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| Technical Report |
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Contents

Foreword 4

1 Scope 6

2 References 6

3 Definitions of terms, symbols and abbreviations 7

3.1 Terms 7

3.2 Abbreviations 7

4 Introduction to Extended Reality 8

4.1 Extended Reality Types 8

4.2 Human Perception and Tracking 8

4.3 Capture, Encoding and Delivery 9

4.3.1 Video 9

4.3.2 Audio 10

4.4 XR Engines and Rendering 10

4.5 Characteristics and Requirements 10

4.5.1 General 10

4.5.2 Video 11

4.5.3 Audio 11

4.5.4 Pose Information 11

5 XR Enhancements for NR 11

5.1 XR Awareness 11

5.1.1 General 11

5.1.2 Layer 2 Structure 12

5.2 Power Saving Techniques 13

5.2.1 Physical Layer Enhancements 13

5.2.2 Layer 2 Enhancements 13

5.3 Capacity Improvements Techniques 13

5.3.1 Physical Layer Enhancements 13

5.3.2 Layer 2 Enhancements 13

6 Conclusions 14

Annex A: Evaluation Methodology 15

Annex B: Evaluation Studies 16

Annex C (informative): RAN2 Agreements 17

C.1 RAN2#119-e 17

C.2 RAN2#119bis-e 17

Annex Z (informative): Change history 19

# Foreword

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

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

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where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

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Y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**Should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**Can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**Will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

The present document is intended to capture the output of the study item on XR Enhancements for NR [10], which aims at investigating power saving and capacity enhancements techniques tailored for XR services, as well as means to provide XR-awareness in RAN.

This study follows a series of earlier studies conducted in 3GPP by SA1 [2], SA4 [5] [6] [7] and RAN1 [8]. It is complemented by work in SA2 [12], SA4 [11] and SA6 [4].

# 2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR [21.905](http://www.3gpp.org/ftp/Specs/html-info/21905.htm): "Vocabulary for 3GPP Specifications".

[2] 3GPP TR [22.842](http://www.3gpp.org/ftp/Specs/html-info/22842.htm): "Study on Network Controlled Interactive Service (NCIS) in the 5G System (5GS)".

[3] 3GPP TR [23.748](http://www.3gpp.org/ftp/Specs/html-info/23748.htm): "Study on enhancement of support for Edge Computing in 5G Core network(5GC)".

[4] 3GPP TR [23.758](http://www.3gpp.org/ftp/Specs/html-info/23758.htm): "Study on application architecture for enabling Edge Applications".

[5] 3GPP TR [26.918](http://www.3gpp.org/ftp/Specs/html-info/26918.htm): "Virtual Reality (VR) media services over 3GPP".

[6] 3GPP TR [26.926](http://www.3gpp.org/ftp/Specs/html-info/26926.htm): "Traffic Models and Quality Evaluation Methods for Media and XR Services in 5G Systems".

[7] 3GPP TR [26.928](http://www.3gpp.org/ftp/Specs/html-info/26928.htm): "Extended Reality (XR) in 5G".

[8] 3GPP TR [38.838](http://www.3gpp.org/ftp/Specs/html-info/38838.htm): "Study on XR (Extended Reality) evaluations for NR".

[9] 3GPP TR [23.700-60](https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=4007): "Study on architecture enhancement for XR and media services".

[10] [RP-220285](http://3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_95e/Docs/RP-220285.zip): "Study on XR Enhancements for NR".

[11] [SP-210043](http://3gpp.org/ftp/tsg_sa/TSG_SA/TSGs_91E_Electronic/Docs/SP-210043.zip): "Feasibility Study on Typical Traffic Characteristics for XR Services and other Media".

[12] [SP-220705](http://3gpp.org/ftp/tsg_sa/TSG_SA/TSGS_96_Budapest_2022_06/Docs/SP-220705.zip): "Study on XR (Extended Reality) and media services s".

[13] [S4-220505](http://3gpp.org/ftp/tsg_sa/WG4_CODEC/TSGS4_118-e/Docs/S4-220505.zip): "LS Reply on QoS support with PDU Set granularity".

[14] [S4aV220921](https://www.3gpp.org/ftp/tsg_sa/WG4_CODEC/3GPP_SA4_AHOC_MTGs/SA4_VIDEO/Docs/S4aV220921.zip): "Reply LS on further details on XR traffic".

[15] 3GPP TS [38.300](https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3191): "NR and NG-RAN Overall description; Stage-2".

*Editor's Note: hyperlinks, responsible groups and corresponding releases are used for convenience, they can be removed once the TR is presented for approval.*

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

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

**Field of view:** the angle of visible field expressed in degrees measured from the focal point.

**PDU Set**: A PDU Set is composed of one or more PDUs carrying the payload of one unit of information generated at the application level (e.g. a frame or video slice for XRM Services, as used in TR 26.926 [6]). In some implementations all PDUs in a PDU Set are needed by the application layer to use the corresponding unit of information. In other implementations, the application layer can still recover parts or all of the information unit, when some PDUs are missing.

**Multi-modal Data**: Multi-modal Data is defined to describe the input data from different kinds of devices/sensors or the output data to different kinds of destinations (e.g. one or more UEs) required for the same task or application. Multi-modal Data consists of more than one Single-modal Data, and there is strong dependency among each Single-modal Data. Single-modal Data can be seen as one type of data.

**Data Burst:** Data produced by the application in a short period of time, comprising PDUs from one or more PDU Sets.

## 3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1], TS 38.300 [15] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1] and in TS 38.300 [15].

3DoF Three Degrees of Freedom

6DoF Six Degrees of freedom

AR Augmented Reality

DASH Dynamic Adaptive Streaming over HTTP

FEC Forward Error Coding

FoV Field of view

FPS Frames Per Second

GBR Guaranteed Bit Rate

GFBR Guaranteed Flow Bit Rate

HEVC High-Efficiency Video Coding

HMD Head-Mounted Display

HUD Heads-Up Display

PDB Packet Delay Budget

PDU Protocol Data Unit

PER Packet Error Rate

PSDB PDU-Set Delay Budget

PSER PDU-Set Error Rate

QCI QoS Class Identifier

QFI QoS Flow ID

QoE Quality of Experience

QoS Quality of Service

VR Virtual Reality

XR Extended reality

# 4 Introduction to Extended Reality

## 4.1 Extended Reality Types

Extended Reality (**XR**) refers to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables. XR is an umbrella term for different types of realities (see TR 26.918 [5] and TR 26.928 [7]):

- Virtual reality (**VR**) is a rendered version of a delivered visual and audio scene. The rendering is designed to mimic the visual and audio sensory stimuli of the real world as naturally as possible to an observer or user as they move within the limits defined by the application. Virtual reality usually, but not necessarily, requires a user to wear a head mounted display (HMD), to completely replace the user's field of view with a simulated visual component, and to wear headphones, to provide the user with the accompanying audio. Some form of head and motion tracking of the user in VR is usually also necessary to allow the simulated visual and audio components to be updated in order to ensure that, from the user's perspective, items and sound sources remain consistent with the user's movements.

- Augmented reality (**AR**) is when a user is provided with additional information or artificially generated items or content overlaid upon their current environment. Such additional information or content will usually be visual and/or audible and their observation of their current environment may be direct, with no intermediate sensing, processing and rendering, or indirect, where their perception of their environment is relayed via sensors and may be enhanced or processed.

- Mixed reality (**MR**) is an advanced form of AR where some virtual elements are inserted into the physical scene with the intent to provide the illusion that these elements are part of the real scene.

Other terms used in the context of XR are Immersion as the sense of being surrounded by the virtual environment as well as Presence providing the feeling of being physically and spatially located in the virtual environment. The sense of presence provides significant minimum performance requirements for different technologies such as tracking, latency, persistency, resolution and optics.

This document uses the acronym XR throughout to refer to equipment, applications and functions used for VR, AR and MR. Examples include, but are not limited to HMDs for VR, optical see-through glasses and camera see-through HMDs for AR and MR and mobile devices with positional tracking and camera. They all offer some degree of spatial tracking and the spatial tracking results in an interaction to view some form of virtual content.

## 4.2 Human Perception and Tracking

For providing XR experiences that make the user feel *immersed* and *present*, several relevant quality of experience factors have been collected (see TR 26.926 [7]). Presence is the feeling of being physically and spatially located in an environment. Presence is divided into 2 types: Cognitive Presence and Perceptive Presence. Cognitive Presence is the presence of one's mind. It can be achieved by watching a compelling film or reading an engaging book. Cognitive Presence is important for an immersive experience of any kind. Perceptive Presence is the presence of one's senses. To accomplish perceptive presence, one's senses, sights, sound, touch and smell, have to be tricked. To create perceptive presence, the XR Device has to fool the user's senses, most notably the audio-visual system. XR Devices achieve this through positional tracking based on the movement. The goal of the system is to maintain your sense of presence and avoid breaking it. Perceptive Presence is the objective to be achieved by XR applications.

The Human field of view (**FoV**) is defined as the area of vision at a given moment (with a fixed head). It is the angle of visible field expressed in degrees measured from the focal point. The monocular FoV is the angle of the visible field of one eye whereas the binocular FoV is the combination of the two eyes fields (see TR 26.918 [5]). The binocular horizontal FoV is around 200-220°, while the vertical one around 135°. The central vision, which is about 60°, is also called the comfort zone where sensibility to details is the most important. Although less sensitive to definition, the peripheral vision is more receptive to movements.

In XR, actions and interactions involve movements and gestures. Thereby, the Degrees of Freedom (**DoF**) describe the number of independent parameters used to define movement in the 3D space (see TR 26.928 [7]):

- 3DoF: three rotational and un-limited movements around the X, Y and Z axes (respectively pitch, yaw and roll). A typical use case is a user sitting in a chair looking at 3D 360 VR content on an HMD.



Figure 4.2-1: 3DoF

- 6DoF: 3DoF with full translational movements along X, Y and Z axes. Beyond the 3DoF experience, it adds (i) moving up and down (elevating/heaving); (ii) moving left and right (strafing/swaying); and (iii) moving forward and backward (walking/surging). A typical use case is a user freely walking through 3D 360 VR content (physically or via dedicated user input means) displayed on an HMD.



Figure 4.2-2: 6DoF

An **XR View** describes a single view into an XR scene for a given time. Each view corresponds to a display or portion of a display used by an XR device to present the portion of the scene to the user.

An **XR Viewport** describes a viewport, or a rectangular region, of a graphics surface. The XR viewport corresponds to the projection of the XR View onto a target display. An XR viewport is predominantly defined by the width and height of the rectangular dimensions of the viewport.

An **XR Pose** describes a *position* and *orientation* in space relative to an XR Space. An essential element of XR is the spatial tracking of the viewer pose.

## 4.3 Capture, Encoding and Delivery

### 4.3.1 Video

XR content may be represented in different formats, e.g. panoramas or spheres depending on the capabilities of the capture systems. Since modern video coding standards are not designed to handle spherical content. Projection is used for conversion of a spherical (or 360°) video into a two-dimensional rectangular video before the encoding stage. After projection, the obtained two-dimensional rectangular image can be partitioned into regions (e.g. front, right, left, back, top, bottom) that can be rearranged to generate "packed" frames to increase coding efficiency or viewport dependent stream arrangement.

There are mainly three approaches that can be considered for 360 video delivery (see TR 26.918 [5]):

- Single stream approach: the single stream approach consists in providing the full 360 video and showing the interesting part only. Solutions that lie within this group have the drawback that either they may not be scalable or they may impose a big challenge in terms of required network resources (high bitrate of high resolution video) and required processing at the client side (decode a very high resolution video).

- Multi-stream approach: the multi-stream approach consists of encoding several streams, each of them emphasizing a given viewport and making them available for the receiver, so that the receiver decides which stream is delivered at each time instance.

- Tiled stream approach: the tiled stream approach consists in emphasizing the current user viewport through transmitting non-viewport samples with decreased resolution. The tiles can be provided as one common bitstream (using motion-constrained HEVC tiles) or as separate video streams.

In modern video codecs (see S4-220505 [13]):

- Complex prediction structures are used that take into account application constraints, encoding complexity, latency and dynamic decisions in the encoding. This may result in irregularities, for example based on sequence properties. In particular for low-latency delivery with error resiliency, different flavours of encoding operations are in use, and the concept of I, P and B pictures is not generally applicable.

- All PDUs in a PDU Set are needed by the application layer to use the corresponding unit of information in some implementations; while in some others, receivers may use the data up to the first lost fragmentation unit to recover at least parts of the video data and apply error concealment afterward.

- Furthermore, in motion-compensated predicted video decoding, some frames refer to other frames based on the video encoding configuration but also based on dynamic operational decisions. As a consequence, a PDU Set may “depend” on previously received PDU Sets. However, such dependencies do not necessarily result in discarding dependent information units.

### 4.3.2 Audio

For Audio, we can distinguish channel-based and object-based representations (see TR 26.918 [5]):

- Channel-based representation using multiple microphones to capture sounds from different directions and post-processing techniques are well known in the industry, as they have been the standard for decades.

- Object-based representations represent a complex auditory scene as a collection of single audio elements, each comprising an audio waveform and a set of associated parameters or metadata. The metadata embody the artistic intent by specifying the transformation of each of the audio elements to playback by the final reproduction system. Sound objects generally use monophonic audio tracks that have been recorded or synthesized through a process of sound design. These sound elements can be further manipulated, so as to be positioned in a horizontal plane around the listener, or in full three-dimensional space using positional metadata.

## 4.4 XR Engines and Rendering

XR engines provide a middleware that abstracts hardware and software functionalities for developers of XR applications (see TR 26.928 [7]). Typical components include a rendering engine for graphics, an audio engine for sound, and a physics engine for emulating the laws of physics. In the remainder of this Technical Report, the term *XR engine* is used to provide any type of typical XR functionalities as mentioned above.

The processing of an XR engine is not exclusively carried out in the device GPU. In power and resource constrained devices, it can be assisted or split across the network through edge computing (see TR 22.842 [2]): the UE sends the sensor data in uplink direction to the cloud side in a real time manner and when the cloud side receives the sensor data, it performs rendering computing and produces the multimedia data and then sends back to the user devices for display. This is where NR can play an essential role.

## 4.5 Characteristics and Requirements

### 4.5.1 General

In general, it is difficult to identify characteristics common for different XR applications since they heavily depend on the application choices, such as the application itself, the codec in use, the data formats and the encoding operation (see S4-220505 [13]). In particular, low-latency XR and cloud gaming video services such as Split-Rendering or Cloud Gaming typically would not use the traditional coding structure with a fixed Group of-Picture (GOP). In addition, the field of low-latency video delivery is undergoing heavy innovation and new coding methods may be established frequently. Thus, the traffic characteristics and requirements derived from the work done in SA4 (TR 26.926 [6] and TR 26.928 [7]) and listed below, can only be used as a baseline when specific examples for XR traffic characteristics are needed – bearing in mind that they are not universally applicable for all XR applications.

### 4.5.2 Video

The **frame rate** for XR video varies from 15 frames per second up to 90 or even 120 frames per second, with a typical minimum of 60 for VR (see TR 26.918 [5] and TR 26.926 [6]).

According to TR 26.918 [5], the **latency** of action of the angular or rotational vestibulo-ocular reflex is known to be of the order of 10 ms or in a range from 7-15 milliseconds and it seems reasonable that this should represent a performance goal for XR systems. This results in a motion-to-photon latency of less than 20 milliseconds, with 10ms being given as a goal.

Regarding the **bit rates**, between 10 and 200Mbps can be expected for XR depending on frame rate, resolution and codec efficiency (see TR 26.926 [6] and TR 26.928 [7]).

### 4.5.3 Audio

According to TR 26.918 [5], due to the relatively slower speed of sound compared to that of light, it is natural that users are more accustomed to, and therefore tolerant of, sound being relatively delayed with respect to the video component than sound being relatively in advance of the video component. Recent studies have led to recommendations of an accuracy of between 15 ms (audio delayed) and 5 ms (audio advanced) for the **synchronization**, with recommended absolute limits of 60 ms (audio delayed) and 40 ms (audio advanced) for broadcast video.

### 4.5.4 Pose Information

To maintain a reliable registration of the virtual world with the real world, as well as to ensure accurate tracking of the XR Viewer pose, XR applications require highly accurate, low-latency tracking of the device at about 1kHz sampling frequency. The size of a XR Viewer Pose associated to time, typically results in packets of size in the range of 30-100 bytes, such that the generated data is around several hundred kbit/s if delivered over the network (see TR 26.928 [7]).

Pose information has to be delivered with ultra-high reliability, therefore, similar performance as URLLC is expected i.e. packet loss rate should be lower than 10E-4 for uplink sensor data – see TR 22.842 [2].

*Editor's Note: LS sent to SA4 to clarify the requirements of pose information.*

# 5 XR Enhancements for NR

## 5.1 XR Awareness

### 5.1.1 General

In both uplink and downlink, XR-Awareness contributes to optimizations of gNB radio resource scheduling and relies at least on the notions of PDU Set and Data Burst (see TR 23.700-60 [9]): a PDU Set is composed of one or more PDUs carrying the payload of one unit of information generated at the application level (e.g. a frame or video slice), while a Data Burst is a set of data PDUs generated and sent by the application in a short period of time.

NOTE: A Data Burst can be composed of multiple PDUs belonging to one or multiple PDU Sets.

In order to handle QoS flows and PDUs efficiently, the following information is to be provided by the CN (see TR 23.700-60 [9]):

- Semi-static information for both UL and DL provided via control plane (NGAP):

- Periodicity for UL and DL traffic of the QoS Flow via TSCAI/TSCAC;

- Traffic jitter information (e.g. jitter range) associated with each periodicity of the QoS flow;

- PDU Set QoS parameters:

- PDU Set Error Rate (PSER): defines an upper bound for the rate of PDU Sets that have been processed by the sender of a link layer protocol (e.g. RLC in RAN of a 3GPP access) but that are not successfully delivered by the corresponding receiver to the upper layer (e.g. PDCP in RAN of a 3GPP access). Thus, the PSER defines an upper bound for a rate of non-congestion related packet losses. The purpose of the PSER is to allow for appropriate link layer protocol configurations (e.g. RLC and HARQ in RAN of a 3GPP access). For every 5QI the value of the PSER is the same in UL and DL. If any PDU within the PDU Set is not successfully transmitted, the PDU Set is treated as error.

- PDU Set Delay Budget (PSDB): defines an upper bound for the delay that a PDU Set may experience for the transfer between the UE and the N6 termination point at the UPF, i.e. time between reception of the first PDU and the successful delivery of the last arrived PDU of a PDU Set. PSDB applies to the DL PDU Set received by the UPF over the N6 interface, and to the UL PDU Set sent by the UE. For a certain 5QI the value of the PSDB is the same in UL and DL.

- PDU Set Integrated Indication (PSII) i.e. whether all PDUs are needed for the usage of PDU Set by application layer (optional).

- Dynamic information for DL provided by user plane (GTP-U header):

- PDU Set Sequence Number;

- PDU Set Size in bytes;

- PDU SN within a PDU Set;

- End PDU of the PDU Set;

- PDU Set Importance: this parameter is used to identify the importance of a PDU Set within a QoS flow. RAN may use it for PDU Set level packet discarding in presence of congestion;- End of Data Burst indication in the header of the last PDU of the Data Burst (optional).

In the uplink, the UE needs to be able to identify PDU Set and Data Bursts dynamically but in-band marking of PDUs is not needed. Further information can be considered if the BSR is not enough though (see subclause 5.3.2 below).

When a certain *number* of PDUs of a PDU Set are known to be required by the application layer to use the corresponding unit of information (for instance due to the absence or limitations of error concealment techniques, see TR 26.926 [6]), as soon as the number of PDUs known to be lost exceeds this *number*, the remaining PDUs of that PDU Set are no longer needed by the application and may be subject to discard operation (see subclause 5.3.2).

NOTE 1: This depends on the application and it cannot always be assumed that the remaining PDUs are not useful and can safely be discarded.

NOTE 2: In case of Forward Error Coding (FEC), active discarding of PDUs when assuming that a large enough number of packets have already been transmitted for FEC to recover without the remaining PDUs is not recommended as it might trigger an increase of FEC packets (see S4aV220921 [14]).

### 5.1.2 Layer 2 Structure

Depending on how the mapping of PDU Sets onto QoS flows is done in the NAS and how QoS flows are mapped onto DRBs in the AS, we can distinguish the following alternatives (as depicted on Figure 5.1.2-1 below):

- 111: one-to-one mapping between types of PDU Sets and QoS flows in the NAS and one-to-one mapping between QoS flows and DRBs in the AS. From a Layer 2 structure viewpoint, this alternative is already possible and requires as many DRBs as types of PDU Sets. Providing different QoS for the types of PDU Sets sent in different DRBs is already possible.

- NN1: one-to-one mapping between types of PDU Sets and QoS flows in the NAS and possible multiplexing of QoS flows in one DRB in the AS. From a Layer 2 structure viewpoint, this alternative is already possible but gives each QoS flows multiplexed in a DRB the same QoS. Providing different QoS for the types of PDU Sets (i.e. QoS flows) multiplexed in a single DRB is currently not possible.

- N11: possible multiplexing of types of PDU Sets in one QoS flow in the NAS and one-to-one mapping between QoS flows and DRBs in the AS. From a Layer 2 structure viewpoint, this alternative is already possible but gives each QoS flow/DRB one QoS. Providing different QoS for the types of PDU Sets multiplexed in a single QoS flow/DRB is currently not possible.

- N1N: possible multiplexing of types of PDU Sets in one QoS flow in the NAS and demultiplexing of types of PDU Sets from one QoS flow on multiple DRBs in the AS. From a Layer 2 structure viewpoint, demultiplexing of types of PDU Sets from one QoS flow onto multiple DRBs is currently not possible.

*Editor's Note: the mapping of PDU Sets on QoS flows is up to SA2 and it is FFS how DRB(s) is/are mapped to LCH(s) for each of the alternatives.*



Figure 5.1.2-1: Mapping Alternatives

When comparing these alternatives, it was agreed that a QoS flow cannot be mapped onto multiple DRBs, thereby excluding alternative N1N. The splitting of a DRB onto multiple logical channels (as in Dual Connectivity) is however FFS.

*Editor's Note: LS to SA2/SA4 sent to understand the need for treating the PDU Sets of the same QoS flow differently over the air interface (R2-2213351).*

In addition, the notion of PDU Set does not impact the granularity of:

- SDAP SDU handling: SDAP still maps every incoming SDU to a single PDU for a single PDCP entity;

- Retransmissions: HARQ still relies on MAC PDUs and ARQ on RLC PDUs.

In terms of logical channel prioritisation in uplink, a delay criteria was considered but agreed not to be pursued further.

## 5.2 Power Saving Techniques

### 5.2.1 Physical Layer Enhancements

### 5.2.2 Layer 2 Enhancements

Some XR frame rates (15, 30, 45, 60, 72, 90, 120fps) corresponds to periodicity which is not an integer (66.66, 33.33, 22.22, 16.66, 13.88, 11.11 and 8.33ms respectively). The corresponding alignment of DRX will be dealt with in a semi-static manner (e.g. via RRC signalling).

## 5.3 Capacity Improvements Techniques

### 5.3.1 Physical Layer Enhancements

### 5.3.2 Layer 2 Enhancements

In order to enhance the scheduling of uplink resources for XR, the following improvements are envisioned:

- One or more additional BS table(s) to reduce the quantisation errors in BSR reporting (e.g. for high bit rates);

- Delay knowledge of buffered data, consisting of e.g. remaining time, and distinguishing how much data is buffered for which delay. It is to be determined whether the delay information is reported as part of BSR or as a new MAC CE. Also, how the delay information can be up to date considering e.g. scheduling and transmission delays needs to be investigate further.

- Additional BSR triggering conditions to allow timely availability of buffer status information can be investigated further.

- Some assistance information (e.g. periodicity, packet size) with the understanding that not all UE may be able to provide all assistance information. The periodicity will be exchanged by re-using/extending the TSCAI/TSCAC definitions. For PDCP discard operation in uplink, the timer-based discard operation should apply to all SDUs/PDUs belonging to the same PDU Set. Furthermore, when, for a PDU Set, the number of PDUs known to either be lost or associated to discarded SDUs, exceeds a threshold (see subclause 5.1.1), all remaining PDUs of that PDU Set could be discarded at the transmitter to free up radio resources.

NOTE: this means that the granularity of the discard operation at PDCP in the transmitter should be the PDU Set.

The usage of Configured Grant brings potential benefits (REF) .

*Editor's Note: add a reference to RAN1 TP.*

# 6 Conclusions

*Editor's Note: this clause will capture the conclusions of the SI.*

Annex A:
Evaluation Methodology

*Editor's Note: this Annex will capture the deployment scenarios, traffic models and KPI.*

Annex B:
Evaluation Studies

*Editor's Note: this Annex will capture the evaluation studies.*

Annex C (informative):
RAN2 Agreements

# C.1 RAN2#119-e

Agreements from RAN2#119-e meeting:

- RAN2 does not intend to ask RAN1 to change their simulation assumptions;

- RAN2 should take SA2/SA4 work into account.

- RAN2 assumes that PDU Set based parameters and PDU Set related information may be used for better support of XR services. RAN2 can consider both UL and DL directions.

- RAN2 will study PDU Set based parameters and PDU Set related information handling in Network and UE.

- RAN2 to adopt the current SA2 definition of PDU Set as an application media unit as working assumption, subjected to further guidance from SA2 and SA4.

- XR awareness discussion in RAN2 should consider PDU set characteristics and how to use the information available on those (for UL and/or DL). Can also consider how to handle data bursts.

- RAN2 can study e.g. periodicity, arrival time, jitter and frame-size variations for XR awareness to enable power savings and capacity enhancements. Can study also how often such parameters change (i.e. how dynamic they are).

- RAN2 can consider how PDU sets can be mapped to DRBs (FFS if SA2 discussion on PDU set mapping to QoS (sub-)flows impacts this).

- RAN2 to focus on the following issues for power saving, as well necessary parameters XR-awareness to support such enhancements, i.e.:

- DRX enhancements to address the issues of DRX cycle mismatch and jitter;

- Identify necessary parameters from CN for XR-awareness for power saving.

- Enhancements to Rel-17 PDCCH adaptation can be discussed based on RAN1 feedback, if they have any RAN2 impact.

- RAN2-specific aspects can be studied based on contributions (e.g. multiple XR traffic flows with different periodicities, SFN wrap-around, RAN2-specific CDRX aspects, …).

- As starting point, RAN2 can further discuss the solutions in TR 38.838 that can impact on L2 operation (e.g., BSR, LCP, assistance information for scheduling, packet discarding, prioritization) for XR-specific capacity improvement. RAN2-specific solutions are not precluded (even if RAN1 hasn’t discussed them before).

- Enhancement to SPS/CG should be justified for XR scheduling and should be evaluated against dynamic grant (DG) scheduling which should be considered as baseline. Should justify why enhancements are needed.

- RAN2 considers SPS enhancements may not be needed in Rel-18 XR since PDCCH capacity is not assumed to be a problem for XR. FFS if SPS has some power consumption benefits.

# C.2 RAN2#119bis-e

Agreements from RAN2#119bis-e meeting:

- From RAN2 viewpoint, the following information would be useful for PDU set handling in UL and DL:

- Semi-static information (from CN to RAN): At least PSER and PSDB;

- Dynamic information: At least identifying which PDU belongs to which data burst/PDU set is also needed, including means to determine at least PDU set boundaries.

- Capture the models 1a/b, 2a/b (from [R2-2209777](https://www.3gpp.org/ftp/TSG_RAN/WG2_RL2/TSGR2_119bis-e/Docs/R2-2209777.zip)) in TR and indicate what is possible in current specifications and how. FFS how LCH options work in each case

- SDAP maps each data packet in a PDU set to a single PDCP SDU, as in legacy (i.e. each PDU is only mapped to a single SDU).

- HARQ and RLC re-/transmissions for XR traffic are done as in legacy (i.e. they are not based on XR PDU sets).

- For UE transmitter, the PDCP discard should be performed per PDU set basis.

- For UE transmitter, the PDCP discard is managed per SDU for PDU set, the PDCP entity discards all PDCP SDUs associated with the PDU set.

- At least RRC pre-configuration and switching of configurations of DRX could be considered for enhancements of XR power saving. Other solutions are not precluded and can be further discussed.

- Introduce new BS table(s) to reduce the quantisation errors (e.g. for high bit rates). FFS how new BSR tables are created and how they impact BSR formats (can be discussed in WI phase).

- Delay information consists of at least “remaining time”.

- RAN2 considers a delay information is useful for XR. FFS if dynamic reporting from UE to network (e.g. via BSR) is needed, or whether PSDB is sufficient. If we have delay information, it needs to distinguish how much data is buffered for which delay value. Stage-3 details (e.g. what’s contained, how the triggering is done) can be discussed in the WI phase.

- If we have delay information reporting, RAN2 aims to define how the UE determines the “remaining time” in the delay information.

- Current CG configurations can be reused for UL XR traffic. FFS if enhancements are needed (RAN1 is already discussing something). RAN2 can discuss this in the next meeting.

- RAN2 can discuss potential enhancement to provide some assistant information on UL XR traffic for CG configurations at the gNB. FFS whether TSCAI can already provide all necessary information.

- RAN2 discuss whether additional traffic or QoS related information on downlink traffic beyond what has been agreed by SA2 needs to be provided to RAN for UE power savings.

- RAN2 study what traffic and QoS related information on uplink traffic (e.g. counterpart of what has been agreed by SA2) should be provided to RAN for UE power savings and how the information may be provided to RAN.

- Capture in TR that traffic parameters and Jitter are semi-static info.

- Can capture also SA2 agreements related to how they impact RAN2.

# C.2 RAN2#120

Agreements from RAN2#120 meeting:

- N1N excluded.

- Splitting DRB into multiple LCH (DC like) FFS.

- Should try to understand why we would need to treat PDU sets differently over the radio and why different PDU sets are muxed over same flows. Also need to understand need for reordering. LS to SA2/SA4 sent in R2-2213351.

- Agree that UE identifies PDU Sets / Bursts.

- In-band marking not needed. Further information considered if BSR is not enough.

- Handling of discard FFS.

- Regarding making LCP delay aware:

- If delay-aware LCP is introduced, need the ability to turn it off;

- SRBs not impacted.

- Not considered further unless fundamental issues are identified.

- RAN2 to support timer-based discarding of UL transmit side of PDCP PDU/SDUs of a PDU set. FFS how this is modelled in PDCP specification, can be discussed in WI phase.

- RAN2 aims to allow XR frame rates that correspond to non-integer periodicities in at least semi-static manner (e.g. RRC). Details can be left to WI phase.

- RAN2 thinks we need one or more additional BSR table(s) for XR. FFS whether these are static (=specified) or dynamic (e.g. generated, differs according to some RRC parameter), can be discussed in WI phase.

- RAN2 will introduce data volume information associated with delay information (e.g. remaining time) in a MAC CE. FFS if this is extension of BSR or new format. FFS how to do that (e.g. what exactly is reported) and how to ensure this information is up-to-date e.g. considering UL scheduling delay.

- RAN2 needs to discuss additional BSR triggering conditions to allow timely availability of buffer status information at gNB. This can be discussed in WI phase.

- RAN2 sees some benefit from CG to XR services. RAN2 will address enhancements triggered by RAN1 work. - RAN2 agrees some assistance information can be beneficial (e.g. periodicity, packet size). RAN2 assumes baseline could be TSCAI (pending SA2 conclusions), can discuss during WI phase whether something additional is needed on top of that. If any assistance information is needed, its definition should be standardized.

- RAN2 thinks all information may not be always available at UE application.

Annex Z (informative):
Change history

|  |
| --- |
| Change history |
| Date | Meeting | TDoc | CR | Rev | Cat | Subject/Comment | New version |
| 2022-04 | RAN1#109 | R1-2204673 |  |  |  | Initial Skeleton | 0.0.1 |
| 2022-08 | RAN2#119 | R2-2207373 |  |  |  | Initial Skeleton | 0.0.1 |
| 2022-08 | RAN2#119 | R2-2207374 |  |  |  | Updated Structure | 0.0.2 |
| 2022-08 | RAN2#119 | R2-2208748 |  |  |  | First Endorsed Baseline | 0.1.0 |
| 2022-08 | RAN2#119 | R2-2208749 |  |  |  | Table of Content updated | 0.1.1 |
| 2022-09 | RAN2#119 | R2-2209220 |  |  |  | Overview and first RAN2 agreements included | 0.2.0 |
| 2022-10 | RAN2#119bis | R2-2210814 |  |  |  | Relevant definitions from 23.700-60 includedUseful pieces of information from SA4 LS added ([S4-220505](http://3gpp.org/ftp/tsg_sa/WG4_CODEC/TSGS4_118-e/Docs/S4-220505.zip) and [S4aV220921](https://www.3gpp.org/ftp/tsg_sa/WG4_CODEC/3GPP_SA4_AHOC_MTGs/SA4_VIDEO/Docs/S4aV220921.zip))RAN2 agreements on PDU Set handling, discard, L2 structure captured, BS tables and delay reporting added. | 0.3.0 |
| 2022-11 | RAN2#120 | R2-2212908 |  |  |  | Minor editorial corrections | 0.3.1 |
| 2022-11 | RAN2#120 | R2-22xxxxx |  |  |  | RAN2 agreements on PDU Set handling, L2 architecture, BSR, discard and assistance information captured.SA2 agreements on KI#4,5 ([S2-2211440)](https://www.3gpp.org/ftp/tsg_sa/WG2_Arch/TSGS2_154_Toulouse_2022-11/Docs/S2-2211440.zip) and KI#8 ([S2-2211404](https://www.3gpp.org/ftp/tsg_sa/WG2_Arch/TSGS2_154_Toulouse_2022-11/Docs/S2-2211404.zip)) captured | 0.4.0 |