# IMT-2020 Key Performance Indicators: Evaluation and Extension Towards 5G New Radio Point-to-Multipoint

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Abstract-5G New Radio (5G NR) is the first technology standard to enable mobile communications in three different usage scenarios: enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC). As a result of its technical impact, ITU-R considers 5G NR as candidate technology for the International Mobile Telecommunications for 2020 (IMT-2020) evaluation process. To assess 5G NR performance, IMT-2020 defines multiple Key Performance Indicators (KPIs) related to specific requirements to enable Point-to-Point communications (PTP). IMT-2020 does not consider Point-to-Multipoint (PTM) communications due to the absence of multicast/broadcast capabilities in the current 5G NR standardized solution. Nevertheless, PTM communications are proved to be a key feature for 5G applications in a wide number of vertical sectors as Media & Entertainment, Public Warning or Internet of Things. This paper performs an analysis of different IMT-2020 KPIs for 5G NR PTP and extends the evaluation to a PTM perspective. The results contribute to enhance the role of PTM communications towards the IMT-2020 landmark.

Keywords—5G New Radio (5G NR), IMT-2020, Key Performance Indicators (KPIs), Point-to-Point (PTP), Next generation of broadcasting standards and systems, Point-to-Multipoint (PTM).

# I. INTRODUCTION

5G New Radio (5G NR) is the fifth generation of mobile communications systems defined in the latest release of 3GPP (3rd Generation Partnership Project), i.e. Release'15 (Rel'15). Designed towards the landmark of International Communications at 2020, i.e. IMT-2020, 5G NR enables the distribution of different communication services in three main usage scenarios: enhance mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC) and massive Machine-Type Communications (mMTC) [1]. To introduce these functionalities, 3GPP Rel'15 last drop defines a complete 5G NR standardized solution with full user and control plane capabilities in the Radio Access Network (RAN) and the System Architecture (SA). Thanks to it, 5G NR offers a flexible and scalable solution to deliver Point-to-Point (PTP) communications. Nevertheless, the definition of a specific 5G NR Point-to-Multipoint (PTM) mode is still missed.

3GPP considers the introduction of PTM capabilities as a 5G requirement [2]. The efficiency of PTM communications has been proved in different scenarios, particularly when the same content has to be simultaneously transmitted to large amounts of users, e.g. Media and Entertainment, Public Warning or Vehicle-to-Everything (V2X) communications [3]. The design of a specific 5G NR PTM mode, i.e. 5G NR

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Multicast Mixed Mode, is expected to be addressed during the next 3GPP releases, i.e. Rel'17 or Rel'18 [4].

5G NR is considered as a candidate technology for the IMT-2020, a global process where the state-of-the-art of mobile technologies is evaluated for the design of International Mobile Telecommunications for 2020 and beyond [5]. IMT-2020 assessment, which is performed by the ITU-R (International Telecommunication Union Radiocommunication Sector) in collaboration with different organizations and evaluation groups, targets specific performance requirements related to eMBB, URLLC and mMTC through the definition of Key Performance Indicators (KPIs) [1] [6] [7] [8]. The evaluation phase, which was kicked off by the end of 2018, considers the latest version of 5G NR Rel'15, thus evaluating only the PTP component. The assessment of PTM capabilities in 5G NR would enrich the IMT-2020 evaluation study, contributing at the same time to enhance the role of PTM communications in mobile technologies.

This paper evaluates the 5G NR air interface performance when delivering PTP and PTM communications in the context of IMT-2020. The study assesses a set of requirements for bandwidth, peak data rate and peak spectral efficiency KPIs. First 5G NR is evaluated in PTP conditions and then extended to a PTM perspective, where different guidelines are given to enable multicast and broadcast capabilities in 5G. Note that the evaluation is focused on the downlink (DL) side since it is the main component in PTM transmissions.

The paper is structured in five sections. Section II describes the current 5G NR air interface. Section III presents the evaluation methodology and the list of addressed KPIs. Section IV shows the results of the IMT-2020 evaluation for 5G NR PTP and extends the analysis for PTM communications. Finally, Section V presents different conclusions derived from the study.

## II. 5G NR RADIO AIR INTERFACE

This section gives an overview of the current 5G NR air interface design [9]. In particular, those components relevant for the subsequent evaluation are described.

#### A. 5G NR Frame Structure

5G NR air interface resources are allocated in frames of 10 ms duration. Each frame is composed of 10 subframes with 1 ms duration each. Subframes are split into one or several slots depending on the numerology option, which is given by a positive integer factor ( $\mu$ >0). Each slot conveys a different number of OFDM symbols depending on the cyclic prefix (CP) configuration. In particular, 14 OFDM symbols are

allocated with normal CP and 12 OFDM symbols with extended CP. In frequency domain, each OFDM symbol contains a variable number of subcarriers. The allocation of 1 subcarrier in 1 OFDM symbol is defined as Resource Element (RE). The consecutive allocation of 12 RE in the frequency domain is defined as Resource Block (RB). The number of subcarriers depends on the subcarrier spacing (SCS) and the available system bandwidth.

Different system bandwidths are defined depending on the frequency range of operation (FR) [10]:

- FR1 (450 MHz 6 GHz):
  - 5, 10, 15, 20, 25, 40, 50, 60, 80 or 100 MHz.
  - Guard band ratio from 2 to 20%.
- FR2 (24.25 GHz 52.6 GHz):
  - 50, 100, 200 or 400 MHz.
    - $\circ$  Guard band ratio from 5 to 8%.

On the other hand, SCS depends directly on the numerology:

$$SCS = 2^{\mu} \cdot 15 \ kHz \tag{1}$$

The influence of numerology on other relevant framing parameters is shown in Table 1.

# B. Physical Channels and Signals

Physical channels are defined as flows of information transmitted between the physical and the MAC layer. On the other hand, physical signals are flows of information transmitted only at the physical layer. Physical layer resources are mapped to downlink or uplink (UL) physical channels and signals. The proportion of resources used in DL or UL is given by the duplexing mode, i.e. Frequency Division Duplex (FDD) or Time Division Duplex (TDD) and the Slot Format Indicator (SFI). Considering the PTM focus of this study, only DL physical channels and signals are detailed in the following:

**Physical Broadcast Channel (PBCH):** Transmits the static part of the System Information (SI) to all the User Equipments (UE) requiring access to the network.

**Primary and Secondary Synchronization Signals (PSS, SSS):** Allow the UE network access together with the PBCH. In particular, provide radio frame timing information and Cell Identity at the initial cell search.

**Physical Downlink Control Channel (PDCCH):** Conveys the Downlink Control Information (DCI), which specifies the scheduling and allocation of the data content for every UE that requests it.

**Physical Downlink Shared Channel (PDSCH):** Transmits the data content to the UE and the System Information Blocks (SIBs).

**Demodulation Reference Signals (DMRS):** Used for channel estimation in the demodulation process of PBCH, PDCCH and PDSCH.

TABLE 1. 5G NR AIR INTERFACE PARAMETERS: OFDM SYMBOL DURATION  $(T_U)$ , CP type, CP duration  $(T_{CP})$ , SLOT duration and Number of slots per subframe.

μ	SCS	Tu	Туре СР	T <sub>CP</sub> (µs)	Slot	Slots
	(kHz)	(µs)			(µs)	
0	15	66.66	Normal	5.21/4.69	1000	1
1	30	33.33	Normal	2.60/2.34	500	2
2	60	16.66	Normal	1.30/1.17	250	4
			Extended	4.16	250	4
3	120	8.33	Normal	0.65/0.59	125	8
4	240	4.17	Normal	0.33/0.29	62.5	16



Fig 1. 5G NR Frame structure for  $\mu = 0$ , 8 antenna ports and SFI = 0.

**Phase Tracking Reference Signals (PT-RS):** Used to estimate the phase noise in PDSCH. Only used at high frequency ranges (FR2).

**Channel State Information Reference Signals (CSI-RS):** Used to send the channel state information needed for link adaptation.

An example of physical channel and signal allocation in the 5G NR framing for DL transmissions is shown in Fig.1.

# III. METHODOLOGY AND KEY PERFORMANCE INDICATORS

This section describes the set of IMT-2020 methodologies and Key Performance Indicators considered for the evaluation of 5G NR PTP and PTM technologies [8].

# A. Methodology

According to the methodology proposed in the IMT-2020 process, two different methods are considered in this study [8]:

**Inspection:** Procedure performed by reviewing the functionality and parameterization of specific design-dependent KPIs that can be assessed by looking into general system design information.

Analysis: Procedure carried out through mathematical analysis based on technical information.

# B. IMT-2020 Key Performance Indicators

IMT-2020 evaluation guidelines define 13 different KPIs analysed against specific performance requirements [8]. Considering the magnitude of the process, a small subset of KPIs is analysed in this study:

**Bandwidth (Hz):** Maximum aggregated system bandwidth including frequency guard bands for a single or multiple radio frequency (RF) carriers. Bandwidth is evaluated through inspection. IMT-2020 sets a requirement of 100 MHz.

**Peak data rate (bit/s):** Maximum achievable data rate under ideal conditions when all assignable radio resources are utilized, i.e. excluding the synchronization, reference signals, control region, guard bands and guard times overhead. It can be calculated for DL and UL transmissions combined with FDD and TDD modes. Peak data rate ( $\gamma_p$ ) is calculated analytically for all configurations by following the expression [12]:

$$\gamma_p = \sum_{j=1}^{J} \left( \alpha^{(j)} \cdot v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu \cdot 12}}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right)$$
(2)

where:

- *J* is the number of aggregated carriers in a frequency band. The available values are from 1 to 16.
- $\alpha^{(j)}$  is the normalized scaling factor related to the ratio of resources used in the DL/UL for the *j* component carrier. In FDD,  $\alpha^{(j)} = 1$ . In TDD,  $\alpha^{(j)}$  is calculated according to the frame structure and the SFI.
- $v_{Layers}^{(j)}$  is the number of layers when multiple antennas, i.e. MIMO, are configured. Up to 8 layers can be transmitted in DL and up to 4 in UL.
- $Q_m^{(j)}$  is the modulation order. The maximum value is equal to 8 (256QAM).
- $f^{(j)}$  is the scaling factor used to reflect the capability mismatch between baseband and RF. There are two possible values: 1 or 0.75.
- $R_{max}$  is the maximum CR: 948/1024.
- $\mu$  is the numerology option. It goes from 0 to 4.
- $T_s^{\mu}$  is the average OFDM symbol duration in a subframe for numerology,  $\mu$ , including the impact of the CP (See Table 1).
- N<sup>BW(j),μ</sup><sub>PRB</sub> is the maximum RB allocation in the available system bandwidth with numerology μ [13].
- *OH*<sup>(*j*)</sup> is the overhead calculated as the average ratio of REs occupied by synchronization, PBCH, PDCCH, reference signals and guard periods, compared to the total number of REs available in the effective bandwidth and a frame time product (See Fig 1.). IMT-2020 peak data rate requirement is set to 20 Gbps for DL transmissions and 10 Gbps for UL.

**Peak spectral efficiency (bit/s/Hz):** Maximum data rate normalized by the system bandwidth when excluding radio resources used for physical layer synchronization, reference signals, guard bands and guard times. Peak spectral efficiency  $(\eta_p)$  can be calculated for DL and UL with TDD and FDD modes according to:

TABLE 2. 5G NR PTP MAXIMUM SYSTEM BANDWIDTHS WITHOUT AND WITH CARRIER AGGREGATION.

Frequency range	μ	BWmax (MHz)	CC	CA BWmax (MHz)
ED 1	0	50	16	800
FK1 (450 MHz - 6 GHz)	1	100		1600
(450 WILL - 0 GILZ)	2	100		1600
FR2	2	200		3200
(24.25 GHz - 52.6 GHz)	3	400		6400

$$\eta_p = \frac{\gamma_p}{\alpha^{(j)} \cdot BW} \tag{3}$$

where:

- $\gamma_p$  is the peak data rate value obtained for each evaluated configuration.
- α<sup>(j)</sup> is the normalized scaling factor related to the proportion of resources used in the DL/UL ratio for the j component carrier.
- *BW* is the configured system bandwidth.

IMT-2020 peak spectral efficiency requirement is set to 30 bit/s/Hz for DL and 15 bit/s/Hz for UL.

#### IV. IMT-2020 KPI EVALUATION

This section presents the results of the study according to the methodology previously explained. First, 5G NR is evaluated for PTP against the selected IMT-2020 KPIs. Then, the analysis is extended to PTM systems, where some guidelines are given for the air interface design [10] [11].

## A. 5G NR PTP Evaluation

#### 1) Bandwidth

As shown in Section II, different system bandwidths are available in 5G NR for a single RF carrier depending on the frequency range. For each frequency band, 5G NR specifies the maximum system bandwidth depending on the numerology. Larger system bandwidths can be obtained thanks to the use of carrier aggregation (CA), which allows to join up to 16 component carriers (CC) at the expense of introducing inter and intra-band interferences into the system [10].

According to Table 2, 5G NR allows to set system bandwidths up to 6.4 GHz when CA is performed in PTP communications. Thanks to CA, 5G NR is able to meet the IMT-2020 bandwidth requirement, i.e. 100 MHz, in all frequency range and numerology combinations.

#### 2) Peak Data Rate

Following the analytical formula described in Section III, the maximum achievable peak data rate in FDD DL transmissions has been calculated for different numerology and bandwidth options in FR1. The overhead introduced by downlink control channels and signals is close to 10.5% for the evaluated configurations. The highest MIMO configuration, i.e. 8 layers, and modulation orders, i.e. 256QAM, are both considered.

As shown in Table 3, 5G NR is able to provide peak data rate values up to 4.9 Gbps when PTP transmissions are performed.

TABLE 3. FDD DL PEAK DATA RATE [GBPS] WITH MIMO, CARRIER AGGREGATION AND DIFFERENT NUMEROLOGIES IN FR1

μ	BW <sub>max</sub> (MHz)	γ <sub>p</sub> MIMO	СС	$\gamma_p$ MIMO+CA	Req.
0	50	2.40		38.54	
1	100	4.87	16	78.05	20
2	100	4.78		76.62	

TABLE 4. FDD DL PEAK SPECTRAL EFFICIENCY [BPS/HZ] WITH MIMO CONFIGURATIONS AND DIFFERENT NUMEROLOGIES IN FR1

μ	BW <sub>max</sub> (MHz)	MIMO Layers	$\eta_p$ MIMO
0	50	8	48.17
1	100		48.78
2	100		47.89

If the maximum carrier aggregation level is used (16 CC), data rate values up to 78.05 Gbps can be achieved, thus overcoming the IMT-2020 peak data rate requirement of 20 Gbit/s.

# 3) Peak Spectral Efficiency

Peak spectral efficiency is calculated per component carrier for the maximum MIMO configuration according to (3). For that purpose, same peak data rate values and overheads are assumed.

As shown in Table 4, one 5G NR component carrier is able to provide peak spectral efficiency values up to 48.17 bps/Hz for PTP communications when 8 layers are transmitted. Thanks to the impact of MIMO, 5G NR is able to meet the IMT-2020 spectral efficiency requirement of 30 bit/s/Hz.

# B. Extension to 5G NR PTM

The introduction of PTM capabilities over the existing 5G NR air interface design may have an impact on the IMT-2020 KPI evaluation. The influence over the covered KPIs is analysed as follows:

# 1) Bandwidth

Existing PTM technologies like multicast and broadcast lead to considerable bandwidth savings with respect to PTP transmissions when multiple services are delivered to large amounts of users [14]. Bandwidth savings together with the spectrum limitation of UHF bands have traditionally lead to low system bandwidths in Digital Terrestrial Television (DTT) systems, e.g. 6 MHz in ATSC 3.0 or 10 MHz in DVB-T2 [15] [16]. On its behalf, cellular broadcasting systems allow to configure bandwidths slightly higher to enable the multiplexing of unicast and multicast services, e.g. 20 MHz in eMBMS Rel'14 [17].

Considering the technological background, this study proposes the reuse of the existing 5G NR bandwidth flexibility to cover different PTM scenarios. Table 5 shows the frequency band and bandwidth combinations. Low bandwidths up to 20 MHz can be configured to enable traditional DTT transmissions in 700 MHz frequency band. Medium bandwidths up to 100 MHz are proposed to allow the transmission of high-data rate services such as VR/AR (Virtual Reality and Augmented Reality) as well as the delivery of cellular broadcasting services in different verticals such as public warning or V2X.

 TABLE 5. 5G NR PTM MAXIMUM SYSTEM BANDWIDTH WITHOUT AND

 WITH CARRIER AGGREGATION IN FR1.

Freq. Range	Freq. bands	μ	BWmax (MHz)	сс	CA BWmax (MHz)
	700 MHz	0,1	20		100
FR1 FR2	2.4 GHz	0,1,2	80	5	400
	3.5 GHz	0,1,2	100		500
	24 GHz	0,1,2,3	400		2000
	40 GHz	0,1,2,3	400		2000

Higher bandwidths up to 400 MHz would enable the delivery of Programme Making and Special Events services (PMSE) as well as potential applications related to the transmission broadcasting-satellite services [17]. The number of aggregated carriers is limited to 5 CC, following a trade-off between efficiency and complexity. The use of CC = 5 is sufficient to configure maximum bandwidths larger than 100 MHz, thus overcoming the IMT-2020 requirement.

# 2) Peak Data Rate

In PTM communications, the transmission of a common control region (CORESET) within the PDCCH is required to convey the control information to all users that request access to the data [10]. The definition of a single CORESET in PTM avoids the transmission of the same information to all users, thus leading to an overhead reduction of 72 REs per user with respect to PTP. Extrapolating this behavior to (2), data rate gains may appear with respect to PTP when the same content is transmitted to multiple users. To reflect this impact, the maximum data rate achievable in PTM systems has been compared to PTP when a single PTM CORESET is transmitted in 3.5 GHz band (numerology  $\mu = 0$  and 50 MHz bandwidth) for different number of users. The difference between the PTP and PTM data rate has been represented as the data rate gain.

Fig.2. shows the PTM data rate gain when different number of users request the same data. For simplicity sake, ideal channel and reception conditions to reach the maximum throughput are assumed in all users. As depicted, the transmission of a single PTM CORESET may lead up to data rate increases of 570 Mbps when 135 users are involved. It should be noticed that in spite of the data rate gain, the PDCCH overhead is still limited by the number of users that can be allocated in a PTM CORESET. As for PTP, the data rate grows when several component carriers are aggregated. In particular, gains up to 2.85 Gbps when 5 CC are bonded. This calculation can be extrapolated to all the possible numerology and bandwidth combinations, leading to data values greater the 20 Gbps requirement – up to 24.3 Gbps.

# 3) Peak Spectral Efficiency

PTM spectral efficiency has been calculated according to the procedure described in Section III. Considering the data rate influence, same parameter assumptions ( $\mu = 0$ , 50 MHz bandwidth) are made. As shown in Table 6, one 5G NR PTM component carrier is able to offer a constant spectral efficiency of 48.17 bit/s/Hz when different number of users request the same content thanks to the transmission of a single PTM CORESET. Consequently, spectral efficiency gains of up to the 23.51% are introduced with respect PTP communications.



Fig. 2. 5G NR PTM peak data rate gain with respect 5G NR PTP different number of users and carrier aggregation values.

TABLE 6. PEAK SPECTRAL EFFICIENCY GAINS IN PTM COMMUNICATIONS FOR DIFFERENT NUMBER OF USERS

Number of users	PTP (bit/s/Hz)	PTM (bit/s/Hz)	Gain (%)
1	48.17		0
5	47.93		0.48
10	47.51		1.37
25	46.23	48.17	4.03
50	44.09	1	8.45
100	39.83		17.31
135	36.84	1	23.51

As for the previous cases, the proposed PTM configuration can be extrapolated to all the possible numerology options. PTM is also able to meet the IMT-2020 peak spectral efficiency requirement of 30 bit/s/Hz for the DL side.

#### V. CONCLUSIONS

The results discussed in this paper anticipate the feasibility of designing a 5G NR PTM solution towards the IMT-2020 landmark and beyond. The proposed extension of specific 5G NR PTP physical layer capabilities provides initial guidelines for the creation of a PTM solution fully compliant with the IMT-2020 framework. The use of scalable bandwidths allows to cover the IMT-2020 bandwidth requirement in different PTM scenarios. Low bandwidths up to 20 MHz are recommended for traditional DTT applications in FR1 while medium and large scaled bandwidths up to 400 MHz are proposed for the delivery of cellular and satellitebroadcasting services in FR1 and FR2, respectively. The limitation of the carrier aggregation level to 5 is proposed to set an efficient PTM approach with low inter and intrachannel interferences. Additionally, the use of a single PTM control region is recommended to achieve an overhead reduction and therefore data rate and spectral efficiency gains with respect to PTP. The observed gains are especially notable - up to the 23.05%- when large number of users request access to the same content. To analyse the capacity impact, ideal channel and reception conditions have been assumed in all users. Thanks to the use of MIMO configuration and carrier aggregation, the proposed PTM

design is able to reach high data rates up to 24.3 Gbps and spectral efficiencies of 48.17 bit/s/Hz, thus overcoming the 20 Gbps and the 30 bit/s/Hz downlink requirements set by the IMT-2020.

As future work, real channel and reception conditions should be considered to evaluate the real impact of the PTM CORESET on the system capacity. Additionally, other KPIs such as mobility, latency or user spectral efficiency should be evaluated to perform a complete IMT-2020 evaluation of the PTM technology.

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