5G-Xcast Tutorial

Broadcast and Multicast Communication Enablers for 5G

WP3: 5G-Xcast Radio Access Network

WP3

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Disclaimer

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The content is not yet approved nor rejected, neither financially nor content-wise by the European Commission. The approval/rejection decision of work and resources will take place **at the Mid-Term Review Meeting planned in September 2018 and the Final Review Meeting**, after the monitoring process involving experts has come to an end.

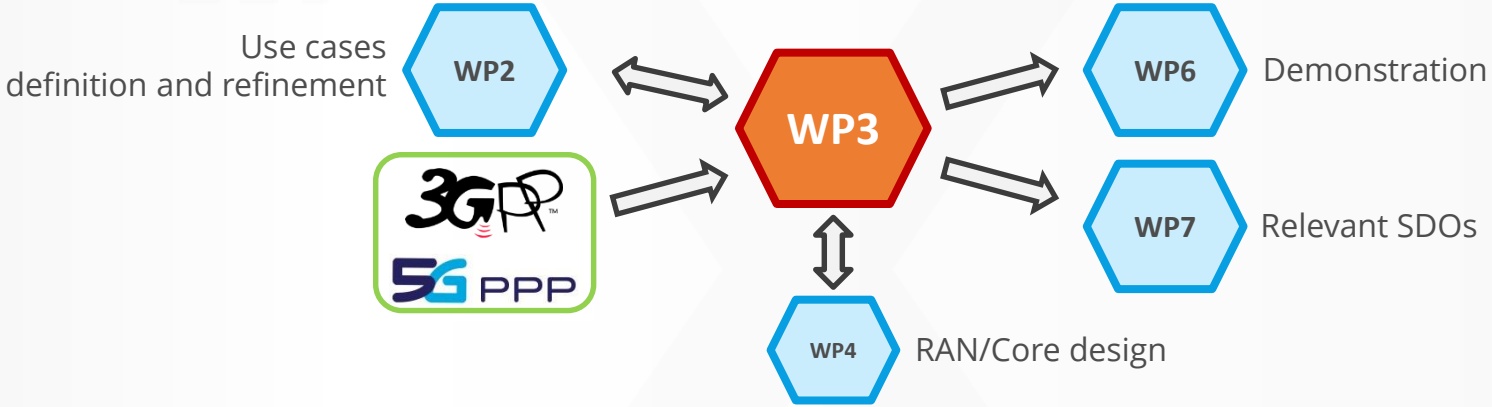
Public Deliverables

- D3.1: Performance of LTE Advanced Pro (Rel'14) eMBMS, Nov. 2017.
  - Download
  - News
- D3.2: Air Interface, Nov. 2018.
- D3.3: RAN Architecture, Jan. 2019.
- D3.4: RAT Protocols and RRM, May 2019.

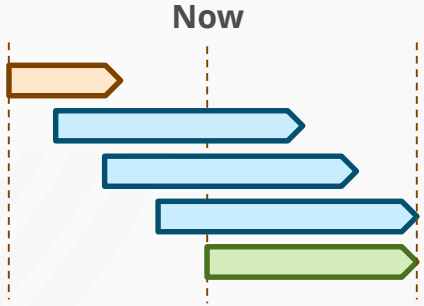
Contents

1. Introduction

- **WP3** within the 5G-Xcast project:



- **Tasks** and **Deliverables**:
  - **T3.1:** LTE-Advanced Pro Broadcast Benchmark — **D3.1** (Nov. 2017)
  - **T3.2:** Air interface — **D3.2** (Nov. 2018)
  - **T3.3:** RAN Logical Architecture — **D3.3** (Feb. 2019)
  - **T3.4:** RAT Protocols and Radio Resource Management — **D3.4** (May 2019)
  - **T3.5:** RAN Proof-of-Concept Prototypes — **D3.5** (May 2019)



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2. 4G LTE eMBMS Rel'14

- Section related to the studies performed in **Deliverable D3.1**.
  - Available in the 5G-Xcast public website.

2.1. System overview

- eMBMS definition. MBSFN and SC-PTM solutions.

2.2. Limitations identified

- Waveform flexibility and synchronization robustness.
- Radio resource management

2.3. RAN Benchmark

- Inspection and analysis.
- Simulations: link-level, system-level and coverage.
- Radio Access Network

Deliverables

+ WP2 – KPI's, Requirements and Use Cases

− WP3 – 5G-Xcast Radio Access Network

ID	Title	Deadline	Link
D3.1	Performance of LTE Advanced Pro (Rel'14) eMBMS	Nov 2017 (M6)	PDF News Article

2.1. LTE-A Pro Rel 14 eMBMS System Overview

eMBMS offers 2 radio delivery modes:

Multicast-Broadcast SFN (**MBSFN**)

Same signal transmitted (via **PMCH**) synchronously by multiple eNB within an MBSFN area

Extended cyclic prefixes to enable **SFN** areas with 3 numerology options

Specific reference signals (**RS**) for correct channel equalization in SFN environment (higher frequency density)

Single-Cell PTM (**SC-PTM**)

Designed for more efficient PTM on a **cell basis**

Keeps eMBMS network architecture

Uses LTE downlink shared channel (**PDSCH**) scheduled by PDCCH (via **Group-RNTI**)

Supports same features as for PDSCH (unicast):

- Use of **multi-antenna** techniques
- Supports **short CP**
- Supports **regular RS**
- **Dynamic resource allocation** according to scheduling on a TTI by TTI basis

2.1. LTE-A Pro Rel 14 eMBMS System Overview

eMBMS (MBSFN) in **Rel'14** has undertaken changes to address requirements for **Terrestrial Broadcasting**:

- Larger inter-site distance support in SFN by means of a **new numerology:**
  - **1.25 kHz** OFDM sub-carrier spacing
  - **200 µs** cyclic prefix with 1 ms OFDM symbol duration
  - New RS according to the new numerology
  - Target 2 bps/Hz with 15 km inter-site distance (ISD)
- **More capacity** for broadcast data:
  - Almost 100% eMBMS carrier allocation with new subframe design with no unicast control region.
  - Reduced synchronization data via a **Cell Acquisition Subframe** with reduced periodicity.

CAS	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN

- **Other enhancements for Terrestrial Broadcast are introduced but not linked to the radio layer:**
  - **Receive-only mode**: free-to-air content delivery without SIM/service subscription
  - **Transport-only service mode**: no need for transcoding (Native formats are supported)
  - Standardized interface to content providers (**xMB**)
  - **Shared MNO** service on a common broadcast carrier

2.2. Main Limitations Identified

MBSFN

	Δ_f (kHz)	# subcarriers / RB	# OFDM symbols per subframe	T_{CP} (µs)	T_U (µs)	Overhead	ISD (km)
Normal Unicast	15	12	7	4.7 5.2 (1st)	66.7	6.5%	1.4
Extended	15		6	16.7	66.7	20%	5
	7.5	24	3	33.3	133.3	20%	10
	1.25	144	1	200	800	20%	60

1. **Limited range of OFDM numerologies.**
   - CP lengths of 16.7, 33.3 and **200 µs**
   - All numerologies for MBSFN present overhead of 20%
   - MBSFN Reference signals are unique per numerology
   - ❖ **200 µs** allows for significantly larger inter-site distances, but limited compared to **DTT** standards

2. **Mobility** in large area SFN deployments
   - Extended Cyclic Prefix → Increased OFDM symbol duration → Reduced Sub-Carrier Spacing
   - There is a trade-off between maximum Inter-Site Distance and User Speed
   - 5G-Xcast link-level simulations show the speed to be limited to **100 km/h@700 MHz.**

3. **Cell Acquisition Subframe (CAS) for 100% broadcast carrier configured with unicast numerology**
   - Mismatch between control and payload numerologies (15kHz extended – 16.7us) vs (1.25kHz – 200us)

4. **Multi-Antenna Techniques are not possible as only SISO is permitted**

2.2. Main Limitations Identified

MBSFN

5. Unicast/broadcast multiplexing

- MBSFN subframes occupy the entire bandwidth (inefficient for large BW)
- Allocation of resources to unicast/broadcast can be configured between **0% and 80%** with steps of 2.5%
- **100% broadcast allocation** possible in R14 with CAS

	0	1	2	3	4	5	6	7	8	9
Mixed MBSFN/unicast Allocation 60%		MBSFN	MBSFN	MBSFN			MBSFN	MBSFN	MBSFN	
100% Broadcast	CAS	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN	MBSFN

SC-PTM

- **Not possible to extend coverage via SFN**
  - The use of PDSCH disables possibility of SFN due to: not-defined numerologies and RS
  - Scrambling is cell-specific

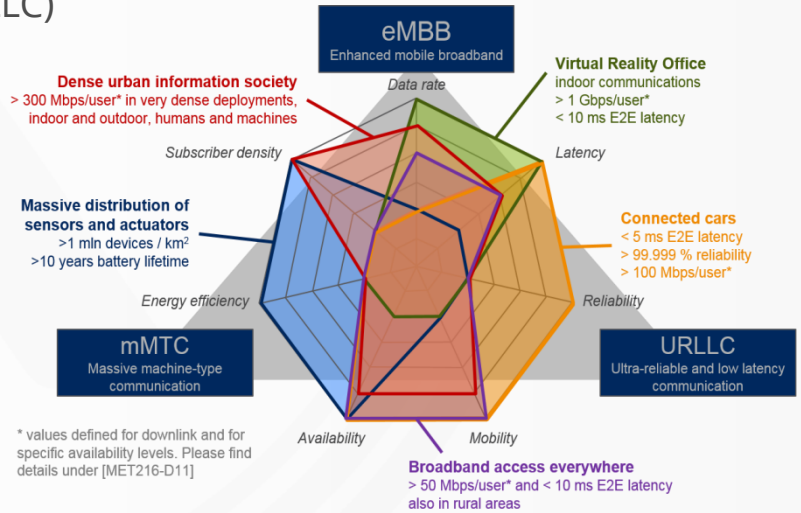
In general…

- **Lack of diversity techniques** (No time or frequency interleaving)
- **Lack of effective feedback mechanisms for multicast transmission**

2.3. RAN Benchmark

2.3.1. IMT-2020 Technical KPIs

- 4G LTE benchmark around the **KPIs** defined in **IMT-2020** [10] and those considered in **WP3**.
- Technical performance requirements defined for three usage scenarios :
  1. Enhanced Mobile Broadband (eMBB)
     - M&E
  2. Ultra-Reliable Low Latency Communications (URLLC)
     - Automotive (V2X)
     - Public warning
  3. Massive Machine-Type Communications (mMTC)
     - IoT



* values defined for downlink and for specific availability levels. Please find details under [MET216-D11]

[11]

2.3. RAN Benchmark

2.3.1. IMT-2020 Technical KPIs

- The **methodology** [12] is associated to the KPI under evaluation.

	KPI	IMT-2020 Scenario	5G-Xcast vertical	Methodology
IMT-2020	Bandwidth	eMBB, URLLC	M&E, PWS, V2X	Inspection
	Peak data rate	eMBB	M&E	Analytical
	Peak spectral efficiency	eMBB	M&E	Analytical
	Average spectral efficiency	eMBB	M&E	System Level Sim.
	User spectral efficiency	eMBB	M&E	System Level Sim.
	User plane latency	eMBB, URLLC	M&E, PWS, V2X	Analytical
	Control plane latency	eMBB, URLLC	M&E, PWS, V2X	Analytical
	Mobility	eMBB, URLLC	M&E, V2X	Link Level Sim.
5G-Xcast	BICM spectral efficiency	eMBB	M&E	Link Level Sim.
	Peak BICM spectral efficiency	eMBB	M&E	Analytical
	Coverage	eMBB, mMTC	M&E, IoT	Coverage Sim.
Not Considered	User experienced data rate	eMBB	M&E	Analytical
	Area traffic capacity	eMBB	M&E	Analytical
	Reliability	URLLC	PWS, V2X	System Level Sim.
	Energy efficiency	eMBB, mMTC	M&E, IoT	Inspection
	Connection density	mMTC	IoT	System Level Sim.

- **Simulation**:
  - Method applied for KPIs that are heavily dependent on the instantaneous network conditions.
- **Analytical**:
  - Via mathematical analysis.
  - Evaluation based on calculations that use technical information.
- **Inspection**:
  - It can be assessed by looking into general system design information.

2.3. RAN Benchmark

2.3.2. Inspection and Analysis

Bandwidth [inspection]

- LTE-Advanced Pro Rel'14:
  - It allows to use bandwidths of 1.4, 3, 5, 10 and **20 MHz**.
  - Carrier aggregation of up to **5 RF carriers** is permitted.
  - The maximum supported bandwidth is **100 MHz**.

Peak data rate [analytical]

- The peak data rate KPI is calculated as:

$$\gamma_p = \frac{TBS_{max}}{T_s}$$

- TBS_{max} is the maximum Transport Block size (input data bits).
- T_s is the subframe duration (1 ms)

- **MBSFN:**

$$\gamma_p = \frac{84760}{10^{-3}} \frac{39}{40} = 82.6\ Mbps$$

1 subframe for CAS every 40 ms

- **SC-PTM:**

SISO

$$\gamma_p = \frac{97896}{10^{-3}} = 97.9\ Mbps$$

MIMO 2x2

$$\gamma_p = \frac{195816}{10^{-3}} = 195.8\ Mbps$$

MIMO 4x4

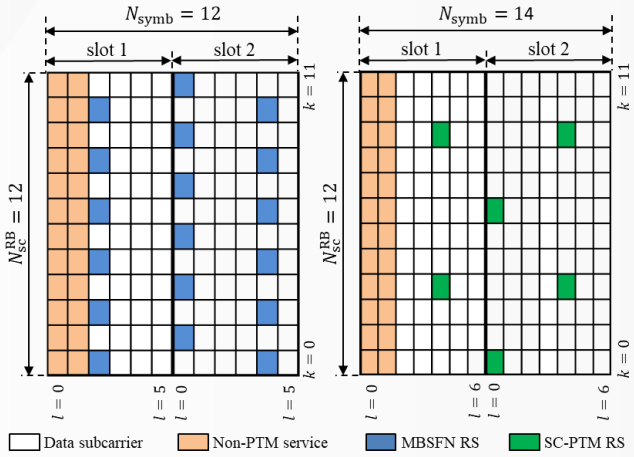
$$\gamma_p = \frac{391656}{10^{-3}} = 391.6\ Mbps$$

2.3. RAN Benchmark

2.3.2. Inspection and Analysis

Peak BICM spectral efficiency [analytical]

$$\eta_p^{BICM} = m_{max} \cdot CR_{max} \cdot N_{Tx/Rx}$$



- **MBSFN (200 μs):**

$$CR_{max} = \frac{TBS_{max}}{N_b} = \frac{84760}{96000} = 0.882$$

$$\eta_p^{BICM} = 8 \cdot 0.882 = 7.06\ bpc$$

$$N_b = m \cdot N_{RB}\left(N_{symb} N_{sc}^{RB} - N_{ref}\right) = 8 \cdot 100(1 \cdot 144 - 24) = 96000$$

- Ensuring CR < 0.925 (CQI 15), the maximum TB size is 84760.

- **SC-PTM:**

$$CR_{max} = \frac{TBS_{max}}{N_b} = \frac{97896}{110400} = 0.887$$

$$\eta_p^{BICM} = 8 \cdot 0.882 \cdot N_{Tx/Rx}$$

$$N_b = m \cdot N_{RB}\left(N_{symb} N_{sc}^{RB} - N_{ref}\right) = 8 \cdot 100(12 \cdot 12 - 6) = 110400$$

SISO:	7.09 bits/s/Hz
MIMO 2x2:	14.18 bits/s/Hz
MIMO 4x4:	28.36 bits/s/Hz

2.3. RAN Benchmark

2.3.2. Inspection and Analysis

Peak spectral efficiency [analytical]

$$\eta_p = \frac{\gamma_p}{BW_{max}}$$

MBSFN:

$$\eta_p = \frac{82.6 \cdot 10^6}{20 \cdot 10^6} = 4.13 \text{ bits/s/Hz}$$

SC-PTM:

$$\eta_p = \frac{97.9 \cdot 10^6}{20 \cdot 10^6} = 4.89 \text{ bits/s/Hz}$$

MIMO 2x2: 9.79 bits/s/Hz MIMO 4x4: 19.58 bits/s/Hz

- **Summary**

Technology	Antenna Scheme	η_p^{BICM} (bpc)	η_p (bits/s/Hz)	Overhead (%)	γ_p (Mbps)
SC-PTM	SIMO	7.09	4.89	30.9	97.9
	MIMO 2x2	14.18	9.79	30.9	195.8
	MIMO 4x4	28.36	19.58	30.9	391.6
MBSFN (200µs)	SIMO 1x2	7.06	4.13	41.5	82.6

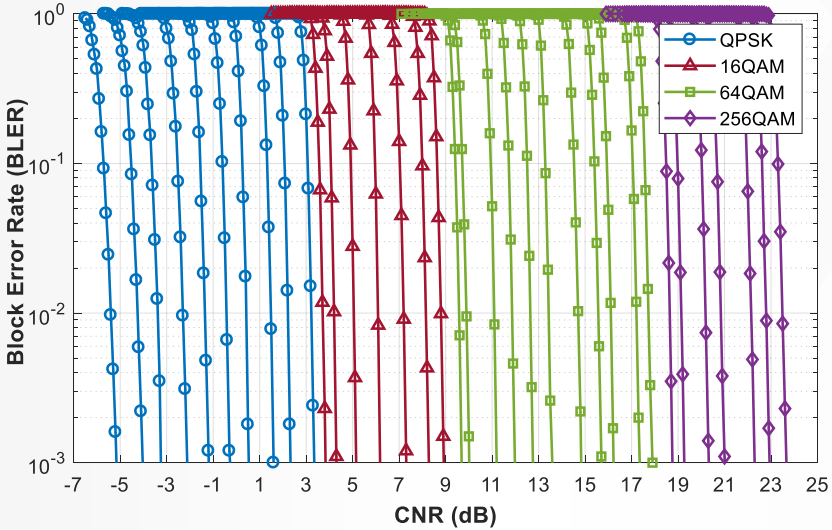
2.3. RAN Benchmark

2.3.3. Link-Level Simulations

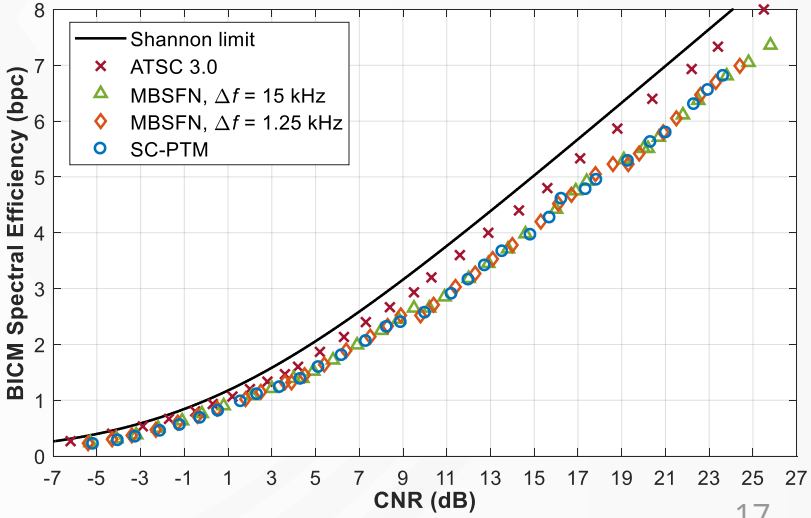
BICM spectral efficiency vs. CNR

- Selected criterion: BLER < 10^{-3} (0.1%)

1. AWGN
   - Example: BLER vs. CNR waterfall
   - SC-PTM:



- Technology comparison:

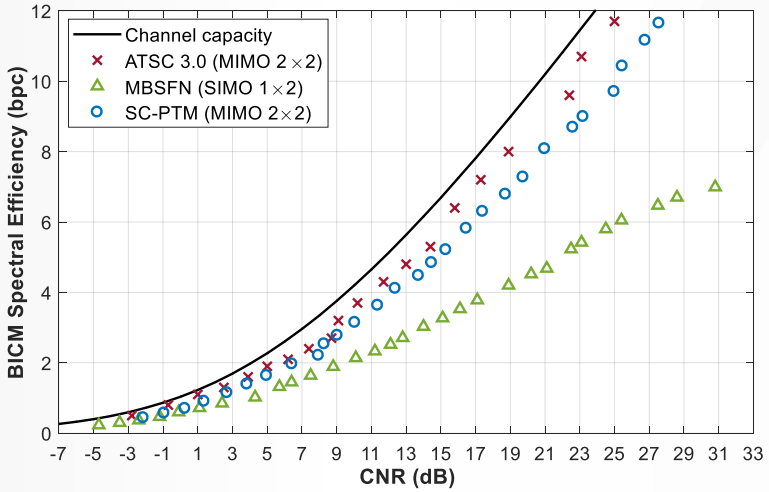


2.3. RAN Benchmark

2.3.3. Link-Level Simulations

BICM spectral efficiency vs. CNR

2. MIMO i.i.d. Rayleigh channel
   - Cross-polarization discrimination factor $\mathrm{XPD} = \infty$.
   - **Minimum Mean Square Error (MMSE)** demapper with **MIMO 2x2** SC-PTM and ATSC 3.0.
   - MBSFN employs a **1x2 SIMO** scheme.
     - MBSFN cannot fully exploit spatial multiplexing gains compared with ATSC 3.0 and SC-PTM.



- **Low spectral efficiencies:** ATSC 3.0, MBSFN and SC-PTM provide similar performance.
- **High spectral efficiencies:**
  - ATSC 3.0 **slightly outperforms** SC-PTM.
  - ATSC 3.0 **clearly outperforms** MBSFN.
- MBSFN is limited to **7 bpc** while SC-PTM and ATSC 3.0 can increase their limits to more than **12 bpc**.

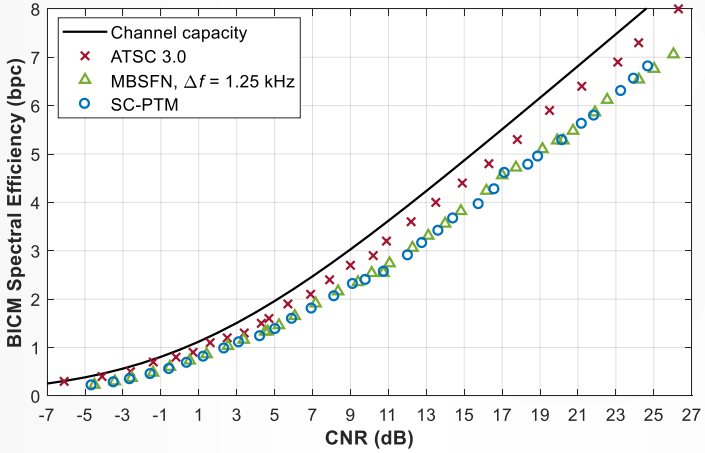
2.3. RAN Benchmark

2.3.3. Link-Level Simulations

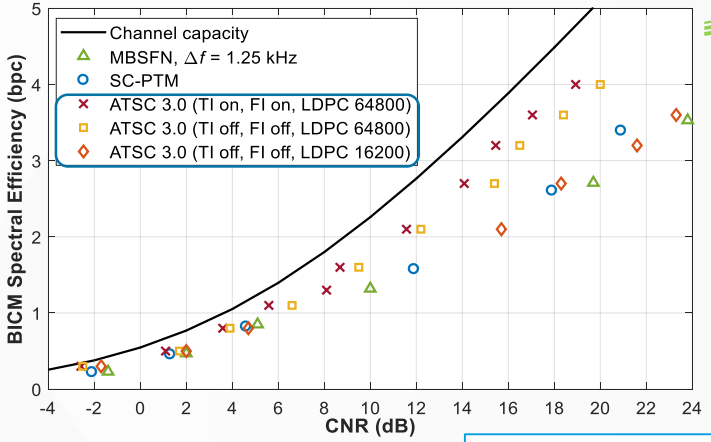
BICM spectral efficiency vs. CNR

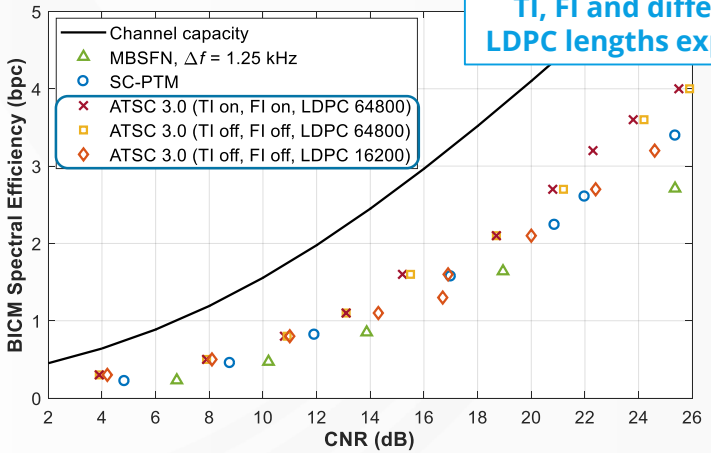
3. **Real scenarios**

a) Fixed-rooftop environment
- DVB-F1 Rice channel
- K=10



b) Portable-outdoor reception
- NGH-PO channel





TI, FI and different LDPC lengths explored

c) Portable-indoor reception
- NGH-PI channel

2.3. RAN Benchmark

2.3.3. Link-Level Simulations

Mobility

1. **Speed tolerance with real estimation**

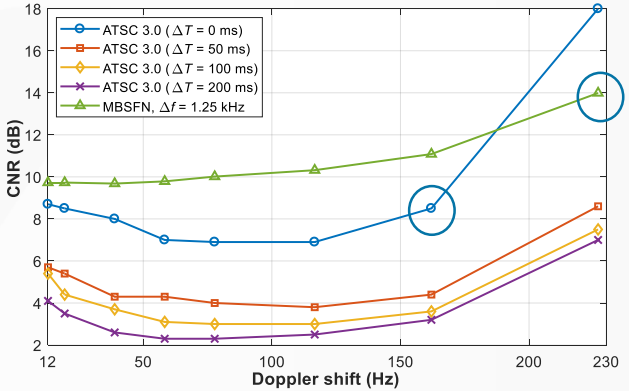
- Wide range of **Doppler** shifts [10 – 230 Hz].
- Frequency band **700 MHz**.
- MBSFN and ATSC 3.0 as critical technologies.
  - MBSFN with 1.25 kHz.
  - ATSC 3.0 FFT size 32K.
  - SC-PTM has wider carrier spacing of 15 kHz.

Theoretical Doppler limit [14]:

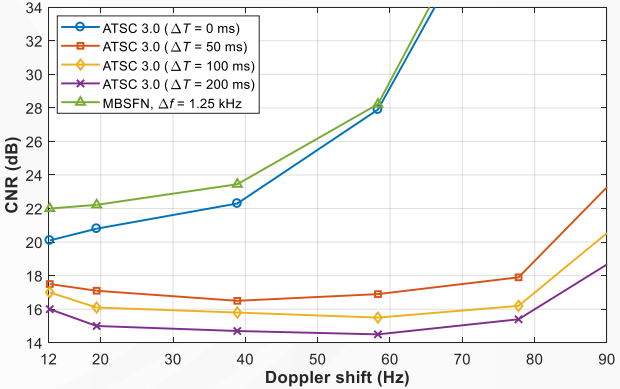
$$f_{D_{ATSC30}} = \frac{1}{2D_y(T_U + T_{CP})} = \frac{1}{2 \cdot 2 \cdot (1407.64\ \mu s)} = \mathbf{177.6\ Hz} \propto 275\ km/h$$

$$f_{D_{MBSFN}} = \frac{1}{2D_y(T_U + T_{CP})} = \frac{1}{2 \cdot 2 \cdot (1000\ \mu s)} = \mathbf{250\ Hz} \propto 385\ km/h$$

MCS 3 (QPSK)



MCS 15 (16QAM)

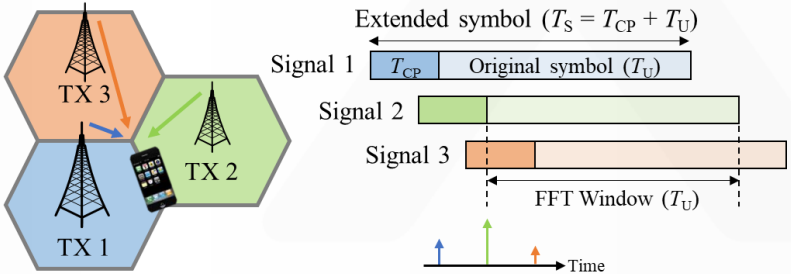


2.3. RAN Benchmark

2.3.4. Coverage

- **Relevant KPI** for assessing **PTM** transmissions
  - Link between system and network deployment

- **Characteristics** evaluated:
  - Role of **cyclic prefix** and OFDM symbol duration in SFN
  - Mismatch between Cell Acquisition Subframe **(CAS)** and payload frames

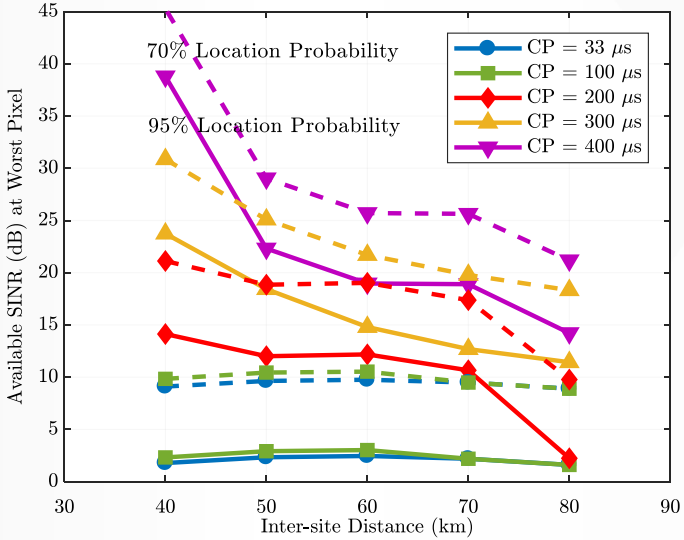


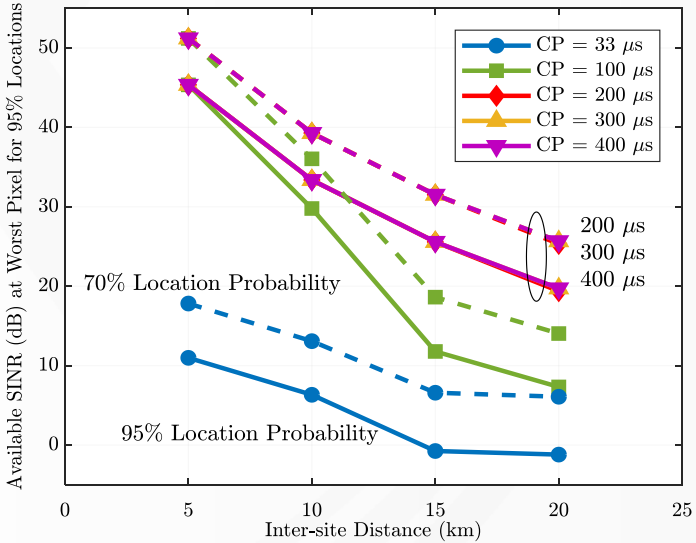
2.3. RAN Benchmark

2.3.4. Coverage

Performance in HPHT and LPLT Networks

- CP length in eMBMS is **sufficient** for **LPLT** but still **unable** to efficiently integrate **HPHT** deployments.
- **200 *µs*** in Release'14 may permit HPHT deployments but for limited data rate services.
- **400 *µs*** would improve performance if introduced in further releases.





2.3. RAN Benchmark

2.3.4. Coverage

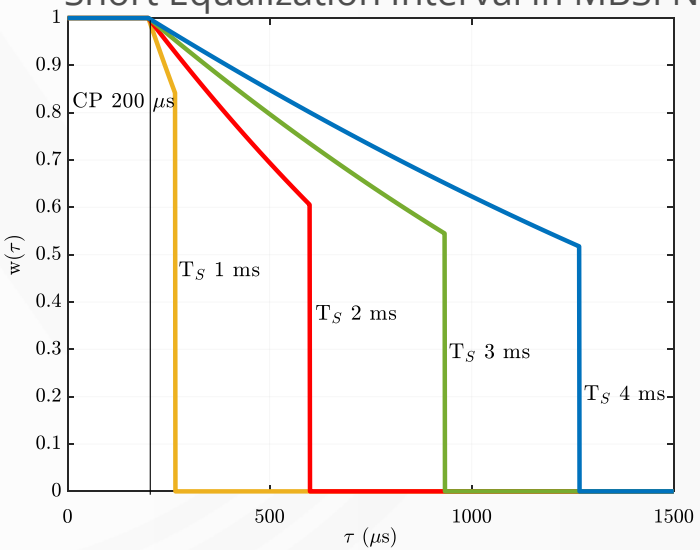
Cyclic Prefix and Symbol Duration

- **Trade-off** between **overhead** and **robustness** against Inter-symbol Interference (ISI).
  - eMBMS is characterized by shorter CP durations than traditional DTT systems (e.g. DVB-T2 or ATSC 3.0).
    - Fixed overhead to 20%
  - Different CP and SCS cannot be combined
  - Not possible to design the system for fixed or mobile reception

ATSC 3.0

CP (# Samples)	Δ(μs)	Overhead (%)			ISD (km)
		8k	16k	32k	
GI1 (192)	27.87	2.3	1.2	0.6	8
GI2 (384)	55.56	4.7	2.3	1.2	16
GI3 (512)	74.07	6.3	3.1	1.6	22
GI4 (768)	111.11	9.4	4.7	2.3	33
GI5 (1024)	148.15	12.5	6.3	3.1	44
GI6 (1536)	222.22	18.7	9.4	4.7	66
GI7 (2048)	296.30	25.0	12.5	6.3	88
GI8 (2432)	351.85	29.7	14.8	7.4	105
GI9 (3072)	444.4	N/A	18.8	9.4	133
GI10 (3648)	527.78	N/A	22.3	11.1	158
GI11 (4096)	592.59	N/A	25	12.5	178
GI12 (4864)	703.70	N/A	N/A	14.8	211

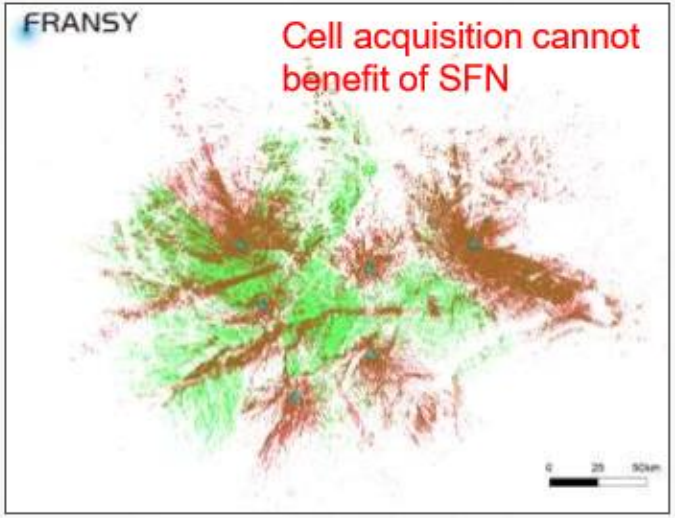
Short Equalization Interval in MBSFN



2.3. RAN Benchmark

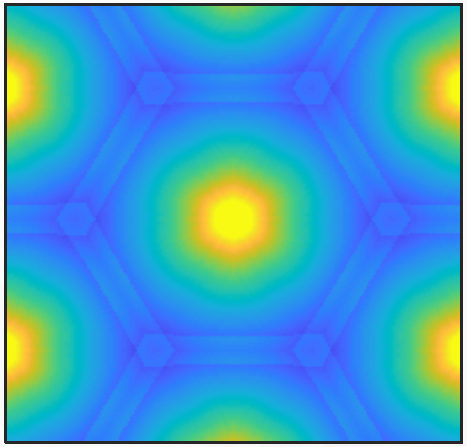
2.3.4. Coverage

- Release'14 introduces the so-called **Cell Acquisition Subframe**.
  - But **reuses** numerology options of unicast control channels.
  - **Mismatch** in terms of sub-carrier spacing, cyclic prefix duration, use of MISO vs SISO.
  - **Control:** 15 KHz, extended CP (16.7us) – **Data:** 1.25 KHz, extended CP (200us)



Signaling -6 dB SNR; Data 0.5 dB SNR

CAS MBSFN CAS+MBSFN



SFN 16.67 μs

2.3. RAN Benchmark

2.3.5. System-Level Simulations

Simulation platform:

- Emulates considerably larger parts of a communication network consisting of multiple base stations, UEs, gateways, application servers, etc.
- Includes layer-2/3 and higher layer functions.
- Abstract models for layer 1.
- Allows for evaluation of **Radio Resource Management** (RRM) and protocol functions.
- Takes into account interference between different concurrent transmissions or higher-layer consideration:
  - Impact of radio network performance on TCP connections
  - User experience at the application level.
- Takes into account UE distributions and mobility according to synthetic models or in “real-world” scenarios.

Test environment:

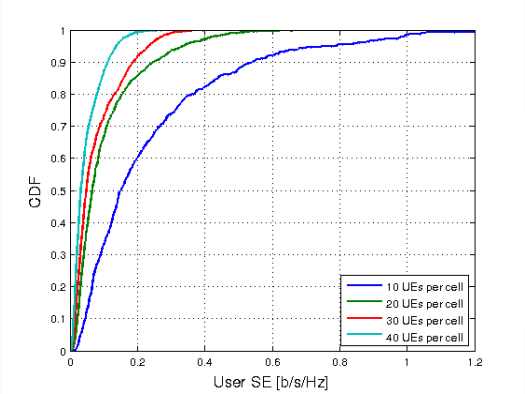
- Defined by the ITU for IMT-2020 evaluation [11].
- **Scope** of the simulation campaign:
  - Urban indoor eMBB
  - Urban outdoor eMBB
  - Rural indoor eMBB
  - Rural outdoor eMBB
  - Indoor hotspot.

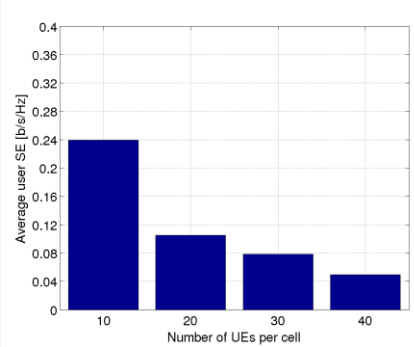
2.3. RAN Benchmark

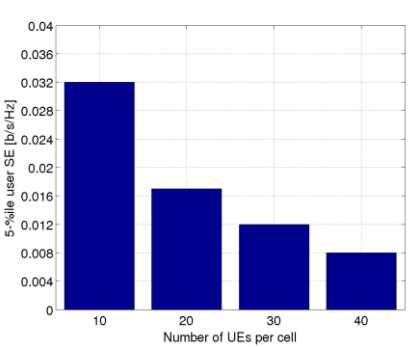
2.3.5. System-Level Simulations

User spectral efficiency

- Example: urban indoor eMBB scenario.







Parameters	*Dense Urban-eMBB*
Configuration	A
Carrier frequency for evaluation	2 GHz
Total transmit power per TRxP	41 dBm for 10 MHz bandwidth
Number of antenna elements per TRxP	4
Inter-site distance	200 m
Percentage of high loss and low loss building type	20% high loss, 80% low loss
Number of UE antenna elements	4
Device deployment	100% indoor, and 100% outdoor (in car) uniformly distributed over the area under macro layer
UE mobility model	Fixed and identical speed |v| of all UEs of the same mobility class, randomly and uniformly drop. Speed is taken into account in the small scale channel.
UE speeds of interest	Indoor users: 3km/h Outdoor users (in-car): 30 km/h
BS noise figure	5 dB
UE noise figure	7 dB
BS antenna element gain	14 dBi
BS antenna elevation 3dB beamwidth	10°
BS antenna azimuth 3dB beamwidth	65°
UE antenna element gain	0 dBi
Thermal noise level	-174 dBm/Hz
Traffic mode	Full buffer
Simulation bandwidth	10 MHz+10 MHz for FDD
Link Level Channel model	3GPP TR 38.901
UE density	Various values evaluated with simulations
UE antenna height	1.5 m

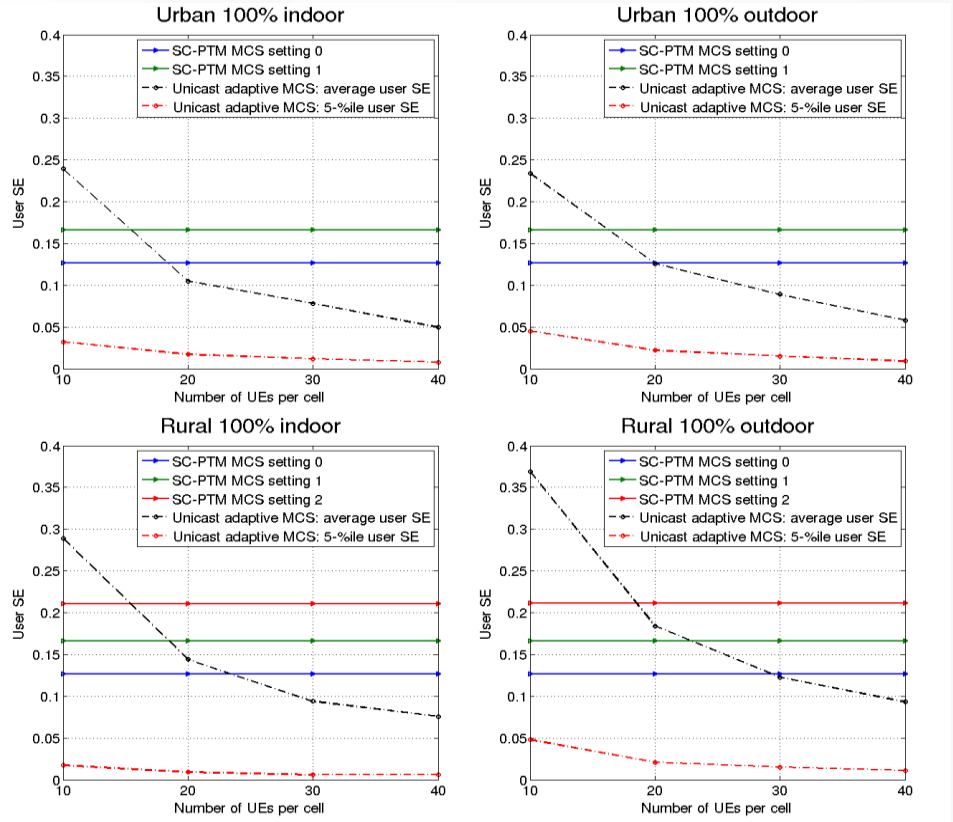
2.3. RAN Benchmark

2.3.5. System-Level Simulations

Overall findings

- Dense **urban and rural** IMT-2020:
  - The **user spectral efficiency** of cell-edge users is higher for SC-PTM as compared to that of unicast.
  - **Average spectral efficiency**
    - Low density of users (~15 users/cell): SC-PTM provides a better result with **negligible packet loss** rate due to the link adaptation and HARQ schemes.
    - **SC-PTM outperforms unicast** for higher density of users as the sharing of resources among numerous users is avoided.

- **Indoor hotspot** IMT-2020:
  - **Unicast** transmission mode has shown to be more promising than SC-PTM.
    - Very high packet loss rate with SC-PTM even at the lowest MCS setting.
    - **Strong interferences**, contributed by the dense deployment.
    - The interference level can be reduced by switching off some of the access points or by using **SFN** schemes.

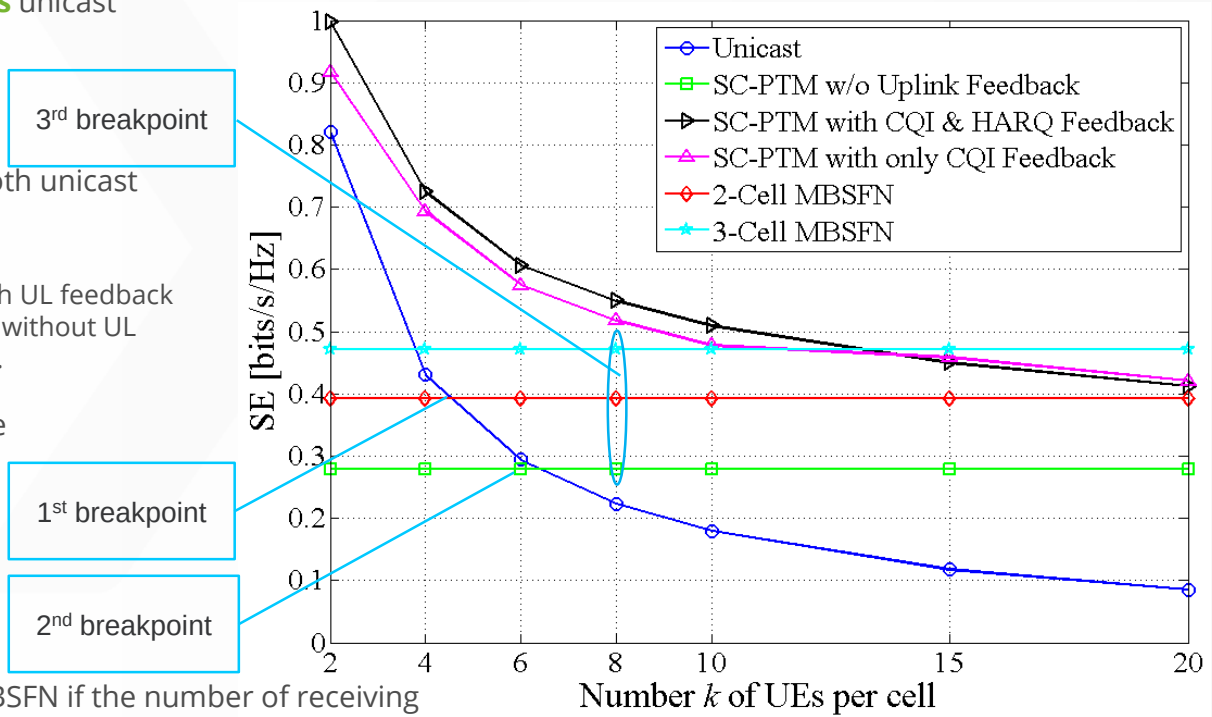


2.3. RAN Benchmark

2.3.5. System-Level Simulations

System level performance of SC-PTM with several feedback schemes:

- SC-PTM **without** UL feedback **outperforms** unicast when number of UEs is **high**.
  - e.g. more than 6 in simulated scenario.
  - Specified in 3GPP standard.
- SC-PTM **with** UL feedback **outperforms** both unicast and SC-PTM without UL feedback
  - Irrespective of number of UEs.
  - However, the performance of SC-PTM with UL feedback converges to the performance of SC-PTM without UL feedback as the number of UEs increases.
- SC-PTM with only CQI feedback can provide a **similar performance** to SC-PTM with CQI and HARQ ACK/NACK feedback.
  - Yet with lower complexity: Relevant for media streaming (Mission critical video for MCPTT, TV services)
- SC-PTM with UL feedback **outperforms** MBSFN if the number of receiving UEs is small.
  - e.g. less than 10 in the simulated 3-cell MBSFN scenario.



2.3. RAN Benchmark

2.3.6. RAN Architecture

User Plane Latency [analytical]

- End-to-end (E2E) – Core to UE
  - **TOTAL: 130 ms**

$$T_u = A + B + C$$

- A is the delay from BM-SC to eNB
  - Assuming SYNC is MSP/2 (**40 ms**)
- B is the acquisition time of the MSP (**80 ms**)
- C is the UE processing time (**10 ms**)

- IMT-2020 requirement is not E2E but Layer 2/3 to UE acquisition.
  - 4 ms for eMBB, 1 ms for URLCC.
  - Related to B and C.
  - NOT FULFILLED

Control Plane Latency [analytical]

- RRC_IDLE UE without updated MCCH information delay
  - **TOTAL: 225 ms**
    - a is the SIB13 acquisition time in MCCH (**10 ms**)
    - b is the average delay of MCCH acquisition (**160 ms**)
    - c is the processing delay at UE to obtain desired TMGI (**10 ms**)
    - d is the average delay of MSP (**40 ms**)
    - e is the acquisition time of MSI (**5 ms**)

$$T_c = a + b + c + d + e$$

- In case that the UE is up-to-date with MCCH, only experiences d and e delays.
- IMT-2020 specifies that this time is from “battery saving” state to Active -> ☑

Contents

3. 5G New Radio Rel'15 (PTP)

- Section related to the studies performed in **Deliverable D3.2** (PTP parts).
  - Final version will be released in **November 2018**.

3.1. Air interface

- New Radio physical layer: framing, numerologies, physical channels.
- PDSCH detailed explanation.
- Inspection and analysis
- Link-level performance results

} IMT-2020 evaluation

3.2. Radio Access Network

- Overall RAN Logical Architecture.
- Interfaces: Core-RAN-UE

3.3. Protocols and Radio Resource Management

3.1. Air Interface

3.1.1. New Radio - Physical Layer

Numerology

- Multiple Waveforms studied but Release 15 adopted **CP-OFDM**
- **Flexible** and **scalable** design to cover different use cases.
- Permits the use of subcarrier spacing (**SCS**) from 15 kHz to 240 kHz.
  - SCS of a BW part is defined as $\Delta f = 2^{\mu} \cdot 15 [\text{kHz}]$
  - μ is a positive integer with values {0,1,2,3,4}, as specified in Rel'15.

μ	SCS (kHz)	T_U (μs)	CP type	T_{CP} (μs)	Slot duration (μs)	slots/subframe
0	15	66,66	Normal	4.69	1000	1
1	30	33.33	Normal	2.34	500	2
2	60	16.66	Normal	1.17	250	4
			Extended	4.16	250	4
3	120	8.33	Normal	0.59	125	8
4	240	4.17	Normal	0.29	62,5	16

Different Numerologies can be multiplexed in TDM and FDM

3.1. Air Interface

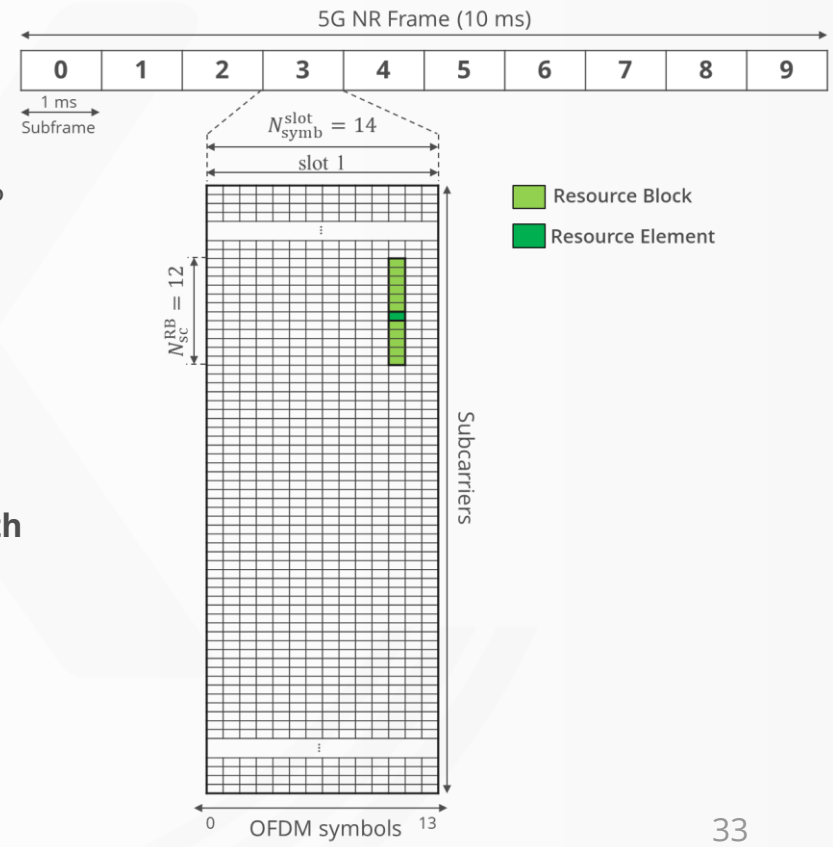
3.1.1. New Radio - Physical Layer

Framing

- **Subframes with variable number of slots** $N_{slot} = 2^{\mu}$.
- Fixed N_{symb}^{slot} **symbols per slot:**
  - N_{symb}^{slot}= 14 for Normal CP, N_{symb}^{slot} = 12 for Extended CP
- **Resource Element (RE)**
  - One subcarrier allocated in one OFDM Symbol.
- **Resource Block (RB)**
  - Group of 12 consecutive REs in the frequency domain.

Bandwidth

- Total Bandwidth can be divided into several **Bandwidth Parts**, each one with different numerology



3.1. Air Interface

3.1.1. New Radio - Physical Layer

Physical Channels and Signals

Downlink

- **Physical Channels:**
  - Physical Broadcast Channel (PBCH)
  - Physical Downlink Control Channel (PDCCH)
  - Physical Downlink Shared Channel (PDSCH)
- **Physical Signals**
  - Primary Synchronization Signals (PSS)
  - Secondary Synchronization Signals (SSS)
  - Demodulation Reference Signals (DMRS)
  - Channel State Information Reference Signals (CSI-RS)
  - Phase Tracking Reference Signals (PT-RS)

Uplink

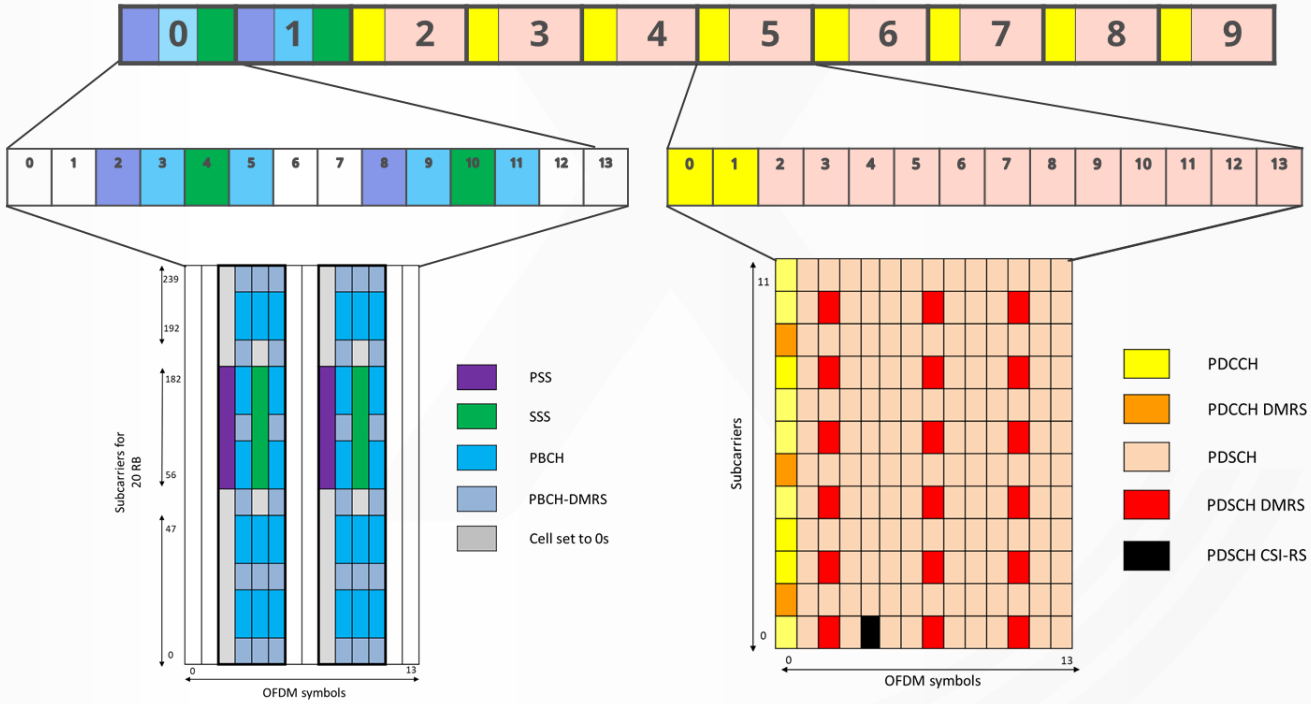
- **Physical Channels:**
  - Physical Random Access Channel (PRACH)
  - Physical Uplink Control Channel (PUCCH)
  - Physical Uplink Shared Channel (PUSCH)
- **Physical Signals**
  - Demodulation Reference Signals (DMRS)
  - Sounding Reference Signals (SRS)
  - Phase Tracking Reference Signals (PT-RS)

3.1. Air Interface

3.1.1. New Radio - Physical Layer

Physical Channels and Signals

Allocation (Slot Format Indicator 0):

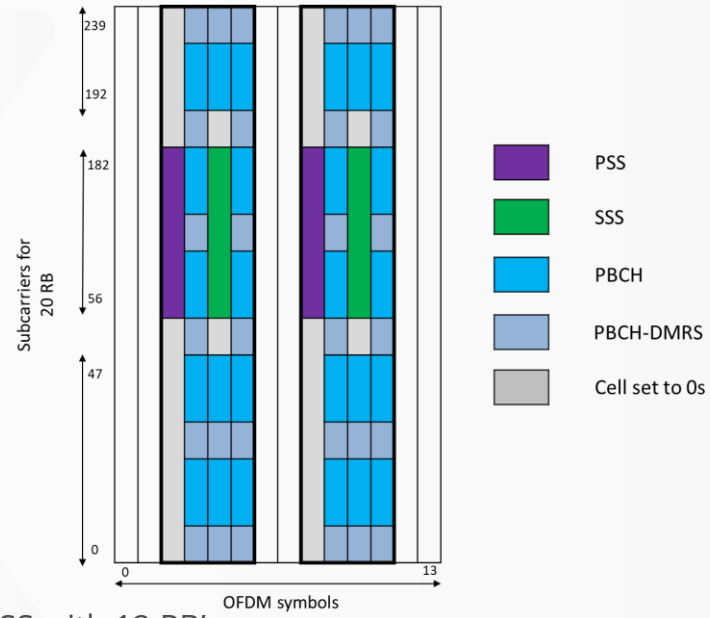


3.1. Air Interface

3.1.1. New Radio - Physical Layer (SS/PBCH)

SS/PBCH

- **PSS and SSS**
  - Used by UE for initial cell search to obtain:
    - frame timing
    - Cell ID
    - Reference signals for demodulation
- **PBCH**
  - **Basic physical layer signalling**
    - Master Information Block (MIB).
  - Polar coded.
  - Includes **DMRS Signals** to estimate the channel.
- **SS/PBCH Block**
  - Formed by **4 OFDM Symbols:** 1 PSS, 1 SSS and 2 PBCH.
  - **240 subcarriers** per OFDM symbol.
  - **Frequency domain:** Allocation depending on the high layer parameter *ssb-subcarrierOffset.*
  - **Time domain:** Sent in periodical bursts, where the number of blocks depends on numerology and frequency band.



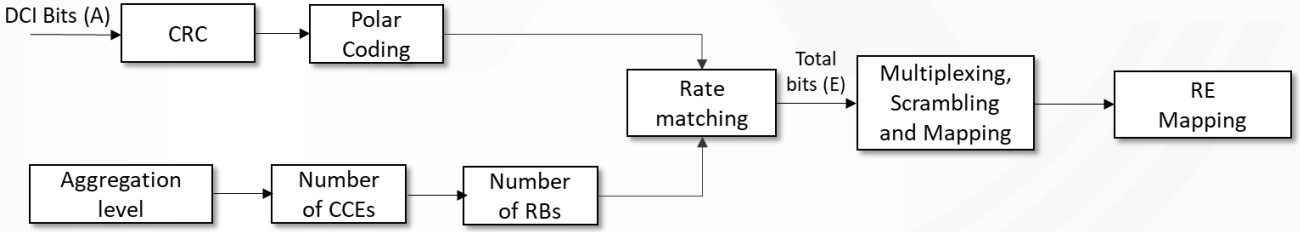
- PSS with 12 RB's
- PBCH with 20 RB's
- SSS with 12 RB's + upper PBCH with 4 RBs + lower PBCH with 4 RBs
- PBCH with 20 RB's

3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDCCH)

PDCCH

- Specific **control** and **scheduling** information.
- **Downlink Control Information** (DCI): indicates data scheduling within PDSCH for a UE.
  - Minimum DCI bits = 12 (same as Format 1C for a 5 MHz channel).
  - Length depending on **DCI formats.**
  - 24 bits CRC.
- **Polar** coded, **QPSK** modulation.
- **Aggregation Level** (AL): related to the total number of consecutive Control Channel Elements (CCE) for transmitting the encoded control message.
  - 1 CCE = 6 continuous REGs (Resource element Groups)
  - 1 REG = 12 REs (Resource Elements)
- Example of PDCCH total bits: 4 (aggregation level of CCE) x 6 (REG/CCE) x 12 (RE/REG) x 2 (bits/RE, QPSK) = 576 bits
- Effective **code rate** is A/E:

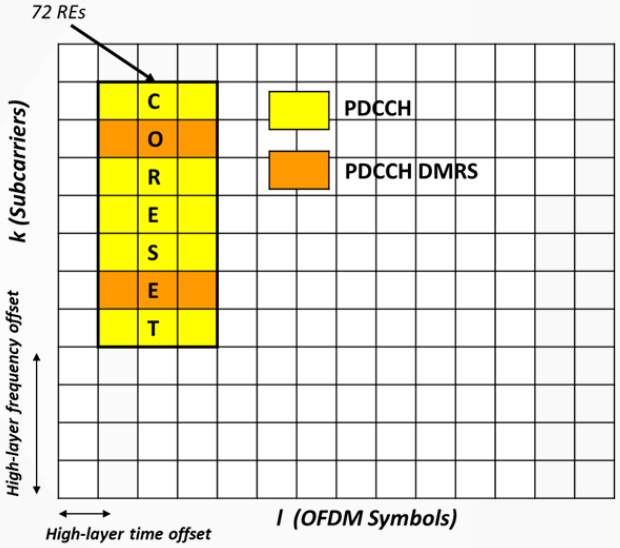


3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDCCH)

PDCCH

- REGs are mapped in **control-resource sets (CORESET)** for a given numerology.
- Time allocation:
  - ❖ OFDM Symbols 0,1 or 2 of subframes with no SS/PBCH blocks.
  - ❖ Content can be distributed in 1,2 or 3 OFDM Symbols.
- **DMRS Signals**
  - Enable the correct **demodulation** of the channel by means of **channel estimation**.
  - Location depending on **DMRS pattern.**



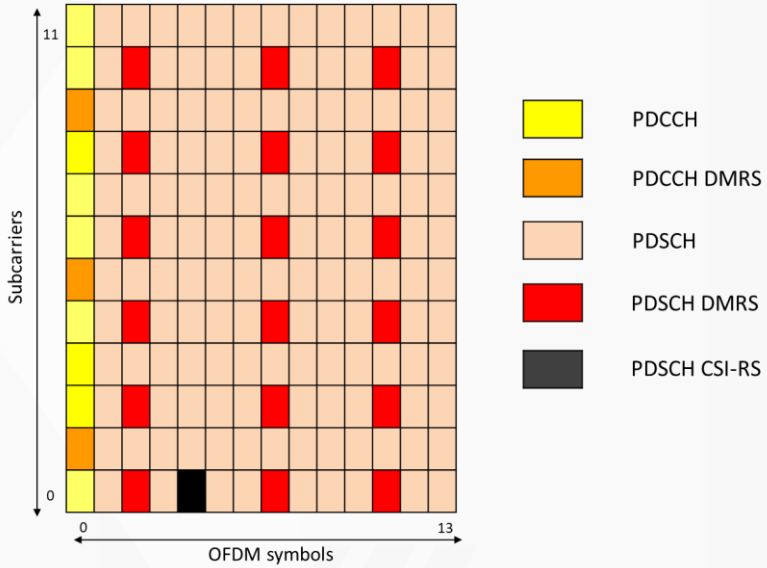
Example of minimum CORESET length allocation

3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDSCH)

PDSCH

- Transmits **data content** and **SIBs** to UEs.
- LDPC Coded.
- Modulation orders: QPSK, 16QAM, 64QAM, 256QAM.
- **Reference Signals**
  - **DMRS:** Used for **channel estimation** to allow demodulation.
  - **CSI-RS:** Provide **channel state information** needed for link adaptation.
  - **PT-RS:** To **estimate the phase noise** at high frequency ranges.
- **PDSCH Allocation:** In any time and frequency position where SS/PBCH and PDCCH are not allocated.

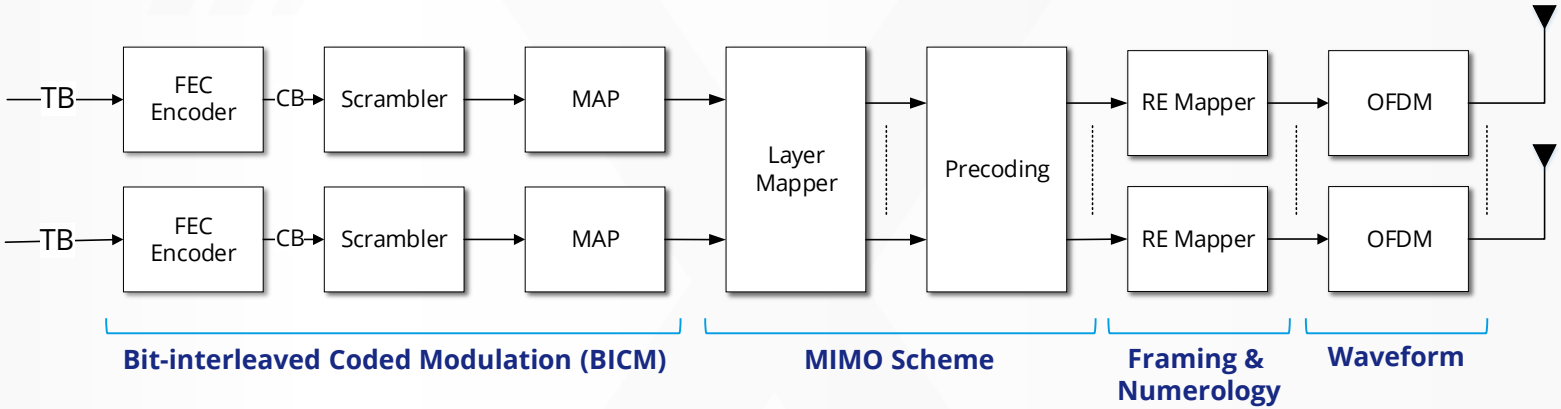


Example of PDCCH and PDSCH slot allocation for FR1.

3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDSCH)

- **PDSCH** Rel'15 block diagram [18-20]:



- **Bit-Interleaved Coded Modulation (BICM).**
  - Channel coding [Segmentation + CRC + LDPC + Rate Matching]
  - Scrambling
  - Modulation mapper

Easy design: the channel encoder and the mapper are separated by a bit-interleaver, and therefore they can be designed independently.

3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDSCH)

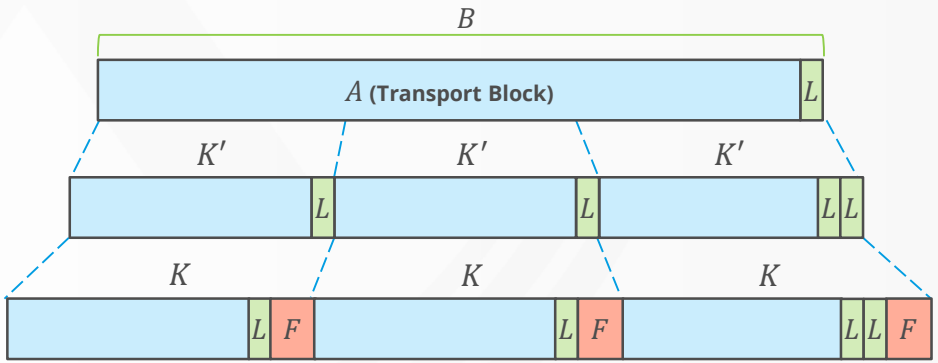
Segmentation + CRC

1. A **first set of CRC** parity bits is generated by a cyclic generator polynomial, with size:
   - $L = 24$ if $A > 3824$
   - $L = 16$ otherwise

2. B is **segmented** into several CBs with size K if $B > K_{cb}$, where $\begin{cases} K_{cb} = 8448 & \text{if Base Graph 1} \\ K_{cb} = 3840 & \text{if Base Graph 2} \end{cases}$

3. An **additional CRC** sequence with always size L = 24 is attached to each K'.

4. **Filler bits** F are placed to fit size K



3.1. Air Interface

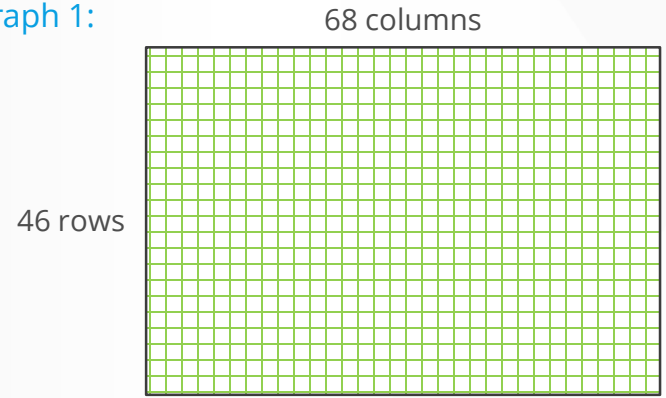
3.1.1. New Radio - Physical Layer (PDSCH)

LDPC coding

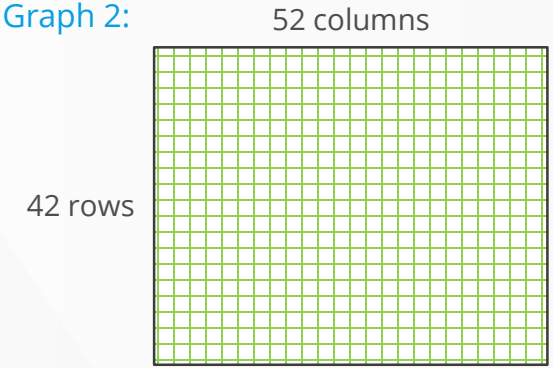
- Each CB with size K is coded using a LDPC matrix.

- **LDPC matrix** generated as follows:
  1. Initial $\mathbf{H_{BG}}$ matrix generated with all zeros.

Base Graph 1:



Base Graph 2:



  2. The elements with row and column indices given in Tables 5.3.2-2 (BG1) and 5.3.2-3 (BG2) in [8] are set to 1.

3.1. Air Interface

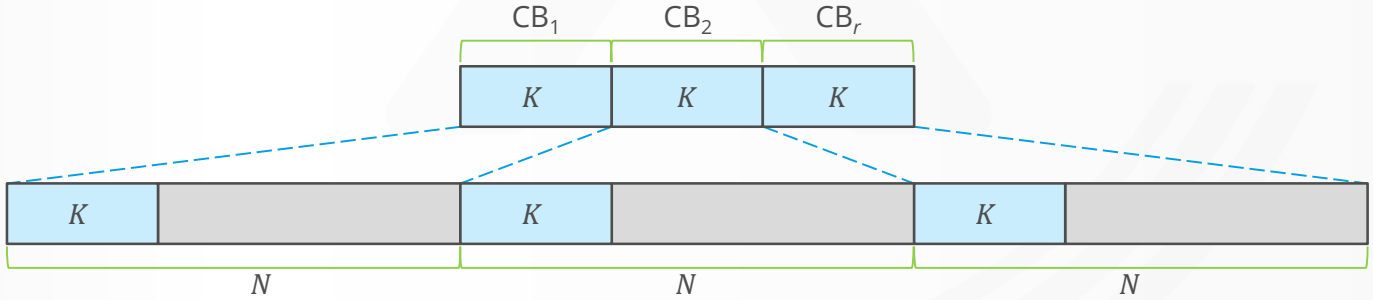
3.1.1. New Radio - Physical Layer (PDSCH)

LDPC coding

3. **H** is obtained by replacing each element of $\mathbf{H_{BG}}$ with a $Z_c \times Z_c$ matrix.
   - Elements in H with value **0** are replaced by a **zero matrix** of size $Z_c \times Z_c$.
   - Elements in H with value **1** are replaced by a **circular permutation matrix** $\boldsymbol{I}(P_{i,j})$ of size $Z_c \times Z_c$.
     - obtained by circularly shifting the identity matrix *I* of size $Z_c \times Z_c$ to the right $P_{i,j}$ times.
     - Values of $P_{i,j}$ are given in **TS 38.212**.

- Parity bits generation and LDPC output:

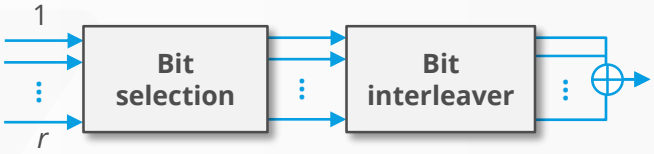
4. Generate the parity bits $\mathbf{w}$ such that $\mathbf{H} \times \begin{bmatrix} \mathbf{c} \\ \mathbf{w} \end{bmatrix} = \mathbf{0}$, where $\mathbf{c}$ is the code block with size *K*.
5. The output with size *N* is generated as follows:



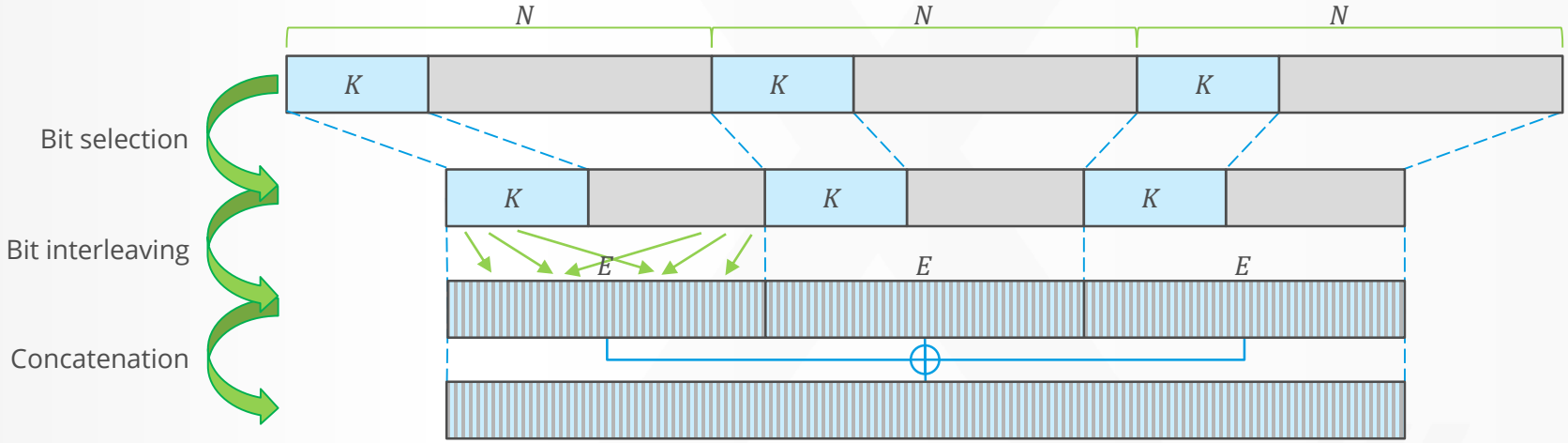
3.1. Air Interface

3.1.1. New Radio - Physical Layer (PDSCH)

Rate Matching and Concatenation



1. **Bit selection and pruning** is applied to the input.
   - The coding rate is adapted to the one selected initially.



2. Full **bit interleaver** applied to each CB with size E.
3. CBs are concatenated:
   - Output with size N_b (total bits initially calculated following 38.214).

3.1. Air Interface

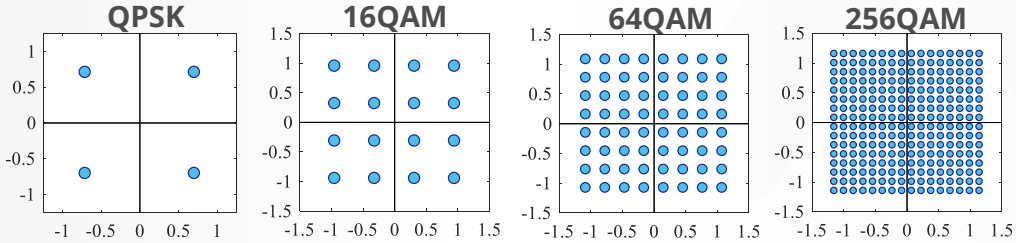
3.1.1. New Radio - Physical Layer (PDSCH)

Scrambling

- Input bits are scrambled prior to modulation for protection against burst errors.
- Bits are multiplied by a scrambling sequence: $\tilde{b}(i) = \left(b(i) + c(i)\right) \bmod 2$

Modulation

- Bits are transformed into symbols using **QAM**.
- 4 different constellation orders used.
  - They depend on the **MCS index**.



KPI
(as defined in 3GPP)

	MCS Index I_{MCS}	Modulation Order Q_m	Target code rate x [1024] R	BICM spectral efficiency
QPSK	0	2	120	0.234
	1	2	193	0.377
	2	2	308	0.602
	3	2	449	0.877
	4	2	602	1.176
16QAM	5	4	378	1.477
	6	4	434	1.695
	7	4	490	1.914
	8	4	553	2.160
	9	4	616	2.406
	10	4	658	2.570
64QAM	11	6	466	2.731
	12	6	517	3.029
	13	6	567	3.322
	14	6	616	3.609
	15	6	666	3.902
	16	6	719	4.213
	17	6	772	4.523
	18	6	822	4.816
	19	6	873	5.115
256QAM	20	8	682.5	5.332
	21	8	711	5.555
	22	8	754	5.891
	23	8	797	6.227
	24	8	841	6.570
	25	8	885	6.914
	26	8	916.5	7.160
	27	8	948	7.406

3.1. Air Interface

3.1.2. Inspection and Analysis

- IMT-2020 requirements evaluated against KPIs considered within the project.

Bandwidth [Inspection]

- Maximum aggregated system bandwidth including frequency guard bands.
- It may be composed of either a single or **up to 16** radio frequency (RF) carriers.
- A single component carrier supports:
  - **FR1** (450 MHz - 6 GHz): 5, 10, 15, 20, 25, 40, 50, 60, 80 or 100 MHz.
  - **FR2** (24.25 GHz - 52.6 GHz): 50, 100, 200, 400 MHz.

Frequency range	Numerology (μ)	Maximum BW (MHz)	Maximum N_{PRB}	Number of CA carriers	Total CA BW (GHz)
FR1 (450 MHz - 6 GHz)	0	50	270	16	0.8
	1	100	273		1.6
	2	100	135		1.6
FR2 (24.25 GHz - 52.6 GHz)	2	200	264		3.2
	3	400	264		6.4

Transmission bandwidths up to **6.4 GHz** are supported to provide high data rates.

3.1. Air Interface

3.1.2. Inspection and Analysis

Peak data rate [Analysis]

- Calculated as [21]:

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

Example:

- – J is the number of aggregated carriers in a frequency band — 16
- – υ is the number of layers when multiple antennas are used — 8
- – Q_m is the maximum modulation order — 8
- – R_{max} is the maximum CR: — 0.925
- – μ is the numerology — 0
- – T_s is the OFDM symbol duration in seconds — 66.67 μs
- – N_{PRB}^{BW} is the maximum RB allocation in the whole BW — 277
- – OH is the overhead — 0.205

$$\gamma_p = \sum_{j=1}^{16}\left(8 \cdot 8 \cdot 0.925 \cdot \frac{277 \cdot 12}{66.67 \cdot 10^{-6}}(1 - 0.205)\right) = 37.56\ Gbps$$

- Extrapolation to all configurations (Gbps):

Freq. Band	Num.	Total OH (%)	γ_p (Gbit/s) SISO	γ_p (Gbit/s) MIMO 8 Layers	γ_p (Gbit/s) SISO + CA	γ_p (Gbit/s) MIMO + CA
FR1	0	20.45	0.29	2.34	4.69	37.56
	1	18.98	0.60	4.78	9.57	76.35
	2	20.56	0.58	4.67	9.35	74.79
FR2	2	32.24	1	8	16	128
	3	30.59	2.05	16.39	32.79	**262.35**

3.1. Air Interface

3.1.2. Inspection and Analysis

Peak spectral efficiency [Analysis]

- Calculated as the peak data rate normalized by carrier bandwidth:

$$\eta_p = \frac{\gamma_p}{BW}$$

Frequency Band	Numerology	η_p (bit/s/Hz) SISO	η_p (bit/s/Hz) MIMO
FR1	0	6.06	48.52
	1	**6.22**	**49.82**
	2	6.06	48.52
FR2	2	5.57	44.60
	3	5.57	44.58

Peak BICM spectral efficiency [Analysis]

$$\eta_p^{BICM} = m_{max} \cdot CR_{max} \cdot \upsilon$$

SISO: **7.41** bit/s/Hz

MIMO 8x8: **59.2** bit/s/Hz

3.1. Air Interface

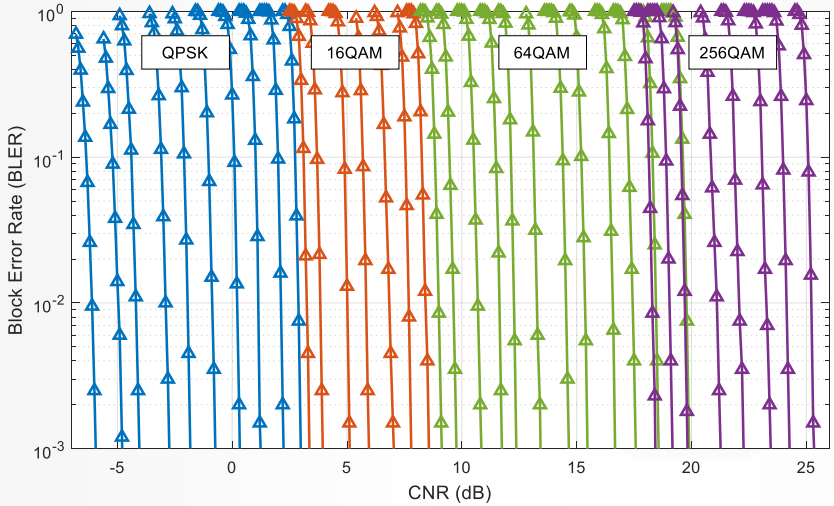
3.1.3. Link-Level Simulations (PDSCH)

BICM spectral efficiency vs. CNR

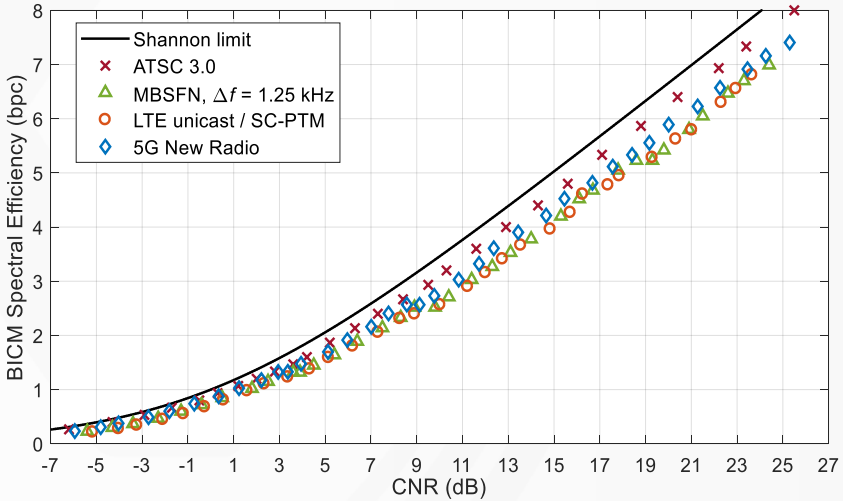
– Selected criterion: BLER < 10^{-3} (0.1%), $\mu = 0$, BW = 10 MHz

1. AWGN

- Waterfall



- Technology comparison vs. 4G / ATSC 3.0



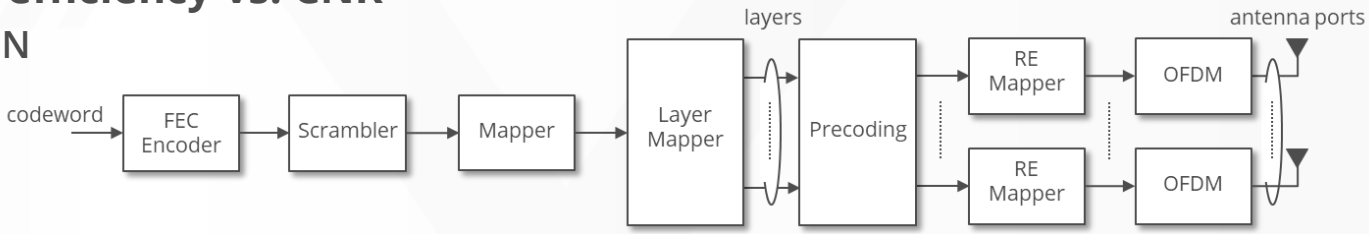
- 5G NR performance significantly **better than LTE**, mainly due to LDPC codes.
- **Worse than ATSC 3.0**: non-uniform constellations and longer LDPC codewords.

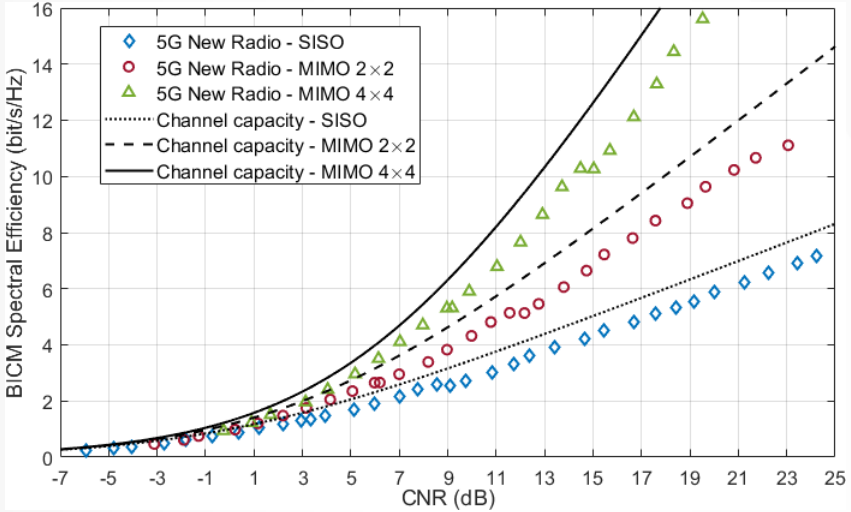
3.1. Air Interface

3.1.3. Link-Level Simulations (PDSCH)

BICM spectral efficiency vs. CNR

2. MIMO - AWGN





- 2 selected MIMO configurations:
  - MIMO 2x2: 2 layers, 1 codeword (TS 38.211).
  - MIMO 4x4: 4 layers, 1 codeword (TS 38.211).
- The use of multiple antennas drastically increases the BICM spectral efficiency.
- Capacities for CNR 15 dB:
  - SISO **4.1** bit/s/Hz
  - MIMO 2x2 **6.8** bit/s/Hz
  - MIMO 4x4 **10.3** bit/s/Hz

3.1. Air Interface

3.1.3. Link-Level Simulations (PDSCH)

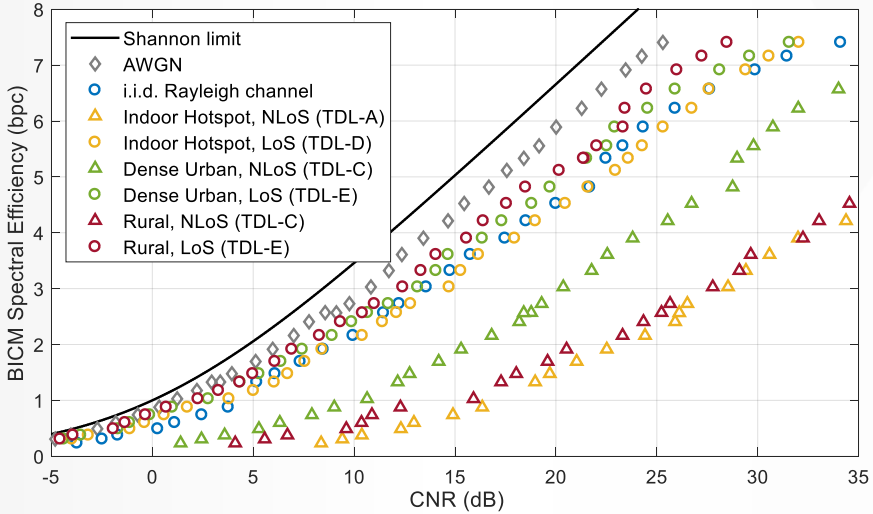
BICM spectral efficiency vs. CNR

3. TDL channel models (IMT-2020) [10]

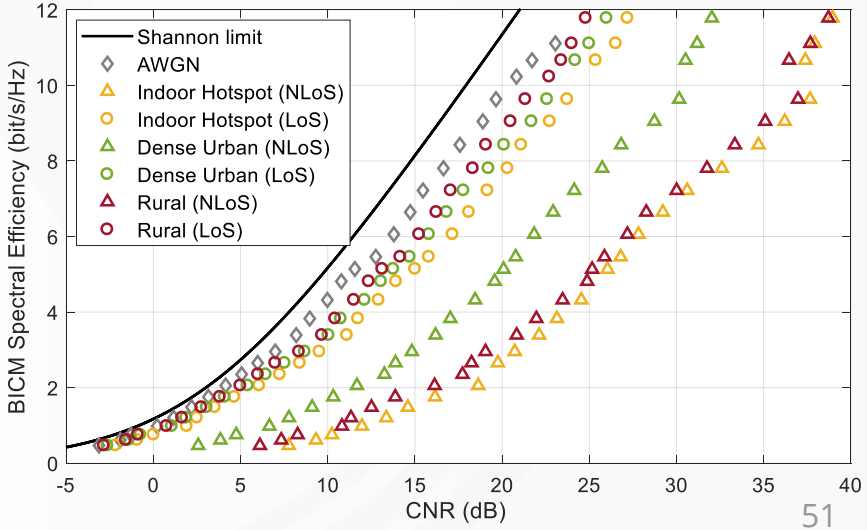
- Frequency band **4 GHz**

Scenario	Indoor hotspot	Dense urban	Rural
NLoS	TDL-A	TDL-C	TDL-C
LoS	TDL-D	TDL-E	TDL-E
Delay spread (ns)	20-30	100-300	30
User speed (km/h)	3	30	120

a) SISO



b) MIMO 2x2



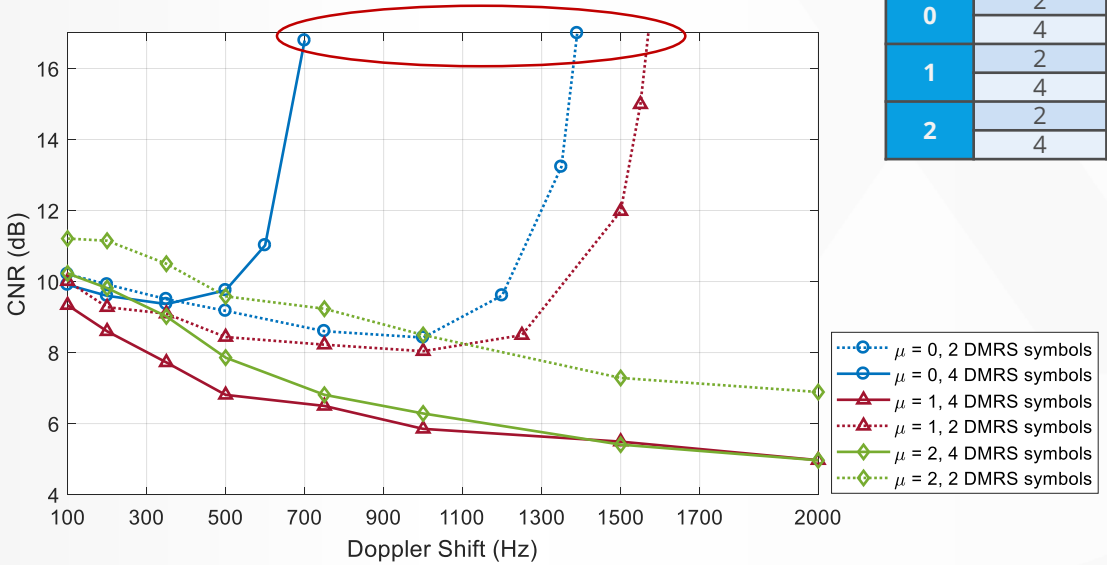
3.1. Air Interface

3.1.3. Link-Level Simulations (PDSCH)

Mobility

- Theoretical Doppler limit: $f_{D_{limit}} = \frac{1}{2D_y(T_U+T_{CP})} = \frac{1}{2\cdot 9\cdot 10^{-3}(66.6+5.2)} = \mathbf{773.1\ Hz}$ — 1192 km/h @ 700 MHz; 208 km/h @ 4 GHz
  - Mapping Type A
  - DMRS configuration type 1
  - 2 DMRS symbols
- IMT-2020 Requirement **500 km/h?**

μ	DMRS Symbols	D_y	f_D	User limit (km/h) @ 700 MHz	User limit (km/h) @ 4 GHz
0	2	9	773.1	1192	**208**
	4	5	1391.6	2147	**375**
1	2	9	1546.2	2385	**417**
	4	5	2783.2	4294	751
2	2	9	3092.4	4771	834
	4	5	5566.4	8588	1502



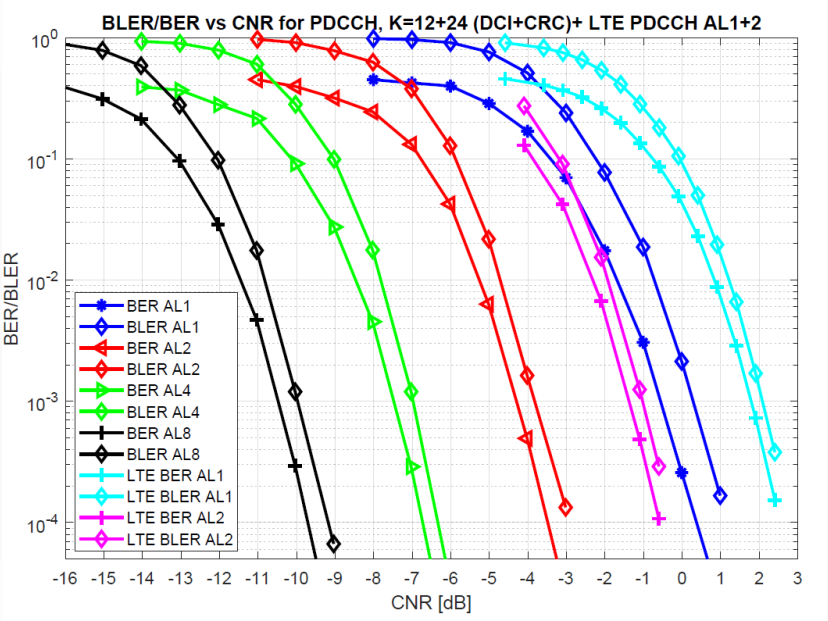
- **MCS 3** (QPSK CR ~1/4).
- **@ 700 MHz:** All configurations fulfil the requirement.
- **@ 4 GHz:** numerology 1 with more than 2 DMRS symbols is at least needed.

3.1. Air Interface

3.1.3. Link-Level Simulations (PDCCH)

BICM spectral efficiency

- **Simulation parameters**
  - Channel BW 5 MHz → CFI = 3
  - **New Radio**:
    - DCI bits (NR) = 12 bits (smallest possible)
    - AL = 1, 2, 4, 8 → CR = $\frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}$
  - **LTE**:
    - DCI bits (LTE) = 12 bits (format 1C)
    - AL = 1, 2 → CR = 0.388, 0.194
  - AWGN SISO channel
  - Maximum Likelihood (ML) Receiver
  - Rate recovery process includes additively combining any repetitions to distinguish the performance difference of higher aggregation level.



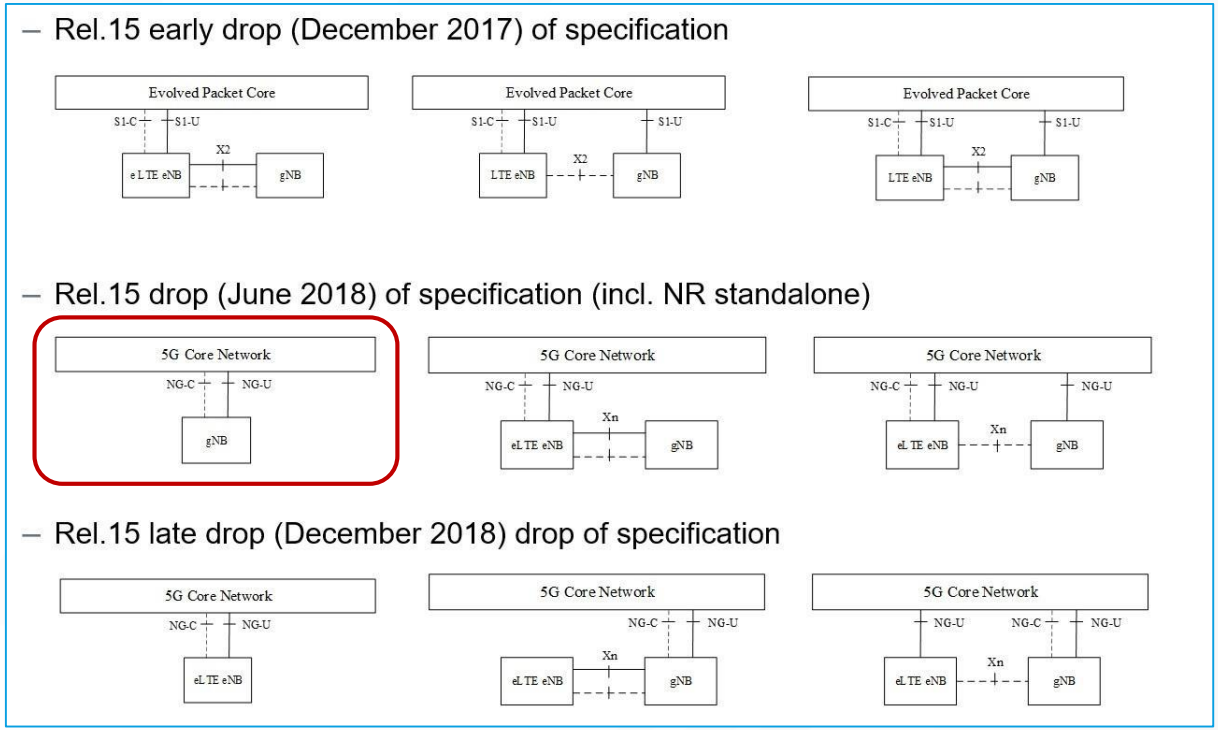
- **Results Analysis**
  - Due to the different CRC and aggregation level for LTE and NR, fair comparison is hard to achieve, but generally Polar **outperforms** Tail-biting.
  - Same 'aggregation level' (e.g., AL1): with the parameters shown, CNR required in NR is about 2.3dB less than LTE to achieve BLER < 10^{-3}.
  - NR AL8: minimum CNR is **-10.5 dB** (lower than any PDSCH configuration).

3.2. Radio Access Network

3.2.1. Overview

5G RAN status in **3GPP**:

- Not possible to connect the 5G RAN to 5GC at the moment (non-standalone).
- **End of June**: NR-standalone deployments.
- **End of 2018**: additional deployment scenarios.

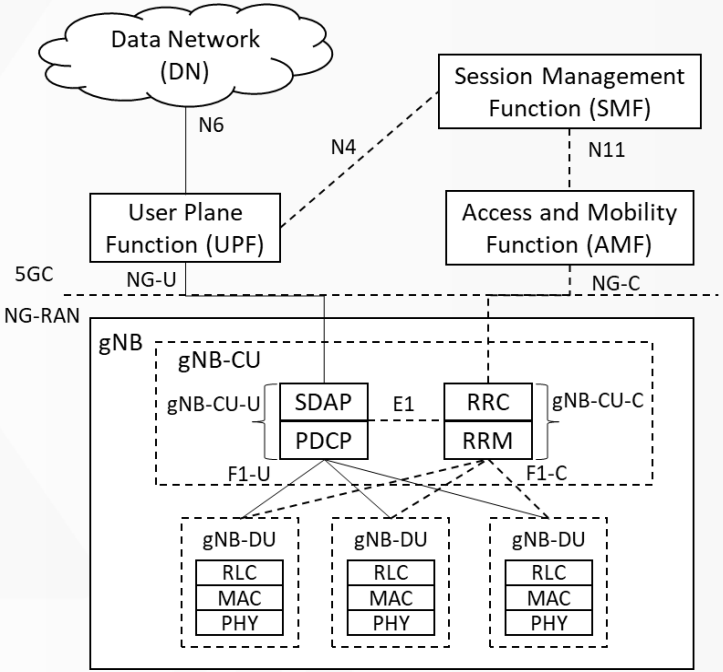


[22]

3.2. Radio Access Network

3.2.2. Overall RAN Logical Architecture

- Rel'15 RAN is called **Next-Gen RAN** (NG-RAN) or **5G-RAN**.
  - Formed by a number of gNB
- Main novelty over E-UTRAN: **Centralized/Distributed Unit** (CU/DU) separation at gNB level.
  - One DU can only belong to a CU
  - One CU can address several DUs
  - The goal is to have **interoperability** between CU and DU of different vendors, and favour Cloud RAN deployments.
- gNB is connected to one or several User Plane Function (UPF) in the user plane.
- gNB is connected to one or several Access and Mobility Management Function (AMF) in the Control Plane
  - NG-Flex only.



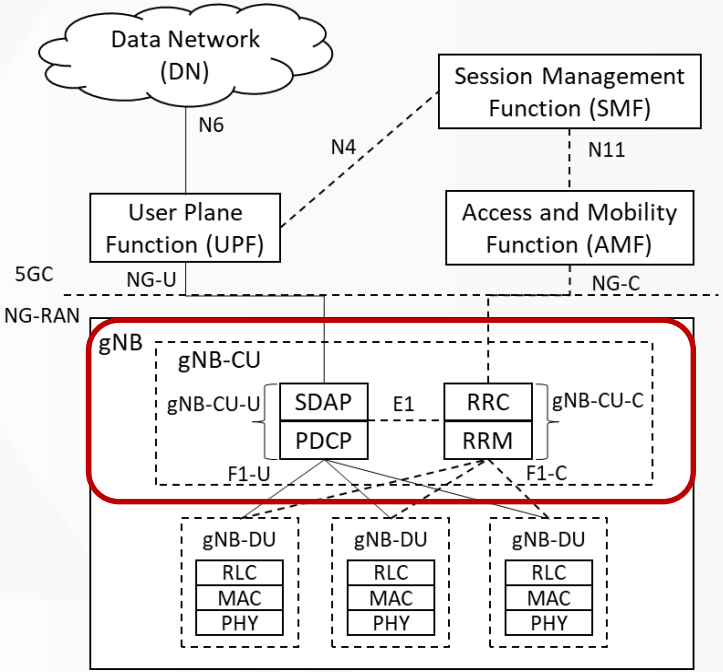
3.2. Radio Access Network

3.2.2. Overall RAN Logical Architecture

- **Centralized Unit (CU)** is tasked with:
  - Service Data Adaptation Protocol (SDAP), **new in 5G**.
  - Packet Data Convergence Protocol (PDCP)
  - Radio Resource Control (RRC)
  - Radio Resource Management (RRM)

- **CUPS** separation can be applied to the CU.
  - Split into CU-C and CU-U, connected by E1

- **Retransmissions**, mobility inter-DU cells is managed by the CU.



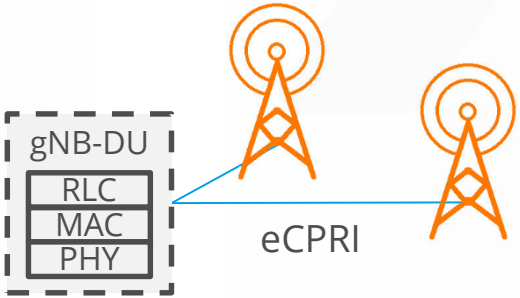
3.2. Radio Access Network

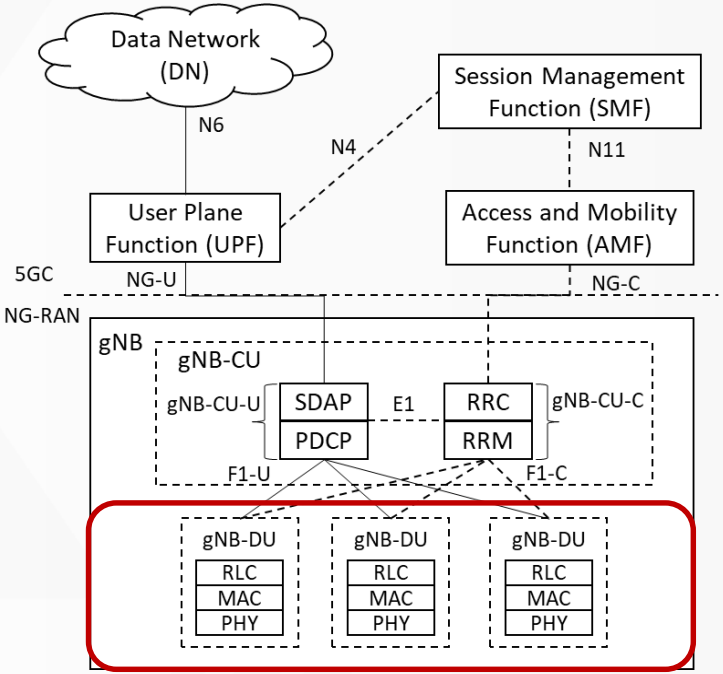
3.2.2. Overall RAN Logical Architecture

- **Distributed Unit (DU)** controls:
  - Radio Logical Control (RLC)
  - Medium Access Control (MAC)
  - Physical (PHY)

- **PHY** can further connect to several cells/RRH, using optical interfaces e.g. eCPRI.
  - Up to 512 cells/RRH per DU

- **Additional studies** to further split the PHY into High-PHY and Low-PHY, but no consensus reached.

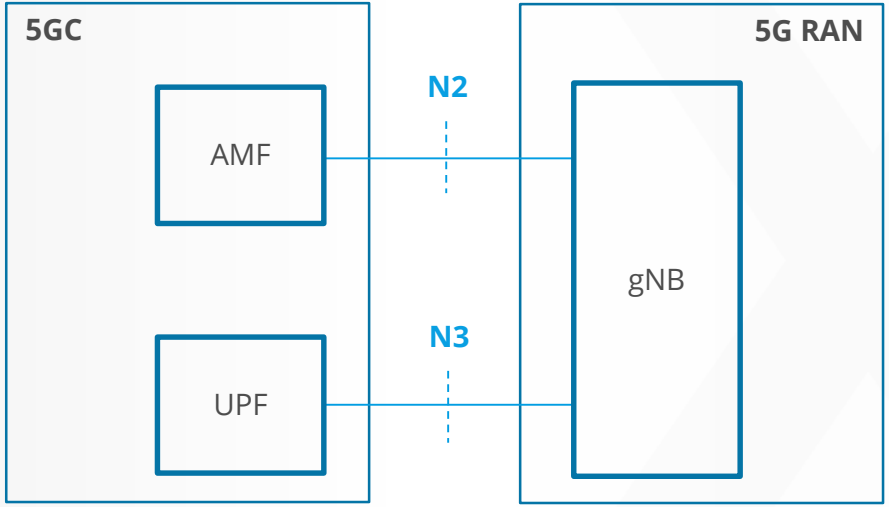




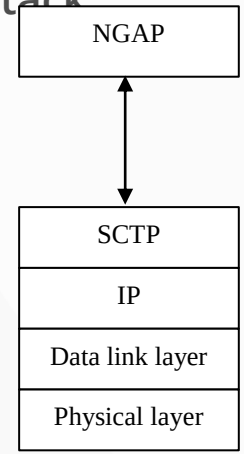
3.2. Radio Access Network

3.2.3. Interfaces

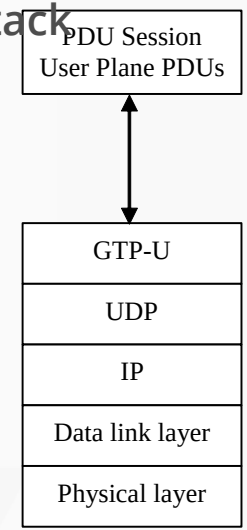
- Interfaces between the **5G Core (5GC)** and the **RAN** [23,24]:



N2 protocol stack



N3 protocol stack

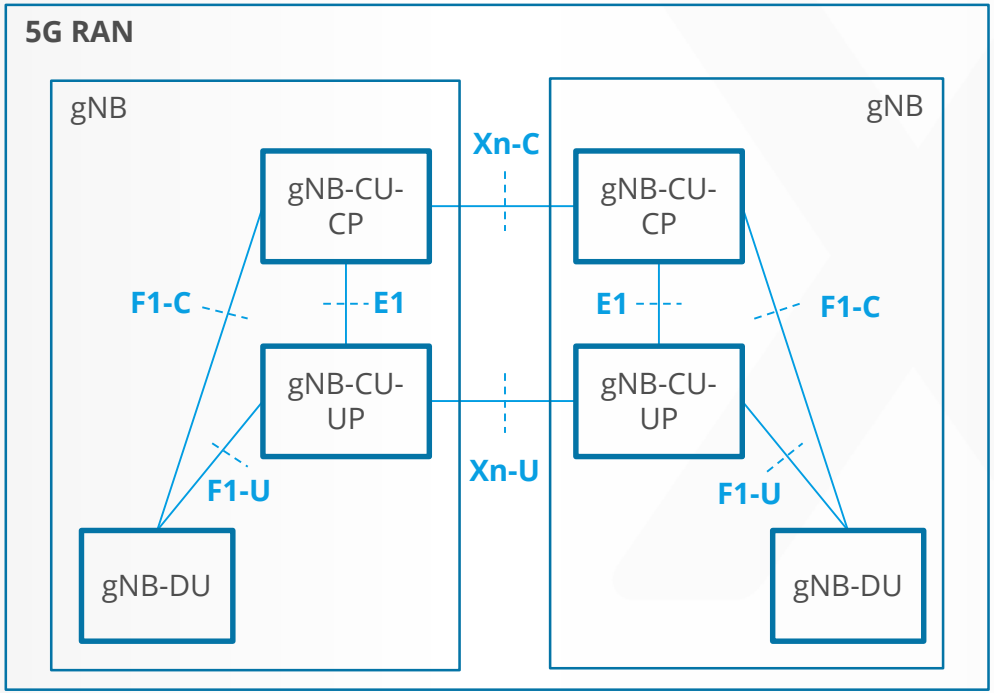


- Also known in 3GPP as 5GC:
  - Separately NG Core on Control Plane (CP) and NG Core on User Plane (UP).
  - 5GC reference point N2 between gNB and **AMF**.
  - 5GC reference point N3 between gNB and **UPF**.

3.2. Radio Access Network

3.2.3. Interfaces

- **RAN internal interfaces** [25]:

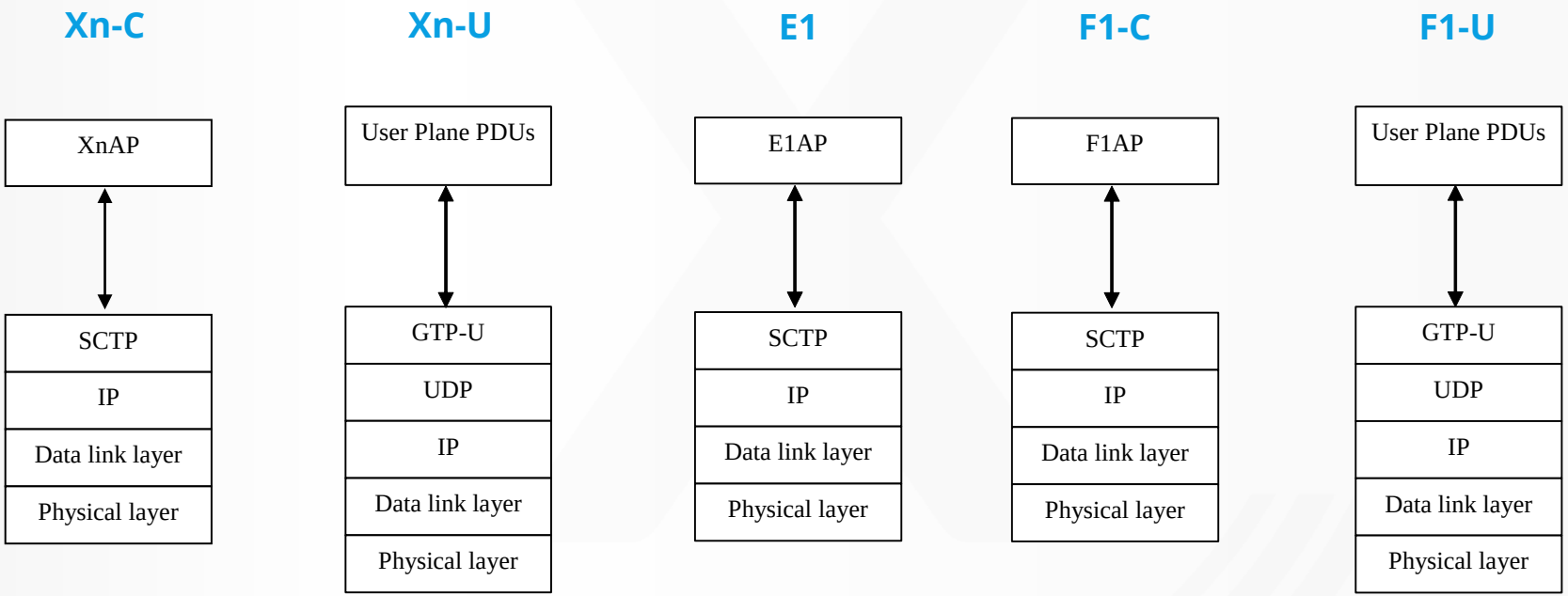


- **Xn** interface between **gNBs**
  - Separate **Centralized Units (CU)** for CP and UP
  - Xn-C between gNB-CU-CPs
  - Xn-U between gNB-CU-UPs
- **E1** between gNB-CU-CP and gNB-CU-UP
- **F1** between CU and Distributed Units (DU)
  - Different F1-C on CP and F1-U on UP
  - F1-C between gNB-CU-CP and gNB-DU
  - F1-U between gNB-CU-UP and gNB-DU

3.2. Radio Access Network

3.2.3. Interfaces

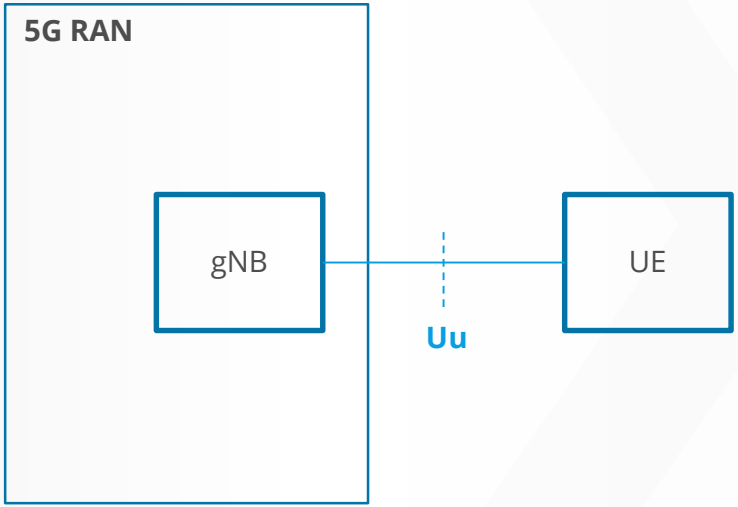
- **Protocol stacks** used for each of the RAN internal interfaces [26-28]:

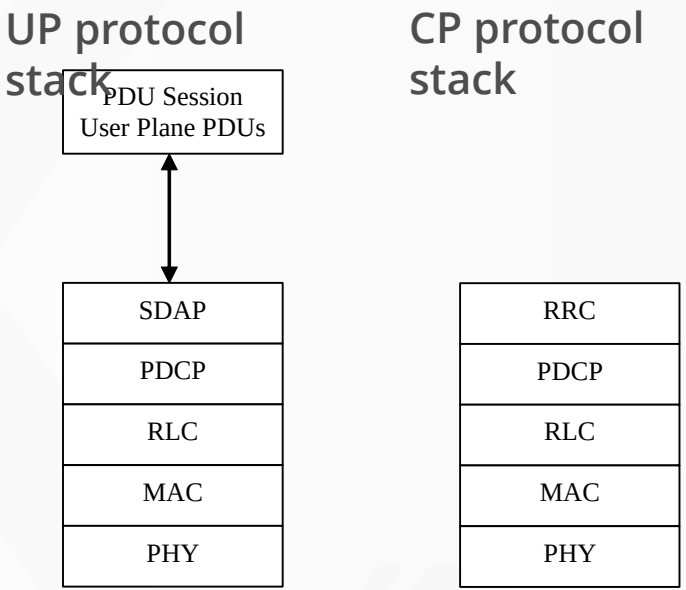


3.2. Radio Access Network

3.2.3. Interfaces

- Interfaces between the **RAN** and users [29]:





- **Uu** is the **air interface** between gNB and UE (previous section).
- Both protocol stacks are combined in the same radio link.

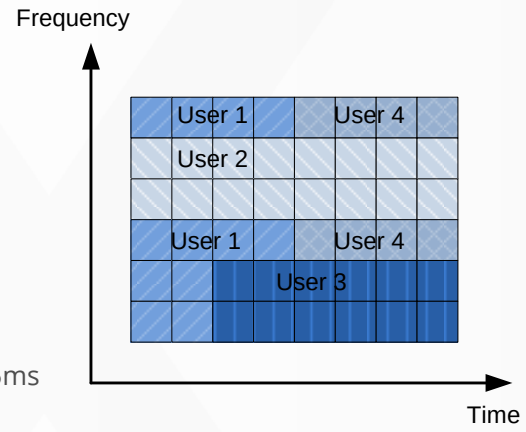
3.3. Protocols and RRM

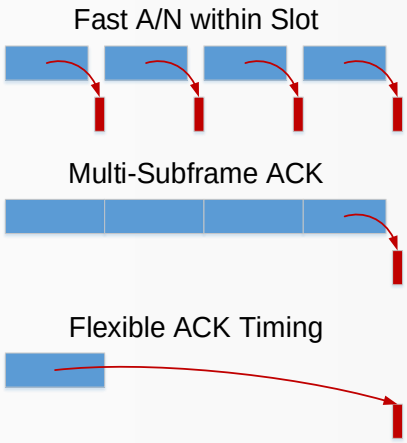
3.3.1. Flexible Resource Allocation Methods

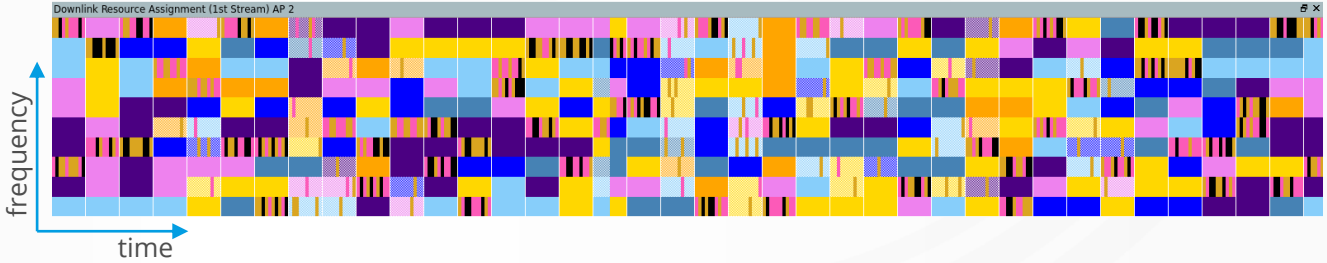
Q: What is new compared to LTE?

A: More of almost everything.

- 5G New Radio is based on MIMO-OFDM
- Flexibility in **time**, **frequency** and **space**.
- Frame structure:
  - Dynamic TDD
    - Theoretically decided on slot basis.
  - Flexible frame structure
    - Smaller time granularity of RRM down to 0.125ms
    - 0.125ms, 0.25ms, 0.5ms, 1ms.
    - Not only one slot length.
    - HARQ feedback configurable and even in the same slot possible.
    - Puncturing of high priority traffic into lower priority traffic.







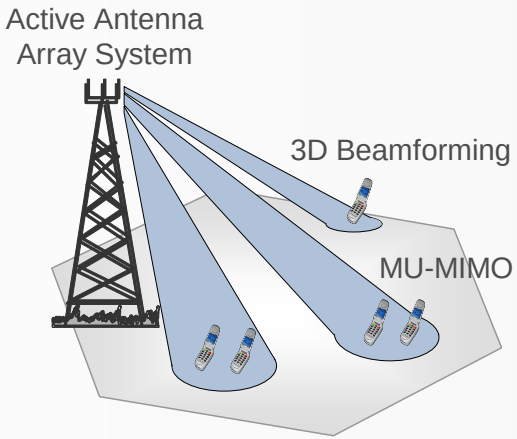
3.3. Protocols and RRM

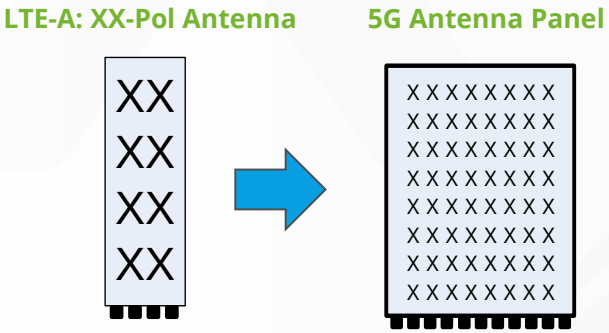
3.3.1. Flexible Resource Allocation Methods

Q: What is new compared to LTE?

A: More of almost everything.

- **Spatial multiplexing**: massive antenna arrays.
  - IMT-2020:
    - Up to 256 for $fc \leq 6$ GHz
    - Up to 2014 for $fc \geq 30$ GHz
  - Already started for LTE with "FD-MIMO"
  - Up to 8 layers.
  - Extreme beamforming and MU-MIMO multiplexing on same time-frequency resource
    - Fully digital
    - Hybrid
    - Analog (no MU-MIMO)





Contents

4. 5G XCAST solution for PTM

- Section related to the studies performed in **Deliverable D3.2** (PTM solution).
  - Final version will be released in **November 2018**.

4.1. Air interface design

- Mixed mode: single-cell (SC-MM) and multi-cell (MC-MM).
- Terrestrial Broadcast mode.

Multicast (one to many)
Broadcast (one to all)

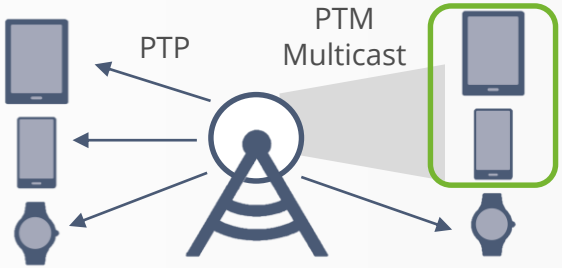
4.2. Radio Access Network design

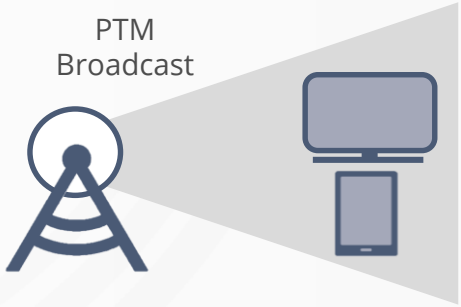
- RAN Architecture to enable broadcast/multicast.
- New interfaces for 5G-Xcast
- Multicast Content Delivery in SC/MC-MM
- Synchronization for SFN area.

4.3. Future work

4.1. Air Interface Design

- 5G-Xcast solution
  - Multicast Mixed Mode
    - Switched PTP/PTM multicast
    - Mixed downlink and uplink
    - High commonality with PTP
    - 2 types of multicast:
      - Single cell (SC-MM)
      - Multiple cells (MC-MM)
  - Terrestrial Broadcast Mode
    - PTM Broadcast only
    - Downlink only
    - Nationwide static SFN areas

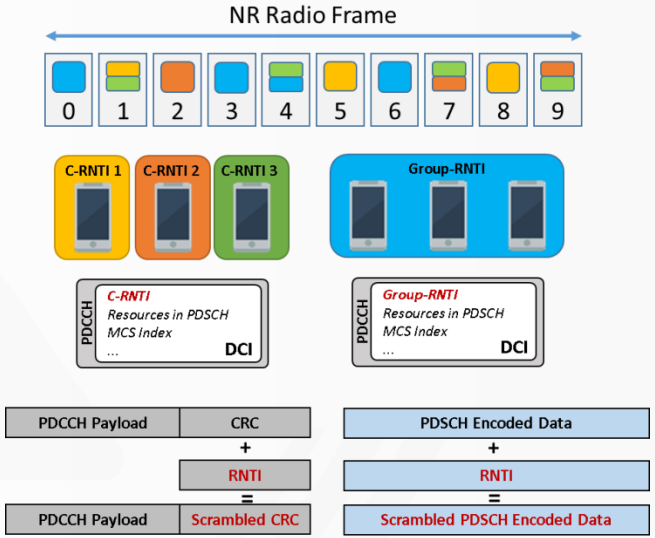




4.1. Air Interface Design

4.1.1. Single-Cell Mixed Mode (SC-MM)

- Enables the **dynamic allocation** of PTP and multicast resources within a single cell.
- Reuses as much as possible the existing 5G NR PTP air interface.
- Some changes are required due to 5G NR PTP air limitations:
  - **C-RNTI**
    - Acquired in RRC connection.
    - Scrambles CRC in PDCCH and PDSCH transmissions.
      - C-RNTI is unique for each UE.
      - Not valid for PTM communications.
    - **Solution**:
      - **Group-RNTI (G-RNTI)** is introduced to enable common transmissions to several UEs.
      - Acquired similarly to C-RNTI.
      - Coexists with C-RNTI.



4.1. Air Interface Design

4.1.1. Single-Cell Mixed Mode (SC-MM)

Required modifications:

- DCI Format
  - DCI formats in 5G NR are designed just considering PTP.
  - **Solution**: New DCI formats to be included for PTM.
- DCI transmissions
  - One DCI is transmitted within a CORESET for each UE.
  - Considerable PDCCH overhead would be introduced for PTM.
  - **Solution**: One DCI transmitted within an only CORESET for a group of UEs interested in the same content. It implies an overhead reduction.

Number of UEs	Number of REs PTP	Number of REs SC-MM	Overhead Reduction (%)
2	144	72	50%
3	216	72	66%
5	360	72	80%
10	720	72	90%

- Feedback retransmissions
  - Feedback mechanisms are only defined for PTP transmissions.
  - Group link adaptation and MCS selection to enable group HARQs will be further reviewed.

4.1. Air Interface Design

4.1.2. Multi-Cell Mixed Mode (MC-MM)

- Enables **coordinated transmissions** across multiple cell areas.
- Based on SC-MM.
- MC-MM introduces some changes due to SC limitations:
  - **Single Frequency Networks (SFNs)**
    - Reuses 5G NR PTP numerology.
    - Maximum Inter-Site Distance (ISD) of 1.4 km.
    - Suitable for use cases such as stadiums, campus, malls or critical communications in urban scenarios.

μ	SCS (kHz)	Type CP	T_{CP} (μs)	ISD (km)
0	15	Normal	4.69	1.41
1	30	Normal	2.34	0.7
2	60	Normal	1.17	0.35
		Extended	4.16	1.25
3	120	Normal	0.59	0.18
4	240	Normal	0.29	0.09

  - **Cell Scrambling Sequence** ($N_{\mathrm{ID}}^{n_{\mathrm{SCID}}}$)
    - Defines control and data location as well as DMRS values.
    - Can be defined in two ways:
      - Depending on the PSS and SSS, it can be equal to Cell ID: $N_{\mathrm{ID}}^{n_{\mathrm{SCID}}} = N_{\mathrm{ID}}^{\mathrm{cell}}$
      - Initializing to a certain value: $N_{\mathrm{ID}}^{n_{\mathrm{SCID}}} \in \{0,1,\ldots,65535\}$
    - Transmissions of different sequences for each cell avoid SFN gains.
    - **Solution**: Initializing the same cell scrambling sequence for all cells.
  - **Coordinated retransmissions**
    - Feedback retransmissions are done from one single gNB.
    - Coordinated retransmissions can be performed from more than one gNB depending on the UE location.

4.1. Air Interface Design

4.1.3. Terrestrial Broadcast Mode (T-Broad)

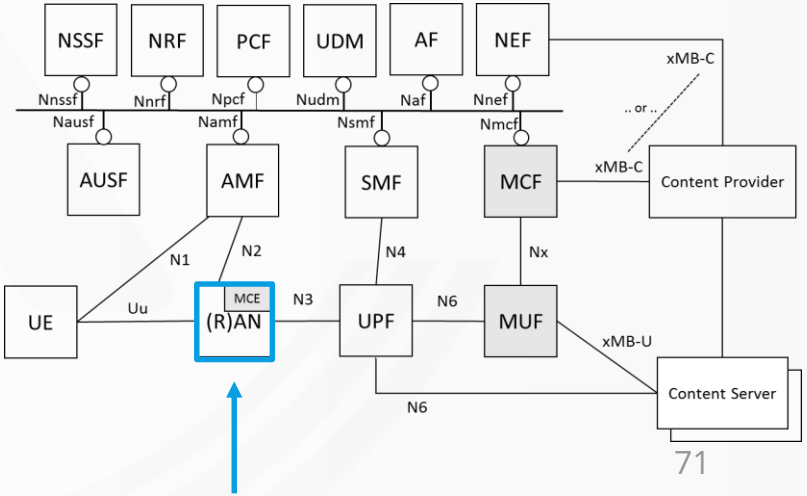
- 5G-Xcast will study solutions for Terrestrial Broadcasting from a **5G NR perspective:**
  - 5G NR brings different features and structures w.r.t. LTE.
  - Possibility to design a new system without constraints from legacy mechanisms.
- The **T-Broad** solution will reuse as much as possible of the NR PTM design to enable:
  - Large area coverage (up to national scale)
  - Integration from LPLT to HPHT networks with different ISDs.
  - Keeping KPI performance of NR eMB when possible in terms of:
    - High mobility performance
    - High spectral efficiency and data rates
- Enabling **SFN** in NR is a concept to be studied.
  - **Proposal in 3GPP for Negative numerologies or mini-slots**
    - Subcarrier spacings lower than 15 kHz.
    - Extended CP.
    - ***Trade-offs? Constraints?***

μ	SCS (kHz)	T_U (µs)	Ext. CP (μs)	ISD (km)
0	15	66,67	16,66	5
-1	7.5	133,33	33,33	10
-2	3,75	266,67	66,66	20

4.2. Radio Access Network Design

4.2.1. RAN Architecture to Enable MC/BC

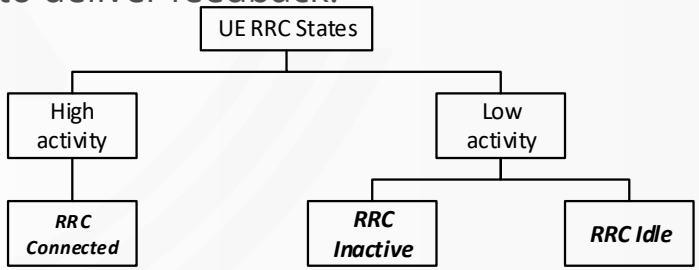
- Modifications to the overall **RAN** architecture need to be addressed in order to enable **multicast / broadcast** capabilities.
- Design principles behind **5G-Xcast RAN**:
  - A flexible and adequate system to support **several verticals** inside the **same framework**.
  - Support for **dynamic switching** between **NR PtP, SC-MM and MC-MM** based on UE activity, mobility and geographical location, alongside seamless transition within delivery modes.
    - Allowing feedback from users to perform link adaptation to optimize QoE.
    - Delivery mode should be transparent to UEs.
  - Support for reconfigurable **large SFN areas** with Core involvement, targeting ROM devices.
  - Support for PTP and PTM **data multiplexing**
    - Reserving subframes for broadcast services → optional
  - Use NR RAN Rel'15 architecture design as the starting point.



4.2. Radio Access Network Design

4.2.1. RAN Architecture to Enable MC/BC

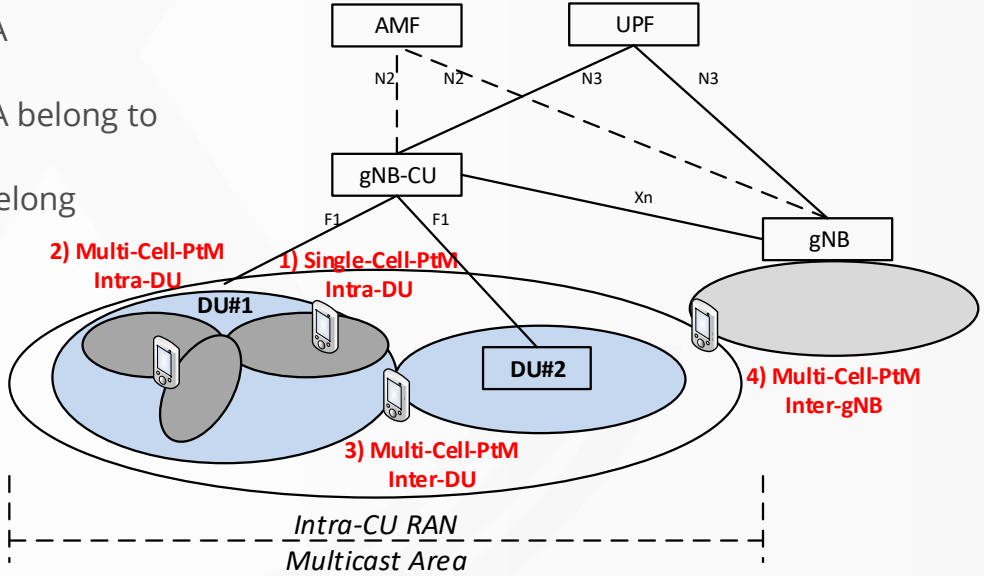
- To fulfil the aforementioned criteria, the **RAN Multicast Area (RMA)** mechanism is introduced.
  - RMA is the region with cell coverage where multicast data is being transmitted.
  - The coverage of the cells who are broadcasting a determined service.
  - SFN operation is allowed inside the RMA.
- RMA managed by the **master/anchor gNB**
  - Although using cells in a secondary gNB is allowed.
- UE can move inside a RMA and still receive the multicast transmission with acceptable QoE.
  - If the UE is close to the edge of the RMA, gNB can add the neighbour cell to the RMA to avoid service interruption.
  - gNB can decide to switch the new user back to unicast at the new cell if having RMA there is not efficient.
- RAN can force a percentage of UE receiving media over unicast (RRC_Connected) to **switch** into multicast (RRC_Inactive). Some UEs stay in RRC_Connected to deliver feedback.
- RRC_Connected UEs are **allowed** to send their feedback to the gNB, but RRC_Inactive UEs **are not**.



4.2. Radio Access Network Design

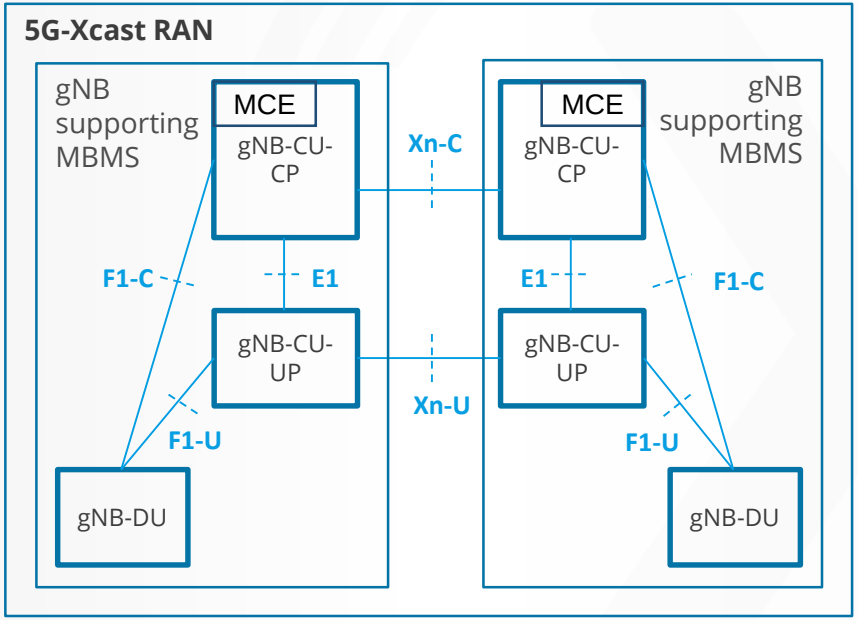
4.2.1. RAN Architecture to Enable MC/BC

- RMA can add or remove cells dynamically.
- RMA can be broadcasted on disjointed areas.
- SFN operation should be available in multi-cell scenarios
- **Types** of RMA deployment:
  1. SC-MM RMA → RMA only covers uncoordinated cells.
  2. RMA Intra-DU → All cells forming the RMA belong to the same DU.
  3. RMA Inter-DU → All cells forming the RMA belong to two or several DUs.
  4. RMA Inter-CU → Cells forming the RMA belong to two or more CUs.



4.2. Radio Access Network Design

4.2.2. Interfaces for 5G-Xcast

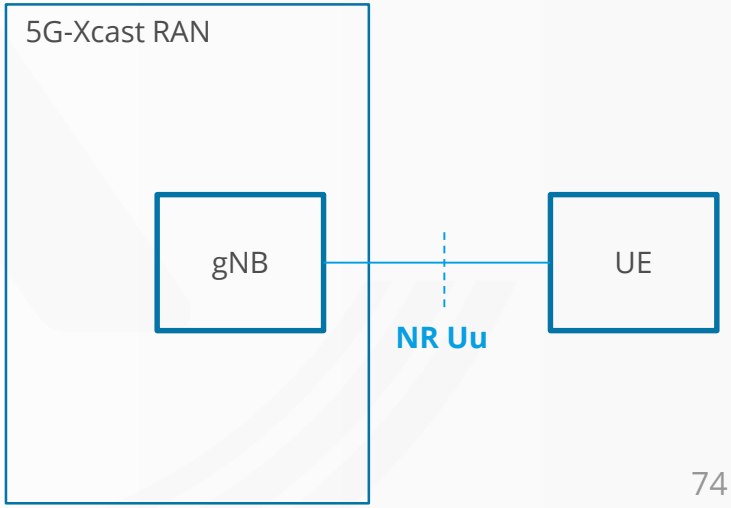


RAN internal interfaces:

- Reuse the current **5G** interfaces.
- However, they need to be enhanced in order to support multicast/broadcast.
- **Additional interfaces** are necessary for some WP4 proposals (M1-NG for Architecture 2).

External interface towards the UE:

- New logical channel introduced for **T-Broad** without feedback
- **SC/MC-MM** new logical downlink channel with feedback

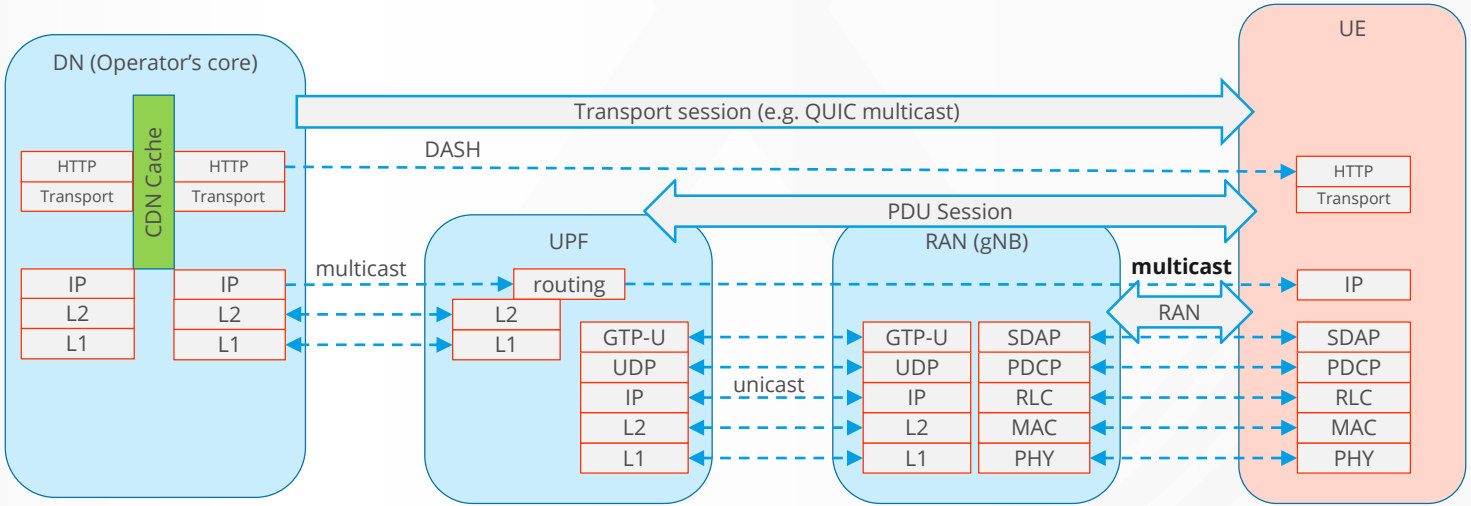


4.2. Radio Access Network Design

4.2.3. Multicast Content Delivery in SC/MC-MM

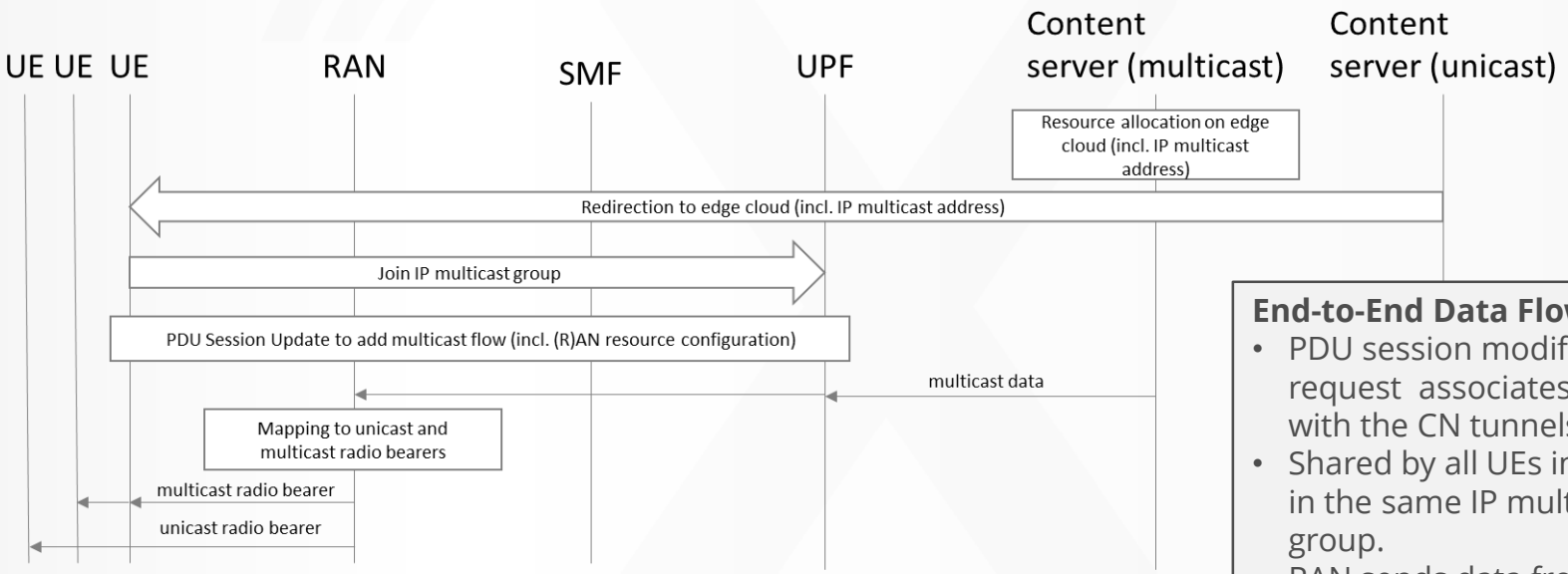
Multicast User Plane:

- The **NG-RAN** receives information about UE's interest to receive multicast data as part of PDU session procedures.
- Multicast data to the **IP multicast group** is delivered to **NG-RAN** over a **N3** tunnel.
- The **NG-RAN** knows for each **N3** tunnel at least the identities of UEs, which are interested to receive the multicast data.



4.2. Radio Access Network Design

4.2.3. Multicast Content Delivery in SC/MC-MM



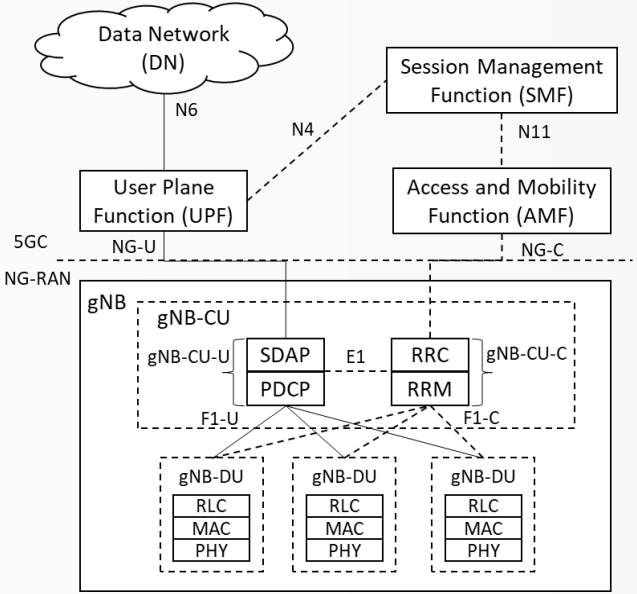
End-to-End Data Flow

- PDU session modification request associates the UE with the CN tunnels.
- Shared by all UEs interested in the same IP multicast group.
- RAN sends data from these tunnels to the UEs according to the association using a set of unicast and multicast radio bearers.

4.2. Radio Access Network Design

4.2.4. Synchronization for SFN Area

- SFN operation has special requirements, fulfilled by **RAN**:
  - **Common scheduling** between synchronized transmitters.
  - **Same radio parameters** across transmitters.
- In **5G-Xcast**, for multi-cell RMA, small-SFN should be possible **without core** involvement.
- Different SFN scenarios occur depending on the cells involved:
  - All cells are inside one DU **(Intra-DU SFN)**.
  - Cells are spread over several DU. These DU are under one CU **(Inter-DU SFN).**
  - Cells are spread over several DU. These DU belong to two or more CU **(Inter-CU SFN).**



- **Assumptions** for the detailed analysis of each scenario:
  - Cells under one DU are geographically close to each other → same delays experienced
  - RMA is already deployed on those cells (RMA triggering already covered in previous slides)
  - If synchronization protocol is needed, it is delivered over the User Plane

4.2. Radio Access Network Design

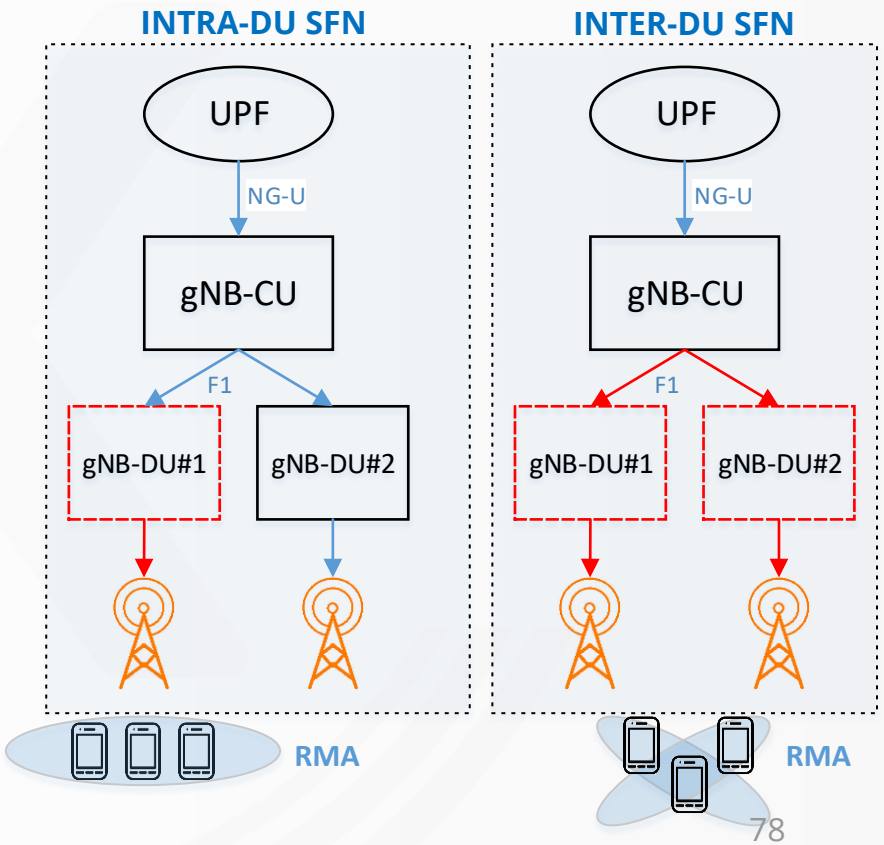
4.2.4. Synchronization for SFN Area

Scenario 1: Intra-DU SFN

- DU MAC entity enforces common scheduling and radio parameters.
- Possible network delays differences are negligible between cells.
  - **No need** of synchronization protocol.

Scenario 2: Inter-DU SFN

- CU enforces common scheduling and radio parameters across cells over F1
- No current specified method in F1 to do this in Rel'15.
- Network delay differences still very small between cells.
  - **No need** of synchronization protocol.

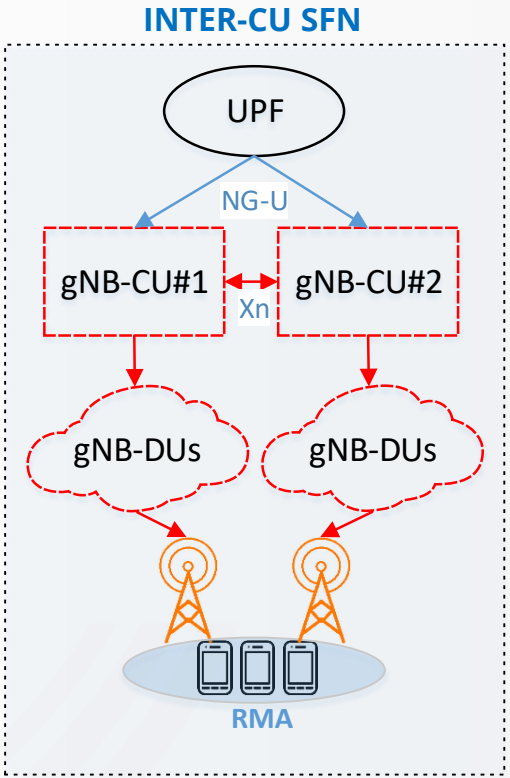


4.2. Radio Access Network Design

4.2.4. Synchronization for SFN Area

Scenario 3: Inter-CU SFN

- Anchor/master CU will enforce common scheduling & radio parameters over **Xn** to the other CUs.
- No current specified method in **Xn** interface to do this in Rel'15.
- CUs besides the Master will experience different delays than the Anchor:
  - Anchor CU Delay = F1 + F1 Proc.Time + Optical Interface
  - Other CU Delay = Xn + Xn Proc.Time + F1 + F1 Proc.Time + Optical
- It might be necessary to use a compensation protocol to take into account this delay difference
  - e.g. SYNC or similar.



Summary

Scenario	Interfaces involved	Expected delay	Notes
Intra-DU	-	Low	gNB-DU applying common scheduling to RRU ensures the SFN operation.
Inter-DU	F1	Low	gNB-CU signals the scheduling via F1 Interface.
Inter-CU	F1, Xn	Medium	Anchor gNB-CU signals the scheduling via Xn Interface. Additional signalling to compensate Xn delay.

- **Changes are required to F1 and Xn interface in order to support SFN operation**

4.3. Future Work

A. Air interface evaluation:

- Link-level simulations for PTM scenarios.
- Coverage and system-level simulations. Comparison with 5G Rel'15.

B. RAN design:

- Define the final RAN architecture for 5G to enable broadcast and multicast PTM transmissions.
- Identify dependencies between Core and RAN for T-Broad delivery mode.
- Supporting a wide range of use cases.

C. Protocols and RRM:

- Flexible Resource Allocation Methods.
- Study on the feasibility and value of feedbacks for link adaptation or cross-layer optimization.
- Study on efficient use of radio transmission methods.
- Propose implementation guidelines for the deployment of 5G broadcast networks.

D. Prototypes

- 5G-Xcast Software Defined Radio (SDR) RAN platform.
- Comprehensive 5G-Xcast RAN software emulator.

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Thank You

Any Questions ?