round, an E2E version of the NSA setup based on OAI RAN and COTS UEs, interoperable with OAI EPC and other commercial Core Networks has also been developed. Significant enhancements with respect to the stability of the setup, supported radio configurations, resources scheduling, and performance improvements are still being integrated in preparation for the 2nd Cycle of IntellIoT.

3.1.2 ARCHITECTURE, IMPLEMENTATION, INTEGRATION AND TESTING

3.1.2.1 SUPPORTED NSA ARCHITECTURE

OAI supports NSA architecture option 3a as described in 3GPP TS 37.340 rel.15. As depicted in Figure 23, according to this deployment, all the control plane traffic is exchanged with the UE through the eNB. In order to successfully add the COTS UE to the NR cell (gNB), the eNB acts as the intermediary node that communicates with the gNB over X2-C interface to convey all required NR configuration to and from the UE. S1-C interface is responsible for the exchanges between the eNB and the 4G EPC (MME component) for the successful attachment of the UE. Once the UE is attached to the CN and connected to the 5G cell, the end-to-end user-plane traffic is delivered to the UE and the core network (S1-U interface to the SGW) exclusively through the gNB. It is noted that as per this architecture option, there is no delivery of user-plane traffic through the X2 interface (i.e., no split bearer option).
3.1.2.2 IMPLEMENTATION AND SOFTWARE ARCHITECTURE

The developments that took place in OAI eNB and gNB components to support the NSA setup can be grouped per layer as follows:

- **MAC/PHY:**
  - Integration of 5G NR Contention Free Random Access (CFRA) procedures to enable successful 5G connection of the UE to the 5G cell according to 3GPP TS 38.213 and 3GPP TS 38.321.
  - Complete integration of SCF 5G FAPI interface between MAC and PHY layer according to SCF 222.10.02.
  - Integration of dynamic scheduling and capability to support multiple users.
  - Integration of HARQ procedures on top of downlink and uplink physical channels to provide support for data acknowledging and retransmissions according to 3GPP TS 38.321.

- **PDCP/RLC:** Complete implementation of NR PDCP and RLC AM (Acknowledged Mode) and UM (Unacknowledged Mode) according to 3GPP TS 38.322 and 3GPP TS 38.323, in order to support data plane traffic over 5G established DRBs.

- **RRC** extensions according to 3GPP TS 36.331 and 3GPP TS 38.331:
  - Integration of the LTE eNB procedures triggering the UE addition/release request to the 5G cell and the data path switch procedures towards the 5G cell,
  - Extensions of LTE RRC messages with NR message containers originating from the gNB
  - Integration of all the gNB NSA configuration procedures for a UE added to the NR cell and construction of the corresponding NR message containers conveyed to the UE through the eNB.

- **X2AP** extensions according to 3GPP TS 36.423: Integration of the required X2AP messages and interfacing with RRC to support the establishment, maintenance and release of an ENDC X2 connection between the eNB and gNB and the addition/release of a UE to the 5G cell.
• **S1AP** extensions according to 3GPP TS 36.413: Integration of the E-RAB Modification procedures initiated from the LTE cell (eNB) to trigger the data path switch towards the NR cell (gNB) at the core network.

### 3.1.2.3 SUPPORTED FEATURES AND PERFORMANCE

Based on the OAI NSA setup, the main focus is on the spectrum below 6 GHz (a.k.a. FR1). More specifically, TDD configuration is used at the gNB side with 30 KHz subcarrier spacing and 106 PRBs. At the end of the 1st Cycle, the most stable performance at the gNB is achieved for 40 MHz channel bandwidth, reaching up to 75 Mbps downlink and 7 Mbps uplink throughput.

We are aiming to achieve performance improvements in the 2nd Cycle (100-200Mbps downlink, 15-30 Mbps uplink) and ensure stable performance for 80 and 100 MHz channel bandwidths.

### 3.1.2.4 HARDWARE ARCHITECTURE

The hardware platform required for the OAI NSA setup consists of two sets of PCS and USRP for the eNB and gNB components. Depending on the configuration used at the gNB side and the associated performance, the required hardware equipment and consequently the deployment cost can differ. Specifically, as shown in the following table, to achieve higher NR performance for 80 or 100 MHz channel bandwidths, a USRP N3xx series has to be used, together with a powerful server (>8 CPU cores). For a limited performance setup (40 MHz channel bandwidth), the cheaper USRP B210 board can be used. More information about the hardware and operating system requirements can be found here².

<table>
<thead>
<tr>
<th>Table 1 OAI 5G Hardware Architecture</th>
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<tr>
<td><strong>PC/Server</strong></td>
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<td>USRP</td>
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### 3.1.2.5 TESTING AND VALIDATION

In the following, we provide some snapshots of the NSA setup from Wireshark traces and OAI logs, to highlight the important steps for the establishment of a 5G connection and user plane traffic flow through the 5G cell.

During the initial attachment of the UE to the LTE cell and the core network, the UE reveals its capabilities for NR connectivity and the eNB provides information to the UE on how to perform 5G NR cell specific measurements on the NR frequencies. Based on this information, after its attachment to the core network, the UE sends RRC measurement reports including measurements from the NR cell (gNB). Upon reception of the NR measurement report, the eNB triggers the addition of the UE to the secondary node (gNB) by sending the X2 sgNB Addition Request message. This message includes RRC and radio bearer configuration, as well as security information elements and other information per layer regarding additional UE capabilities (Figure 24).

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² 5G NR development and setup™ [Online] https://gitlab.eurecom.fr/oai/openairinterface5g/-/wikis/5g-nr-development-and-setup, 05/2021.
After performing the required configuration procedures for the addition of the UE, the gNB replies with the X2 sgNB Addition Request Acknowledge message. This message includes the NR RRC Reconfiguration container which provides the configuration information that the UE needs to know to successfully get connected with the gNB (Figure 25). The eNB then includes the NR RRC Reconfiguration container in the LTE RRC Connection Reconfiguration message sent to the UE. The UE replies with the NR RRC Reconfiguration Complete container (encapsulated in LTE RRC Connection Reconfiguration Complete message) indicating the successful outcome of the RRC Reconfiguration procedure. The eNB then forwards this information to the gNB through the X2 sgNB Reconfiguration Complete message (Figure 26).
In Figure 27, the part of the gNB logs corresponding to the CFRA procedures of the COTS UE towards the 5G cell is depicted. These procedures take place after the UE has successfully synchronized to the 5G cell. The UE initiates RA by sending Msg1 (RA preamble), the gNB receives it and it replies with Msg2 (RA response), and the process gets completed with the reception of Msg3 at the gNB through PUSCH. After that the UE is 5g connected.
In parallel, the eNB initiates the procedures for the data plane path switch towards the core network, so that the traffic between the COTS UE and the CN gets transferred through the gNB from now on. This is done by sending the SIAP E-RAB Modification indication message towards the MME. This message contains information on the IP address of the gNB and the corresponding gtp-u tunnel that should be used for the downlink traffic between the SGW and gNB. The MME indicates the successful modification for the E-RAB through the confirmation message.

After this step, the COTS UE can exchange IP traffic with the CN through the gNB over gtp-u, as shown in the gNB trace below, where 192.172.0.1 corresponds to the SGW interface IP address and 192.172.0.2 corresponds to the COTS UE.

In Figure 30, Figure 31 and Figure 32, some snapshots of the downlink and uplink performance throughput and RTT latency of the NSA setup are shown.
Figure 30: Measured downlink throughput using iperf at COTS UE

Figure 31: Measured uplink throughput using iperf at the core network
As it can be seen, an UL RAN latency larger than 1 ms is reached on NSA, which is mostly due to the NSA architecture. A lower latency is expected for SA. The RTT, however, is significantly longer than the UL latency, due to the backend management, which would need to be reduced both on the SA as well as with an edge/MEC architecture.

3.1.2.6 DEPLOYMENT AND INSTALLATION

A detailed deployment and installation guide for the NSA setup, according to the configuration parameters is provided here in section 3.2.3.

3.2 OAI Based E2E 5G SA Network (5G RAN & 5GC)

We provide here the extension of OAI for SA developments and preliminary results obtained for Cycle 1.

3.2.1 BACKGROUND

After the completion of the procedures required for the E2E NSA setup in OAI, the required developments to support the end-to-end SA setup have been initiated. The target is to deliver an OAI gNB, able to support an end-to-end SA setup based on a 5G CN (OAI or other) and SA capable COTS UE devices. As there are many developments taking place in parallel and capturing the whole RAN stack, intermediate validation steps have been taking place using first the OAI UE (which is also developed in parallel to support SA deployments) in simulation and RF mode, and then the COTS UE devices.

In the following, we provide the implemented software architecture to support SA in OAI, as well as the end-to-end integrated procedures which have already been validated using COTS UEs as per 3GPP Rel.15-16.

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3 Testing gNB with COTS UE" [Online] https://gitlab.eurecom.fr/oai/openairinterface5g/-/blob/develop/doc/TESTING_GNB_W_COTS_Uexual, 04/2021
3.2.2 ARCHITECTURE, IMPLEMENTATION, INTEGRATION AND TESTING

3.2.2.1 SUPPORTED NSA ARCHITECTURE

The 5G standalone access mode does not depend on legacy 4G LTE, but requires a new 5G core network (5GC). This new 5GC uses a cloud-aligned Service-Based Architecture (SBA) that supports control-plane function interaction, re-usability, flexible connections and service discovery that spans across all functions. The main 5GC functions are AMF, SMF, NRF and UPF (SPGW-U-tiny), all of which have been implemented in OAI and can easily be deployed using docker-compose.

Compared to NSA, in SA the gNB needs to also implement the complete RRC layer from 3GPP TS 38.331 and handling of all the associated messages as well as the NGAP from 3GPP TS 38.413 to interface with AMF (N2 interface) and UPF (N3 interface), as shown in Figure 33. Moreover, the gNB needs to support multiple bandwidth parts as the initial access happens only on the initial bandwidth part, which has a smaller bandwidth than the full cell bandwidth. Further support for contention based random access is needed, as well as support for common and dedicated control channels. Only after the initial connection and authentication with the AMF, the full bandwidth part is configured and used for user-plane traffic.

From a deployment perspective, two options are provided for OAI gNB: the monolithic and the CU/DU functional split mode. The former option corresponds to a single gNB program on a single host running the whole 5G NR RAN stack. In the latter option, the OAI gNB portion is divided into two blocks: the Central Unit (CU) that contains the implementation of RRC and PDCP layers and the Distributed Unit (DU) that contains the implementation of RLC, MAC and PHY layers. The two units communicate with each other over the F1-C interface for the control plane and configuration exchanges based on F1AP protocol from 3GPP TS 38.473. The Downlink and Uplink user plane data transfer is made through the F1-U interface over GTP-U protocol. The CU and DU portions can thus run as separate programs in different hosts, offering significant flexibility for the deployment of the OAI 5G SA setup and the interoperability of OAI blocks with other commercial CUs or DUs.

Figure 35 depicts the 5G RAN protocol architecture of the OAI gNB according to the CU/DU functional split deployment. The layers that had to be extended in order to support end-to-end SA functionality are highlighted in yellow.
3.2.2.2 HARDWARE ARCHITECTURE

The hardware requirements for the OAI gNB on the SA deployment scenario are the same as the ones described in Section 3.1.2.4 and Table 1 for the NSA deployment.

3.2.2.3 TESTING AND VALIDATION

At the end of the 1st Cycle, several interoperability tests of the OAI gNB with different 5G CNs and UE components from different vendors have been performed and more are still ongoing. Specifically, interoperability with the OAI CN and Nokia SA Box has been fully validated. With respect to the UE components, interoperability has been fully validated with the Quectel RM500Q-GL module\(^4\), Huawei mate 30 pro smartphone and OAI UE and partially validated with SIMCOM SIM8200EA\(^5\) module.

In the following, we provide some checkpoints for the validation of the end-to-end SA setup, to highlight the establishment of the 5G radio connection, the UE registration to the 5G CN, the PDU session establishment for the exchange of user plane traffic and some basic traffic test. The underlined tests were performed using the Quectel RM500Q-GL module.

After the UE synchronizes to the 5G cell and receives the System Information messages from the gNB, it initiates the contention based random access procedure (CBRA) in order to connect to the 5G cell. The procedure is finalized through the reception of Msg4 (RRCSetup) acknowledgment from the gNB (Figure 36). Then the UE replies with the

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\(^4\) Quectel RM500Q-GL module\(^{[\text{Online}]}\) https://www.quectel.com/product/5g-rm500q-gl/, 05/2021

\(^5\) “SIMCOM SIM8200EA module”\(^{[\text{Online}]}\) https://www.simcom.com/product/SIM8200EA_M2.html, 05/2021
RRCSetupComplete message which encapsulates the NAS registration request message towards the AMF. Upon reception of RRC Setup Complete, the UE state at the gNB becomes RRC Connected.

This NAS message is conveyed transparently from the gNB to the AMF through the NGAP InitialUEMessage (Figure 37). A sequence of NGAP/NAS messages are exchanged afterwards between the gNB, the UE and the AMF to perform the authentication and security procedures leading to the successful Registration of the UE to the AMF (Registration Accept and Registration Complete NAS messages).

The UE then initiates the PDU Session Establishment, which is validated through the PDU Session Establishment Accept NAS message coming from the CN. This message contains the IP address of the UE provided from the SMF. In Figure 38 the configured IP address is shown through the Quectel connection manager software.
At the same time, the gNB also sends a dedicated RRCReconfiguration message to the UE containing the configuration of the DRB that should be established at the UE to enable the user plane traffic flow at the RAN stack (PDCP, RLC, MAC layers). The UE replies with an RRCReconfigurationComplete message to signal the successful reconfiguration. Upon reception of the Reconfiguration Complete message, the gNB performs its own DRB configuration for the lower layers (Figure 39). In parallel, the gNB establishes a gtp-u tunnel with the UPF to enable the user-plane traffic flow over the N3 interface (Figure 35).

After these steps, the UE can exchange IP traffic through the CN. In Figure 40, a snapshot from a ping test initiated from the CN towards the UE is shown.
At the end of the 1st Cycle, further validation and performance improvements of the SA setup with user-plane traffic are ongoing.

3.3 5G FlexRIC Controller

The 5G FlexRIC controller is an extension of the previously available FlexRAN controller available on Mosaic5G. FlexRAN was based on client–server architecture, where FlexRAN clients, embedded on top of OAI 4G/5G protocol stack and capable of direct control of various 4G/5G RRC parameters, interact with a FlexRAN server developed as a Web Technology entity. Accordingly, FlexRAN controllers enable 4G/5G controls through standardized Web technology APIs and message formats, such as REST and JSON, instead of 3GPP-specific ASN.1 standards.

The general principles of RICs are similar to FlexRAN controllers, but an O-RAN⁶ E2 interface has been adopted for enhanced interoperability between various RAN and RIC implementations. The O-RAN E2 interface is used by RICs to control the underlying RAN elements. A E2 interface provides 4 basic operations:

- **Report** – asks the RAN to report a specific information
- **Insert** – the RIC asks the underlying RAN to activate a particular user-plane function
- **Control** – the RIC asks the underlying RAN to activate a particular control-plane function
- **Policy** – the RIC sets a particular policy function on an activated function.

For example, a RIC may ask over the E2 interface to obtain RAN parameters, activate a particular slice or even provide policies for a scheduler.

Accordingly, various enhancements had to be conducted to extend Mosaic5G components to support this new architecture. Accordingly, OAI RAN (gNB stack) has been extended by a E2agent communicating with the FlexRIC controller over the E2 interface.

⁶ Operator Defined and Open RAN (O-RAN) Alliance - [https://www.o-ran.org](https://www.o-ran.org/)
On top of OAI, Mosaic5G extended the FlexRAN controller server to support RIC specifications, in particular real-time functions. FlexRIC has a built-in Service Model (SM) for monitoring and slicing, that can be easily customized and extended to fulfill the diverse 5G use cases. FlexRIC’s Application Protocol (AP) and Service Models (SM) are encoding and decoding agnostic. It also supports the creation of new SMs “à la carte” to satisfy specific, yet not standardized, use cases. Lastly, FlexRIC is expected to act as a booster for the type and quality of Machine Learning algorithms deployed in 5G as it easily enables their validation in real 5G deployments as shown here with the OAI 5G stack.

The Mosaic5G FlexRIC controller provides standardized APIs for third party xApps developments. In IntellIoT nomenclature, FlexRIC xApps are Edge Apps and their deployments are controlled by the Edge orchestrator. The Most important xApp/edge app is the 5G Communication Resource Manager described below.

### 3.3.1 5G FLEXRIC RESOURCE SLICING SERVICE MODEL

One important SM developed and available by FlexRIC is a 5G resource slicing SM, which is defined to operate as a 2-level process:

- **Inter-resource** – schedules resources of entire slices.
- **Intra-resource** – schedules UEs on assigned resources.
A standardized API has been provided to control the OAI 5G RAN RRC, and various schedulers are available (Inter-resource – Static, NVS, EDF; Intra-resources – RR, PF, RT). The Mosaic5G FlexRIC flexible and open scheduling SM enables for fast scheduler enhancement as well as rapid adaptation of scheduling policies within or between slices.

In IntellioT, the FlexRIC will provide a 5G slice control SM as well as a 5G scheduler policy SM. The 5G slice control SM allows the creation, the constant monitoring and the destruction of 5G slices, whereas the 5G scheduler policy SM provides scheduling parameters to the 5G RAN, potentially dynamically changing the scheduler as function of the 5G RAN conditions. These two SMs will be used by the 5G Communication Resource Manager Edge App to provide and adjust the required 5G performance required by the other IntellioT components.

### 3.4 5G FlexCN Controller

The Flexible CN controller (FlexCN) is an extension of the previously available LL-MEC controller available on Mosaic5G. LL-MEC had been initially developed to provide basic CN optimization to support 3GPP edge/ETSI MEC computing functions. The LL-MEC supported ETSI MEC APIs, as well as FlexRAN APIs and could provide basic RAN services such as Radio Network Information Service (RNIS), DNS redirection and traffic shaping.

However, with the creation of FlexRIC as well as to support additional 5GC functionalities, a new FlexCN controller has been also developed. It bears similar objectives as the former LL-MEC, but benefit from a full FlexRIC support and direct access to 5GC through Network Exposure Functions and services.
The 5G FlexCN has been developed to provide open APIs to enable third party xApps developments and even to enable xApps to connect to both the FlexRIC and FlexCN controllers. At the current stage of development, only connection to AMF, SMF and UPF are available, enabling 5G FlexCN with similar MEC/Edge-like functions as the LL-MEC controller. More functionalities will be developed during the IntellIoT Cycle 2 development.

For IntellIoT, the 5G FlexCN will provide RNIS and local DNS redirection. RNIS provides quasi real-time radio conditions at the MEC and as such is used by IntellIoT Edge Orchestrator to deploy Edge Apps where required. Local DNS redirection provides the IP address of the local Edge Apps when a MEC is deployed.

3.5 5G Communication Resource Manager

The 5G Communication Resource Manager is an IntellIoT component aiming at controlling the communication resources allocated by the 5G network. Following the architecture description of the Mosaic5G FlexRIC and FlexCN, the 5G Communication Resource Manager is considered to be an xApp and will control the FlexRIC slicing and scheduling SMs in order to enable dynamic 5G slice creation, resource optimization as well as dynamic adaptation. It will be deployed by the Edge Orchestrator component on each 5G RAN entity as function of the FlexCN RNIS function.

The Communication Resource Manager’s primary functionality is to distribute the communication related resources to the different devices depending on the specific requirements of application to be run in a suitable manner. The parameters that resources should be distributed according to are latency, and bandwidth. Depending on the requested resources the Communication Resource Manager will allocate resources to live up to the request. A more in-depth description of the Communication Resource Manager can be found in deliverable D4.3 ("Dynamic network management").

7 In the course of IntellIoT Cycle 1 and 2, only one 5G RAN entity will be considered.
4 5G NR DEVICE-TO-DEVICE

Known as Proximity Services (ProSe), first mechanisms for Device-to-Device communications between UEs have been standardized by 3GPP at early as in its 12th release for LTE. It was, however, strongly restricted to Public Safety (PS), and a lack of clear market strategy made that 3GPP Prose Rel.12 never appear on any LTE device. With the growing interest for the automotive market, 3GPP updated its LTE D2D specification and extended it for specific V2X functions in its 14th release for LTE. The clear market impact for V2X communications drew a lot of attention to this 3GPP LTE rel.14 V2X specification, which eclipsed the ProSe specification, and is generally considered to be one intend proximity service falling within ProSe (a bit as Wi-Fi OCB enables V2V communications totally outside of the framework of a WiFi service). Various cellular stakeholders developed prototypes and products for the automotive market, but due to various lobbying, performance limitations and standardization restrictions, 3GPP LTE rel.14 V2X devices are not widely available in the market.

Several reasons might explain the delayed deployment of LTE-based V2X technologies, but the most likely one is the largely improved features and performance of the 5G NR-based V2X specification in 3GPP 16th for 5G. Indeed, 3GPP NR V2X Rel.16 provides several improved mechanisms over the LTE specification, such as groupcast, a new feedback channel, increased numerology enabling sub millisecond V2X communications or larger functionalities for radio resource allocations. Accordingly, it is likely that the automotive industry is currently waiting for the first NR V2X prototypes for a larger-scale market deployment.

In parallel, the D2D specification also evolved in the 17th 3GPP NR release for 5G to benefit from the improved flexibility of the NR technology, but the community often confuses both D2D and V2X specifications. In the following sections, we will describe first the 5G ProSe, then 5G V2X as a sub-group of ProSe, although 5G V2X appeared earlier than 5G ProSe in the 3GPP releases.

5G D2D Communication will be applied in IntellIoT in two use cases: UC1 and UC3. Considering that 5G NR ProSe (D2D) is not completed yet, IntellIoT will build its D2D functions on 5G NR V2X rel.16. IntellIoT aims at extending the 5G NR V2X specification to support URLL V2X communications. Considering the lack of currently available 5G NR V2X rel.16 devices, IntellIoT D2D developments will be evaluated via simulations.

4.1 Proximity Services for 5G Systems

The 3GPP Proximity Service architecture for 5G network (5GS) is described in 3GPP TS 23.304. It is a rel.17 version, which indicates that it is a later specification than the NR V2X specification (rel.16) or even the 5G NR specification (rel.15). This should not be confused with the 3GPP TS 23.303 Rel. 16, which is an LTE specification and enhances the LTE ProSe architecture. TS 23.304 adapts the ProSe architecture and service definition from TS 23.303 Rel. 16 to a 5G system. The descriptions of proximity services for 5G systems in TS 23.304 are still not frozen, which means they are still being developed. A brief description of its content at the end of the 1st Cycle is provided next.

4.1.1 Proximity Service Architecture for 5G Systems

The 5GS enablers for ProSe include the following functions:

- **5G ProSe Direct Discovery** – ProSe-enabled UE are able to discover services offered by neighbouring ProSe-enabled UEs.
- **5G ProSe Direct Communication** – ProSe-enabled UEs are able to directly communicate to each other's without requiring or going through a 5G gNB.
- **5G ProSe UE-to-Network Relay** – A ProSe-enabled UE may act as a relay to extend the reach of gNBs. This mode is not described in this document.

Figure 45 depicts the ProSe architecture for the non-roaming case, along with the specific entities and reference points.
ProSe defines three new main entities:

- **ProSe Application** – a Proximity application running on a UE.
- **ProSe Application Server** – Server authorizing one or more UEs to use a particular Prose Application.
- **Direct Discovery NMF** – connects to the NR RAN (PDCP, RRC and MAC) on the UE-side and to the 5GC functions on the infrastructure side to trigger the required service discovery, authorization and link configuration procedures. This entity replaces the ProSe Function from the LTE specification.

ProSe operates on three main reference points in rel.17:

- **PC1** – It connects a ProSe application running on a UE with the ProSe Application server running in a distant data network or an Edge/MEC server. It is used to define application-level signalling requirements. This reference point is not specified in rel.17.
- **PC3a** – The reference point between the UE and the 5G DDNMF (Direct Discovery Network Management Function). PC3a relies on 5GC (5G Core) user plane for transport (i.e., an "over IP" reference point). It is used to authorise 5G ProSe Direct Discovery request, and perform allocation of ProSe Application Codes / ProSe Restricted Codes corresponding to ProSe Application Identities used for 5G ProSe Direct Discovery.
  - **note**: the ‘a’ is provided to differentiate with the PC3 reference point connecting to the LTE-based ProSe function.
- **PC5** – The reference point between ProSe-enabled UEs used for control and user plane for 5G ProSe Direct Discovery, ProSe Direct Communication and ProSe UE-to-Network Relay. It is also often confused with the term ‘sidelink’, which instead refers to ‘communications’ not a reference point.

### 4.1.2 5G PROSE DIRECT DISCOVERY
ProSe Direct Discovery is carried out on the PC5-D (PC5 Discovery) reference point. As depicted on Figure 46, a specific ProSe Discovery Protocol is defined to discover or offer ProSe Services.

![Figure 46 ProSe PC5-D (Discovery) Interface](image)

ProSe defines two times of Discovery modes:

- **Model A** – A service producer, called ‘announcer’ sends an Announcement message, while any service consumer will be monitoring for any service announcement. If a match is found, a transaction may begin.
- **Model B** – Two types of actors, ‘Service Discoverer’ and ‘Service Discoveree’ are defined. Then two types of messages are defined: service solicitation and service response to match a discoverer and a discoveree.

Figure 47 depicts a ProSe Model A direct discovery procedure.

![Figure 47 5G ProSe Model A Discovery](image)

### 4.1.3 5G PROSE DIRECT COMMUNICATION

5G ProSe Direct Communication over PC5 reference point is supported when the UE is "served by NR or E-UTRA" or when the UE is "not served by NR or E-UTRA". A UE is authorized to perform 5G ProSe Direct Communication when it has valid authorization. 5G ProSe Direct Communication supports both the cases of public safety and commercial service. 5G ProSe Direct Communication over NR based PC5 reference point supports broadcast, groupcast and unicast modes.

ProSe Direct Communication (through a ProseApp) support IPv4, IPv6, Ethernet and Unstructured as depicted on Figure 48, which relates the user plane of the PC5 end point:
ProSe also describes the QoS (Quality of Service) metrics called Packet Quality Indicator (PQI) extending the ProSe Per Packet Priority (PPPP) of the LTE and NR V2X specification. A PQI includes IP and non-IP packet filtering according to but not limited to packet source/destination address, UE ID, ProSe Application ID or channel load.

<table>
<thead>
<tr>
<th>PQI Value</th>
<th>Resource Type</th>
<th>Default Priority Level</th>
<th>Packet Delay Budget</th>
<th>Packet Error Rate</th>
<th>Default Maximum Data Burst Volume</th>
<th>Default Averaging Window</th>
<th>Example Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>GBR (NOTE 1)</td>
<td>1</td>
<td>150 ms</td>
<td>$10^{-2}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Mission Critical user plane Push To Talk voice (e.g., MCPTT)</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>2</td>
<td>200 ms</td>
<td>$10^{-2}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Non-Mission-Critical user plane Push To Talk voice</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>2</td>
<td>200 ms</td>
<td>$10^{-3}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Mission Critical Video user plane</td>
</tr>
<tr>
<td>60</td>
<td>Non-GBR</td>
<td>1</td>
<td>120 ms</td>
<td>$10^{-6}$</td>
<td>N/A</td>
<td>N/A</td>
<td>Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)</td>
</tr>
<tr>
<td>61</td>
<td></td>
<td>6</td>
<td>400 ms</td>
<td>$10^{-6}$</td>
<td>N/A</td>
<td>N/A</td>
<td>Mission Critical Data (e.g., example services are the same as 5QI 6/8/9 as specified in TS 23.501 [4])</td>
</tr>
</tbody>
</table>
4.2 Vehicle-to-Everything (V2X) Communications for 5G Systems

As mentioned in the previous section, although the 5G NR V2X may be considered as a special case of the more general 5G NR ProSe services, the NR V2X architecture has been defined before ProSe already in the 3GPP rel.16 specification. It makes the only ProSe service currently defined for 5G NR at the time of writing. Accordingly, IntellIoT will use the 5G NR V2X specification as a realization of D2D communication.

In a nutshell, 5G NR V2X operates similarly to 5G NR ProSe, but considering only a single service (V2X) and a basic group management (all vehicles belonging to the same group). Accordingly, 5G NR V2X does not have a Service Discovery mode.

4.2.1 V2X SERVICE ARCHITECTURE FOR 5G SYSTEMS

Figure 49 depicts the 5G NR architecture for V2X applications for non-roaming case. As it can be observed, it is similar to the ProSe architecture, with the main differences being the following entities:

5G NR V2X defines three new main entities:

- **V2X Application** – Replaces the ProSe Applications, with the same functions.
- **V2X Application Server** – Replaces the ProSe Application Server, with the same functions.

Direct Discovery NMF is not present as discovery services are not supported for V2X in rel.16. However, V2X service authorization, capacity provisioning and QoS handling is provided by the 5G core entity AMF over two reference points N1 and N2.

5G NR V2X operates on three main reference points in rel.16:

- **V5 reference point** – replaces the PC5 with V2X adapted terminology between V2X applications.
- **V1 reference point** – replaces the PC1 reference point with V2X adapted terminology between a V2X application and the V2X application server.
- **PC5** – same reference point as for ProSe.
- **N1** – reference point conveying V2X service policies and authorization between a UE and a 5G core.
- **N2** – reference point conveying V2X service policies and authorization between a gNB and a 5G core.
4.2.2 V2X COMMUNICATIONS FOR 5G SYSTEMS

5G NR V2X may be seen as an extension of the LTE V2X architecture for 5G NR. It, however, has key major service enhancements compared to LTE V2X. The first one is the V2X Unicast support, which was no supported for LTE V2X.

4.2.2.1 V2X BROADCAST COMMUNICATION

This corresponds to a similar service as for LTE V2X and enables one vehicle to communication to all vehicles within 5G NR V2X range.

4.2.2.2 V2X GROUPCAST COMMUNICATION

This is a new service not available in LTE V2X, which enables one vehicle to communication to a selected group of vehicles. 5G NR V2X groupcast is used to build clusters of vehicles belonging to different groups.

4.2.2.3 V2X UNICAST COMMUNICATION

Although unicast communication is available for 5G NR as well as LTE ProSe, it was not supported for LTE V2X. Figure 50 illustrates examples of PC5-U unicast links. As it may be seen, in addition to supporting unicast links, 5G NR V2X also provides multiple QoS flows, opening the door for prioritizing between V2X communication flows. It also enables various V2X services within a V2X application to operate separately. As for LTE V2X, NR V2X supports IP and non-IP unicast links, however, only IPv6 is supported as IP protocol in rel.16 specification. V2X services managements are handled between V2X applications and with V2X application servers over V5, resp. V1 reference points and not on PC5 (as PC5-D is not defined in 5G NR V2X).
4.2.2.4 5G NR V2X QoS HANDLING

Another difference in 5G NR V2X is the QoS handling. LTE V2X handles QoS through ProSe Per Packet Priority (PPPP) or Prose Per Packet Reliability (PPPR). In 5G NR V2X, a similar QoS architecture as communication over 5G infrastructure is used. It is based on a 5QI (5G quality indicator) metric. A PC5 5QI, called PQI for 5G NR V2X, includes a Flow Bit Rate parameter supporting only a Guaranteed Flow Bit Rate (QFBR) and Maximum Flow Bit Rate (MFBR), a PC5 per Link Aggregated Bit Rate parameter (aggregating bits from various flows on a same V2X link), and finally Range parameter, which provides the minimum distance over which the PQI must be fulfilled. 5G QoS in addition depends on 6 additional metrics: a V2X resource type, a V2X Priority Level, a V2X Packet Delay Budget, a V2X Packet Error Rate, a finally a Maximum Data Burst Volume. Table 3 illustrates the characteristics of various PQI and the mapped V2X services.

**Table 3 5G V2X PQI table**

<table>
<thead>
<tr>
<th>PQI Value</th>
<th>Resource Type</th>
<th>Default Priority Level</th>
<th>Packet Delay Budget</th>
<th>Packet Error Rate</th>
<th>Default Maximum Data Burst Volume</th>
<th>Default Averaging Window</th>
<th>Example Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>GBR</td>
<td>3</td>
<td>20 ms</td>
<td>$10^{-4}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Platooning between UEs – Higher degree of automation; Platooning between UE and RSU – Higher degree of automation</td>
</tr>
<tr>
<td>22 (NOTE 1)</td>
<td></td>
<td>4</td>
<td>50 ms</td>
<td>$10^{-2}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Sensor sharing – higher degree of automation</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>3</td>
<td>100 ms</td>
<td>$10^{-4}$</td>
<td>N/A</td>
<td>2000 ms</td>
<td>Information sharing for automated driving – between UEs or UE and RSU - higher degree of automation</td>
</tr>
</tbody>
</table>
### 5G V2X Communication Procedures

Figure 51 depicts the V2X communication procedures for Groupcast communication. As it is shown, group management is handled by the V2X application layer and not a discovery layer as for ProSe. The Application layer will provide the list of L2 ID and target QoS metrics of vehicles participating to the groupcast communication.

<table>
<thead>
<tr>
<th>ID</th>
<th>GBR Type</th>
<th>Delay Critical</th>
<th>Max Latency (ms)</th>
<th>Max Delay (ms)</th>
<th>Packet Size</th>
<th>Application Layer Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>Non-GBR</td>
<td></td>
<td>10</td>
<td>$10^{-4}$</td>
<td>N/A</td>
<td>Cooperative lane change – higher degree of automation</td>
</tr>
<tr>
<td>56</td>
<td></td>
<td></td>
<td>20</td>
<td>$10^{-1}$</td>
<td>N/A</td>
<td>Platooning informative exchange – low degree of automation; Platooning – information sharing with RSU</td>
</tr>
<tr>
<td>57</td>
<td></td>
<td></td>
<td>25</td>
<td>$10^{-1}$</td>
<td>N/A</td>
<td>Cooperative lane change – lower degree of automation</td>
</tr>
<tr>
<td>58</td>
<td></td>
<td></td>
<td>100</td>
<td>$10^{-2}$</td>
<td>N/A</td>
<td>Sensor information sharing – lower degree of automation</td>
</tr>
<tr>
<td>59</td>
<td></td>
<td></td>
<td>500</td>
<td>$10^{-1}$</td>
<td>N/A</td>
<td>Platooning – reporting to an RSU</td>
</tr>
<tr>
<td>90</td>
<td>Delay Critical GBR</td>
<td></td>
<td>10</td>
<td>$10^{-4}$</td>
<td>2000 bytes</td>
<td>Cooperative collision avoidance; Sensor sharing – Higher degree of automation; Video sharing – higher degree of automation</td>
</tr>
<tr>
<td>91</td>
<td>(NOTE 1)</td>
<td></td>
<td>3</td>
<td>$10^{-5}$</td>
<td>2000 bytes</td>
<td>Emergency trajectory alignment; Sensor sharing – Higher degree of automation</td>
</tr>
</tbody>
</table>

NOTE 1: GBR and Delay Critical GBR PQIs can only be used for unicast PC5 communications.
5G V2X unicast communication procedures have in addition a security establishment between two vehicles, which is handled over the PC5-S interface, in a similar way as for LTE V2X.

4.3 5G ProSe D2D Spectrum (FR1/FR2/ITS)

As for LTE, 5G NR ProSe does not have an explicit frequency spectrum, although it is anticipated that any PS ProSe would be operated on PS spectra, and any other ProSe communications be operated on commercial spectra.

5G NR V2X on the other hand, has explicit spectrum bands reserved for V2X services, both in FR1 and FR2. It corresponds to the ITS spectra (5.9Ghz for FR1 and 64Ghz for FR2). However, at the time of writing, the exact channels and communication masks to be used in each band has not been aggregated upon. Following the EU technology neutral access to the ITS bands, NR V2X must coexist with LTE V2X and ITS-G5 devices.

4.4 5G D2D Radio Resource Management

This section provides an overview of the 5G NR V2X radio resource management according to target bit rates, delay and scheduling.

4.4.1 BIT RATE

The target bit rate for NR V2X is not fully clear at the time of writing, notably due to the lack of advanced prototypes. However, NR V2X is a 5G technology, and as such, it should reach the 5G target bit rate:

- **Middle Band (sub 6Ghz):** < 2–3 Gbps
- **Higher Band (>20Ghz):** < 20Gbps

4.4.2 DELAY CONSIDERATION

LTE V2X has two major weaknesses in terms of delay. First, the LTE V2X LBT (Listen-Before-Talk) SBS (Semi-Persistent-Scheduling) requires to select resources over a 20ms time windows, and assuming a 100ms resource statistic history. At the time of writing, a LBT SBS approach remains the main candidate for the NR V2X mode 2(a) (default ad-hoc mode) scheduler. However, new NR V2X scheduling capabilities (see Figure 7) are expected to improve its access delay and reliability.
Second, an LTE V2X slot is 1 ms, which means that regardless of the message size, it will occupy 1ms time. Considering that most of the V2X messages are approximately 500 ms and a limited number of messages allowed in frequency (usually 2), E2E delay can grow beyond what is required for time sensitive communications. NR V2X introduces the concept of mini-slot, which jointly with a more flexible frequency usage (15kHz, 30kHz, 60kHz) provides sub-ms subframe time.

Along with a flexible control of resource blocks, NR V2X aims at providing 1ms delay. It should yet be noted that NR V2X, as LTE V2X needs to integrate wireless cooperative congestion control mechanisms, which are expected to negatively impact such delay.

4.4.3 5G NR V2X SCHEDULER

NR V2X has several improvements in terms of robustness and interference. The first one is the possibility to reserve retransmission opportunities to mitigate the impact of collisions as depicted on Figure 52. LTE V2X also supports retransmissions (called semi-persistent scheduling) but it has been designed to reduce the scheduling delay overhead as well as to improve the receiver gain to increase communication range. LTE V2X could not optimize retransmission based on reception or non-reception of messages.

In order to fully take benefit of this retransmission option, NR V2X provides another innovation called NACK (i.e., Negative Acknowledgments), where messages scheduled but not received by V2X receivers would allow to notify the transmitter, thus enabling the retransmissions.

Finally, the third innovation of NR V2X is an increased flexibility in the scheduling support. The NR V2X ad-hoc mode, called mode 2, is decomposed in 4 sub-groups:

- **Mode 2(a) Autonomous resource selection** – same as LTE V2X mode 4
- **Mode 2(b) UE assists resource selection of other UEs** – a UE may indicate its preferred resources to other UEs
- **Mode 2(c) UE is configured with sidelink grants** – same as LTE V2X mode 4 SPS
- **Mode 2(d) UE schedules sidelink transmission of other UEs** – a cluster-head UE directs V2X communications, like LTE V2X mode 3, yet without eNB

4.4.4 PRACTICAL CONSIDERATION

NR V2X is an evolution of LTE V2X, correcting most of its weaknesses identified for future automated robotics and massive sensor communications. The 3GPP NR V2X Rel. 16 has been frozen in July 2020, with the first commercially available devices no earlier than 2025.
Moreover, if the 5G NR V2X describes 4 types of ad-hoc scheduler (mode 2), only mode 2(a) is specified in rel.16. Accordingly, 5G NR V2X has the same scheduler as LTE V2X.

4.5 5G D2D ProSe Services for IntellIoT use cases

4.5.1 UC1 - AGRICULTURE

D2D communication is envisioned in UC1 in two scenarios. First, a drone can connect to a tractor to provide extra sensor data or AI support. Accordingly, a D2D link will be established between the drone and the tractor. A second scenario envisions a D2D link between tractors in case they would be in range and could exchange sensing data or cooperate on AI.

4.5.2 UC3 - MANUFACTURING

D2D communication is envisioned in UC3 in two scenarios. First, robots and human interactions must be closely monitored and 5G NR ProSe can provide a robot virtual fencing service, notifying and stopping a robot when a human operator approaches within a given range. A second scenario enables robots to exchange information directly between each other either to synchronize movements or to share data or AI knowledge (cooperative training or knowledge services). It could finally also be envisioned to allow a robot operator to directly connect to the robot for remote operation, bypassing and offloading the 5G private backend.

4.6 Preliminary 5G NR V2X Performance Evaluation

Considering the lack of available NR V2X prototypes, 5G NR V2X development will be conducted via simulation. The Network Simulator 3 (NS-3) has been selected as it has already a NR V2X architecture.

4.6.1 NR V2X SOFTWARE ARCHITECTURE ON NS3

Ns-3 is a widely adopted packet-level simulator to develop and evaluate the performance of network protocols and applications, due to the widely available libraries of network models and protocols (WIFI, BLE, LTE, 5G, V2X,...). Recently, a NR V2X architecture has been integrated. We describe here the software architecture of the NR V2X user and control planes. More details related to this NR V2X model may be found here8.

The NR V2X architecture is built on top of the LTE architecture with NR and NR V2X specific extensions. For instance, NR V2X PHY and NR V2X MAC are extended to support NR Phy Slidelink channels as well as NR V2X MAC scheduler. NR functions above the NR PHY and MAC are also available as NR-specific APIs, although the models are still integrated into the LTE architecture. This current architecture allows to evaluate the performance of the NR V2X scheduler in challenging V2X environments and V2X traffic. However, the missing SDAP entity limits the current architecture to model real QoS management.

In our preliminary study, we are only interested in evaluating and comparing the performance of the NR V2X MAC at FR1 and FR2 with LTE V2X. The current architecture limitations are not impacting our study. However, extensions to the ns-3 model architecture to integrate SDAP will be performed in the future.

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Figure 53: Ns3 NR V2X Control Plane architecture

Figure 54: Ns-3 NR V2X User Plane architecture
4.6.2 NR V2X PERFORMANCE COMPARISON BETWEEN FR1 AND FR2

As for 5G NR, the V2X extension supports two frequency ranges FR1 and FR2, and similarly to NR, NR V2X FR2 is expected to be required to support the large amount of sensor or AI/ML data exchanged between vehicles and the infrastructure in the future. A first question could be to compare the performance of NR V2X in FR1 and FR2 considering capacity as the optimization point. The default parameters configured with ns3 are provided on Table 4.

<table>
<thead>
<tr>
<th>Table 4: Ns3 Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NR V2X Parameters</strong></td>
</tr>
<tr>
<td><strong>Frequency Range</strong></td>
</tr>
<tr>
<td>Random Seed</td>
</tr>
<tr>
<td>Performed Frequency</td>
</tr>
<tr>
<td>Topology</td>
</tr>
<tr>
<td>Bandwidth</td>
</tr>
<tr>
<td>SubChannel Size</td>
</tr>
<tr>
<td>MCS</td>
</tr>
<tr>
<td>Numerology</td>
</tr>
<tr>
<td>Available SL symbol per slot</td>
</tr>
<tr>
<td>Sensing Window</td>
</tr>
<tr>
<td>Selection Window</td>
</tr>
<tr>
<td>Reservation Period</td>
</tr>
<tr>
<td>No. Selected Slot per time</td>
</tr>
<tr>
<td>Re-transmission</td>
</tr>
</tbody>
</table>

Considering that NR V2X is planned to be used to exchange larger packet sizes at a higher Tx rate, we wanted to evaluate the impact of large packets (1500 bytes) as well as high Tx rate (1Mbps->100Mbps) on the performance of NR V2X both in FR1 and FR2. In our scenarios, except Figure 55, we only consider 1 Tx and 1 Rx and no interferences. Any packet loss may only come either from the impact of the wireless channel on the selected technology (FR1 or FR2) or from packet being dropped by the NR V2X stack due to the lack of radio resources.

Figure 55, depicts the Packet Reception Rate considering a 2Mbps Tx rate for regular CAM-type packets (200 bytes) both considering 1 Tx-Rx (i.e., no interference) or 10 Tx-Rx (including interferences). As it may be observed on Figure 55(a), the increased capacity available in FR2 enables a very reliable 5G V2X communication up to 100m radio range. Comparatively, FR1 never reaches a PRR higher than 80% due to packet being dropped by the lack of channel resources. We can also observe the impact of mmWAVE channels on NR V2X FR2, which PRR drops faster, and as closer distance compared to FR1. We can, however, see that considering 1 Rx-Tx and no interference, FR2 has a significant benefit on the reliability of NR V2X communications. Considering now interferences created by 10 Tx-Rx, the performance of 5G V2X drops significantly and irrespectively to the FR, as the PRR never gets higher than 30%. This is most likely due to the NR V2X mode (a) scheduler inheriting radio resource selection over a 20ms window and accordingly, dropping packets when resources are not available (and not specifically due to collisions as otherwise we would have observed less collisions in FR2). This limitation being at the NR V2X protocol stack, it impacts both FR1 and...
FR2. This 20ms (configurable) has been designed for LTE V2X in order to limit the mean delay to 10ms. However, NR V2X enhanced numerology could be improved to separate traffic requiring low delay and high capacity and dramatically increasing the resource selection at no impact on delay.

However, when the Tx-Rx distance increases, we can observe the impact of the mmWAVE channel on the PRR, as PRR drops quickly to 0 with distance. Although this performance depends on the beamforming strategy at FR2, it also shows the strong impact the wireless channel has on mmWAVE transmissions. NR V2X in FR1 keeps a higher PRR over distance. It can, however, be observed that neither the distance nor the transmit rate are satisfactory with respect to the objectives of IntellIoT for NR V2X.

![Figure 55 Packet Reception Rate over distance for NR V2X in FR1 and FR2 in a saturation case (rate=2Mbps packet size: 200 bytes)](image)

The second set of results shows the evolution of the PRR when the transmit rate increases up to 100Mbps. In this configuration, we also considered the largest V2X packet size of 1500 bytes in order to fully pressure the NR V2X scheduler. As it can be seen on Figure 56, the PRR remains 100% up to 3Mbps, which is an interesting observation of the impact of the packet size on the V2X scheduler. Indeed, in comparison with the previous figure (for 1Tx-Rx), considering a constant transmit rate, increasing the packet size de facto reduces the flow of packets at the scheduler, therefore, enabling it to operate better. As a consequence, we can observe that the current NR V2X specification, if massive amount of data needs to be exchanged, it might be required to aggregate data over longer packet sizes by PDCP. This, however, is opposite to the NR V2X specification, which forbids this functionality in order to gain in delay.

When the transmit rate further increases, we see that the higher bandwidth available for FR2 enables it to maintain a higher PRR until 10Mbps. After this limit, both FR1 and FR2 suffer from the scheduler saturation and have poor PRR. Nevertheless, we can also observe from this set of results that neither FR1 nor FR2 provides the required V2X capacity expected by NR.
In the previous results, a default MCS 14 has been selected (as recommended for V2X). On Figure 57, we evaluate the impact of increasing the MCS for FR1 and FR2. This scenario is not fully representative of the true impact of MCS, as we do not consider interferences and we only consider broadcast/groupcast traffic. However, it already shows that when transmitting large amount of data, FR2 may better support the MCS increase and provide a higher total capacity. A more complete study should be performed to evaluate the impact of interferences to select the most optimal MCS according to a particular context.

To conclude, this first study aimed at testing NR V2X considering capacity as an optimization point. Accordingly, large packets or transmit capacity up to 50-100 Mbps have been tested for NR V2X. We could observe that NR V2X both considering FR1 and FR2 do not meet the optimal capacity targeted by the 3GPP NR V2X rel.16 standard, but
improvement could be envisioned. A second study is currently being performed on the latency aspect, which aims to test the current scheduler capability to reduce latency compared to LTE V2X.
5 CONCLUSION

This deliverable is the first output of Task 4.2 ("5G network functionalities") and, as such, documented the design and development of the first version of the 5G components and their integration into the third pillar ("efficient, reliable and trustworthy computation & communication infrastructure") of the IntellIoT proposed framework.

Considering the 5G components and their requirements described in deliverable D2.3 ("High level architecture"), this document introduces the first version of the components themselves. It first shed light on the State-of-the-Art in the component specification in the respective standardization organizations, then depicted the software platforms in which these components are implemented and finally described their specifications.

This document also provides a preliminary evaluation of the functionality of selected components (in particular 5G NR RAN SA and NSA) or simulation-based evaluation of the default components (NR V2X).

From the various components described in D2.3, the following components have been targeted for the 1st development Cycle:

- 5G NR NSA & SA basic functionalities with a 5G dongle in FR1 only.
- 5G FlexRIC components capable of controlling the radio resource allocation for the 5G RAN.
- 5G FlexCN component capable of handling MEC/Edge services, including RAN/Slice condition monitoring and RNIS.
- 5G NR V2X performance comparison between FR1 and FR2 and identification of potential extensions to support URLL communication on sidelink.

This deliverable describes the outcome of the 1st Cycle, although work is on-going to improve the components for the Open Call demonstrators in Q1 2022.

In the 2nd Cycle of development of the IntellIoT Framework, the previously described components will be further extended as part of D4.6. The 5G NR SA will be developed for FR2 as well, and an improved URLL numerology will be provided for FR1 and FR2. Modifications to the 5G NR V2X will be proposed and evaluated to differentiate URLL traffic from high-capacity traffic. Finally, the 5G TSN architecture has been postponed to the 2nd Cycle, due to the absence of end-to-end TSN links during the 1st Cycle development.
## ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<tr>
<td>5G</td>
<td>Fifth Generation</td>
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<tr>
<td>5GC</td>
<td>5G Core</td>
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<tr>
<td>5GS</td>
<td>5G System</td>
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<tr>
<td>5QI</td>
<td>5G New Radio Standardized Quality of Service Identifier</td>
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<tr>
<td>AF</td>
<td>Application Function</td>
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<tr>
<td>AMF</td>
<td>Access and Mobility Function</td>
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<tr>
<td>API</td>
<td>Application Programming Interface</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>ARP</td>
<td>Allocation and Retention Priority</td>
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<td>Evolved Packet Core</td>
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<td>E-UTRA</td>
<td>Evolved Universal Terrestrial Radio Access</td>
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<td>FR1</td>
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<tr>
<td>FR2</td>
<td>Frequency Range 2 (&gt; 10Ghz)</td>
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<td>Virtual Reality</td>
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<tr>
<td>V2X</td>
<td>Vehicle to Everything</td>
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</table>
7 REFERENCE

3GPP TS 23.303 V16.0.0, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Proximity-based services (ProSe); Stage 2.

3GPP TS 23.304 V17.0.0, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Proximity based Services (ProSe) in the 5G System (5GS).

3GPP TS 23.287 V16.3.0, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services.

3GPP TS 23.501 V17.2.0, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; System architecture for the 5G System (5GS); Stage 2

3GPP TS 23.548 V17.0.0, 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 5G System Enhancements for Edge Computing; Stage 2