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On the road to

Use cases, technology & EMF standardization

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On the road to 5G use cases

1 Video surveillance & analytics

2 Machine remote control

3 Assisted & autonomous vehicles

4 Cloud robotics & process automation

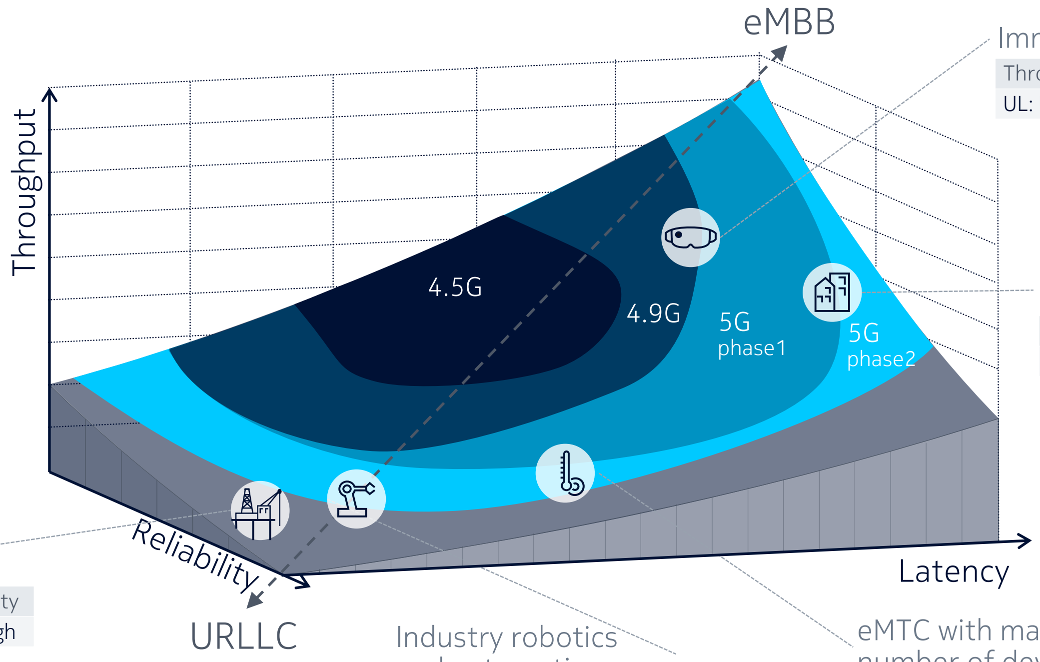
5 eHealth

6 Fixed Wireless Access

7 Immersive experience

8 Smart Stadium

Requirements driven by use cases
Evolution of throughput, reliability and latency



Immersive 360

Throughput	Latency	Reliability
UL: U-high / DL: high	50-100 ms	Medium/high

FWA

Throughput	Latency	Reliability
U-high	15-200 ms	V. High

Mobile Tele-Operation (Vehicle and drone)

Throughput	Latency	Reliability
Varies	1-10 ms	Very high

Industry robotics and automation

Throughput	Latency	Reliability
Varies	1-10 ms	Very high

eMTC with massive number of devices

Throughput	Latency	Reliability
Low	10-100 ms	U. High

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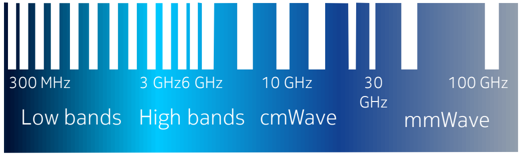
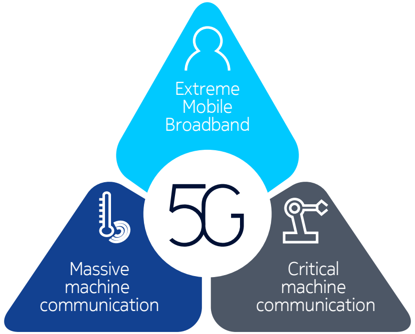
Technology enablers for 5G New Radio (NR) interface and RAN

New **spectrum** options — 1

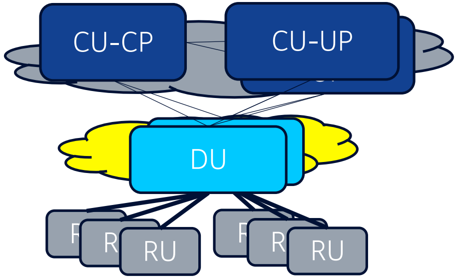
Massive capacity and throughput





Cloud native — 5

Flexible architecture



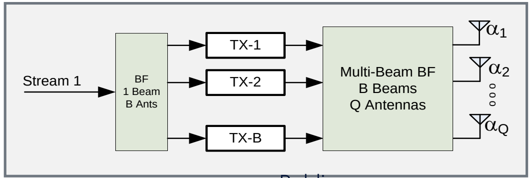
Flexible radio design, dynamic optimization — 2

For all use cases – also mission critical, high capacity, flexibility, new revenue streams

Radio	LTE	New Radio (NR)		
Bands	<4 GHz	< 3GHz	2-6 GHz	> 6 GHz
Multiple access	CP-OFDM / SC-OFDM	CP-OFDM / CP-OFDM (+ SC-OFDM)		
Duplex	FDD, TDD	FDD	TDD	
Sub-carrier (kHz)	15	15, 30, 60	15, 30, 60	60, 120
Carrier BW (MHz)	1.4 .. 20	5 .. 40	5 .. 100	50 .. 400

Massive MIMO and Beam Forming — 3

Massive capacity , improved end-user experience, cell edge throughput



Multi-connectivity and aggregation — 4

End-user experience, extreme mobility, robustness and ultra reliability

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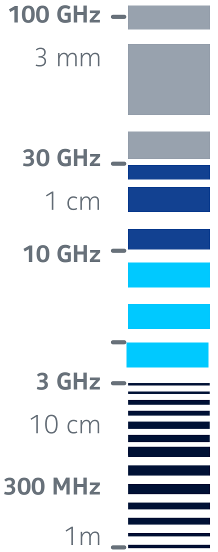
Spectrum: 5G bands from 300 MHz to 100 GHz

First bands		More spectrum x	More beamforming x	More cell sites =	A lot more capacity
		Bandwidth	Beam size	Cell density	Capacity
39 GHz	mm waves 40-100 GHz	Up to 2 GHz	Very small Very narrow beams	Very dense small cell	Ultra high capacity booster
26/28 GHz	cm/mm waves 24-40 GHz	Up to 400 MHz	Small antenna Narrow beams	Dense small cell	Capacity booster
3.5 GHz	3-6 GHz	Up to 100 MHz	Medium antenna Medium beams	Urban Macro and small cell	Coverage and high capacity
600-900 MHz	<3 GHz	Up to 20 MHz	Large antenna Wide beams	All Macro and urban small cell	Coverage and new services



Note: ITU-R is not considering bands between 6 and 24 GHz for IMT2020

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Different spectrum for different use cases
3 key spectrum ranges start to emerge

Cell range ↑ / Data rate ↓

Spectrum range	Bands	Coverage	Peak Data rates	Bandwidth	Use Cases
Low band < 1 GHz	• 600 MHz (US) • 700 MHz • 900 MHz	• Deep indoor • ~ 10 km	~100 Mbps	FDD 2x10 MHz	• Deep indoor coverage for sensors and IoT (mMTC) • TMO US started to promote also MBB
Mid-band 3 – 6 GHz	• 3.4-3.6 GHz (B42) • 3.6-3.8 GHz (B43) • 4.5-4.9 GHz (JPN)	• Same grid as LTE1800 • ~1 km	~1 Gbps	TDD <100 MHz	• 5G eMBB coverage on LTE grid • Major commercial 5G launches are expected in this spectrum range (JPN, KRN, CHN, EUR)
mmWaves > 24 GHz	• 26 GHz (EUR) • 28 GHz (KOR, US) • 39 GHz (US)	• Hot spots • Line of sight • 100 m	~10 Gbps	TDD <1 GHz	• Extreme data rates for e.g. VR in local areas like stadiums • Used in US due to lack of 3-6 GHz • Used also in KOR Olympics trial

Global snapshot of 5G spectrum

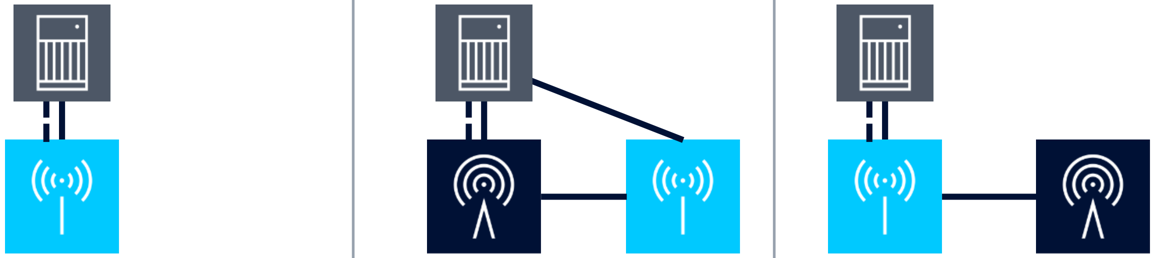
Around the world, there is a pattern of band allocation

1. Spectrum

New 5G band
- Licensed
- Unlicensed / shared
- Existing band

<1GHz	3GHz	4GHz	5GHz	24-28GHz	37-40GHz	64-71GHz
600MHz (2x35MHz)	2.5GHz (LTE B41)	3.5GHz (150MHz)	5.9–7.1GHz	27.5-28.35GHz	37-37.6GHz 37.6-40GHz	64-71GHz
600MHz (2x35MHz)		3.5GHz (150MHz)	5.9–7.1GHz	27.5-28.35GHz	37-37.6GHz 37.6-40GHz	64-71GHz
700MHz		3.4–3.8GHz	5.9–6.4GHz	24.5-27.5GHz		
		3.4–3.8GHz		26GHz, 28GHz		
		3.4–3.7GHz		26GHz, 28GHz		
		3.46 –3.8GHz		26GHz		
		3.6–3.8GHz				
		3.3 –3.6GHz	4.8 –5GHz	24.5-27.5GHz	37.5-42.5GHz	
		3.4–3.7GHz		26.5-29.5GHz		
		3.6–4.2GHz	4.4–4.9GHz	27.5-29.5GHz		
		3.4–3.7GHz		28GHz	39GHz	

Stand-Alone (SA) and Non-Standalone (NSA)
3GPP background – New Radio (NR) functionality



Feature	Standalone (SA)	Non-standalone (NSA)	
Master carrier	NR	LTE and eLTE	NR
Secondary carrier	-	NR	eLTE
Core choice	5G core (5GC)	4G EPC or 5G core (5GC)	5G core (5GC)
Operator perspective	Simple, high performance overlay	Leveraging existing 4G deployments	
Vendor perspective	Independent RAN product	Requires tight interworking with LTE	
End user experience	Peak bitrate set by NR Dedicated Low Latency transport	Peak bitrate is sum of LTE and NR Latency impacted if routed via LTE master	

Flexible radio design

“New Radio” (NR) numerology building on LTE

Radio	LTE	New Radio (NR)		
Bands	<4 GHz	< 3GHz	2-6 GHz	> 6 GHz
Multiple access	CP-OFDM / SC-OFDM	CP-OFDM / CP-OFDM (+ SC-OFDM)		
Duplex	FDD, TDD	FDD	TDD	
Sub-carrier (kHz)	15	15, 30, 60	15, 30, 60	60, 120
Carrier BW (MHz)	1.4 .. 20	5 .. 40	5 .. 100	50 .. 400
Carrier loading	90%	90 .. 97%	90 .. 98%	95%
Slot per 10ms frame	10	10-20	10-80	80
Channel codes	Turbo	LDPC (plus Polar for PBCH and PxCCH channels)		

NR radio interface: a more flexible OFDM than LTE

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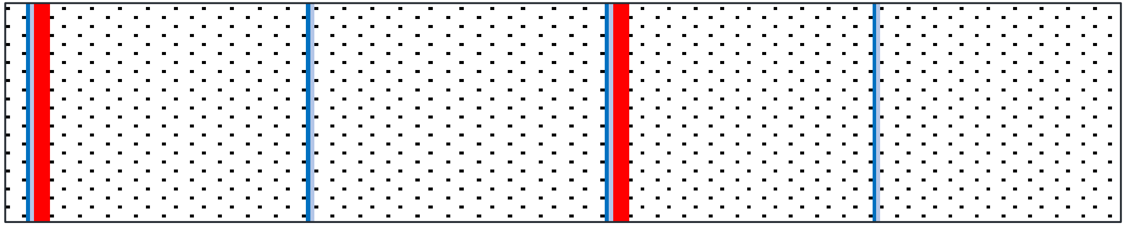
Flexible radio design

Lean carrier also offers base station energy savings

- = Primary synchronization
- = Secondary synchronization
- = Broadcast channel
- = LTE cell reference signals

LTE



Very limited capability for base station energy savings due to continuous transmission of cell reference signals

- **Cell specific reference signal transmission 4x every millisecond**
- **Synchronization every 5 ms**
- **Broadcast every 10 ms**

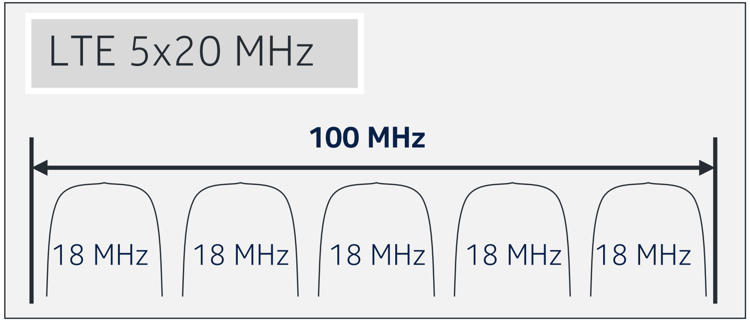
NR

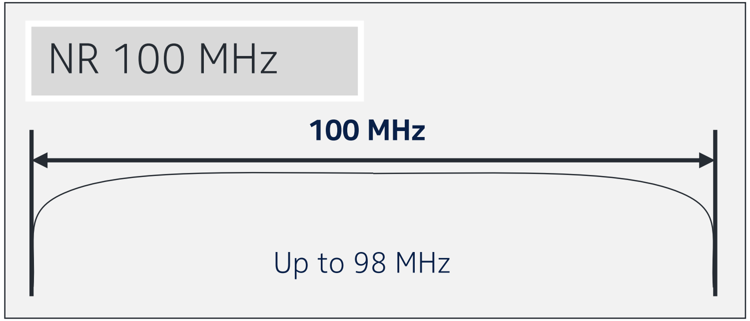
5G enables advanced base station energy savings

- **No cell specific reference signals**
- **Synchronization every 20 ms**
- **Broadcast every 20 ms**
- **Adjustable slot >20 ms planned**

5G Enhances Spectral Utilization

Example: loading within 100 MHz spectrum allocation

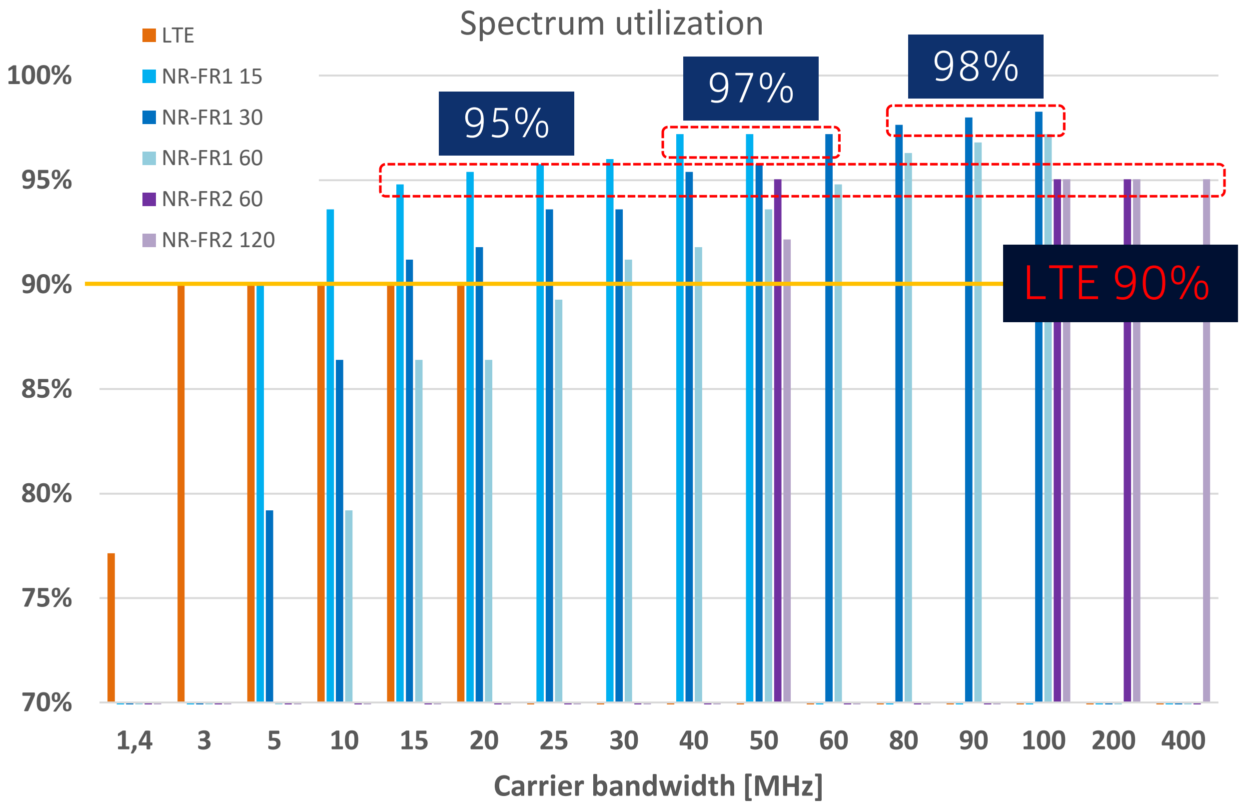




More efficient than multicarrier LTE

- LTE limited to 100 PRB per 20 MHz carrier (i.e. 90% of carrier bandwidth)
- NR supports wider carriers and larger transmit BW (up to 98% of carrier BW)
- No unnecessary guard bands between narrow carriers

5G Spectrum Utilization up to 98%



5G spectrum utilization is up to 98% of carrier bandwidth 40-100 MHz

LTE utilization maximum 90%

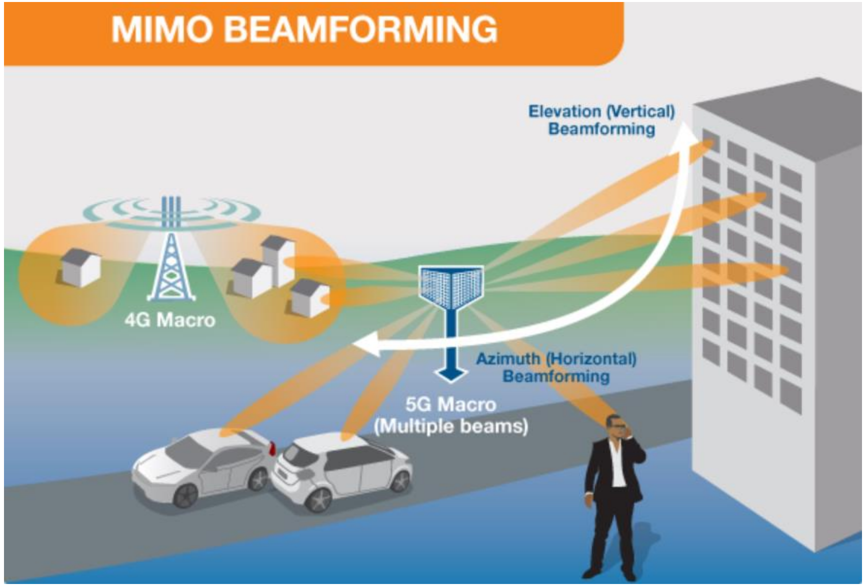
Offers up to **+8%** improvement in max spectrum utilization

Scalable Massive MIMO and Beam Forming

Bringing the benefits of large antenna arrays without overburdening devices

Roles

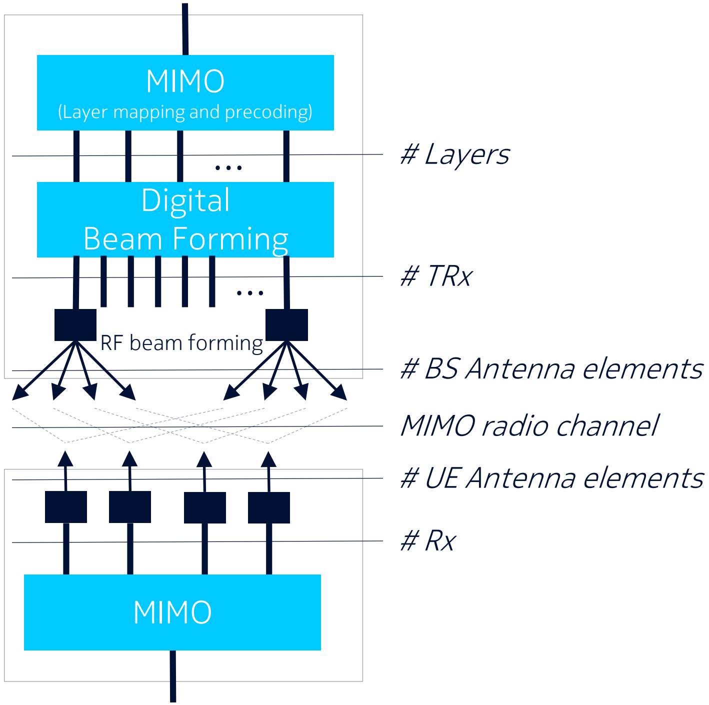
- Coverage, especially with high bands
- Capacity and performance
- Spectrum efficiency, especially in lower bands



[Source: www.emfexplained.info]

Massive MIMO

MIMO and beam forming dimensions



MIMO layers

- Sets total number of parallel data paths in sector for SU- and MU-MIMO
- Determines overall sector capacity limits

Transmitter / Receiver (TRx)

- Sets number of parallel beams during same TTI

Base station Antenna elements (AE)

- Structured in rows, columns and polarisation (e.g. 8 columns x 8 rows x 2 xpol= 128 elements)
- With digital BF, sets net beam gain

UE Receivers (Rx)

- Sets maximum number of layers towards a given UE for SU-MIMO. 4 Rx minimum for NR

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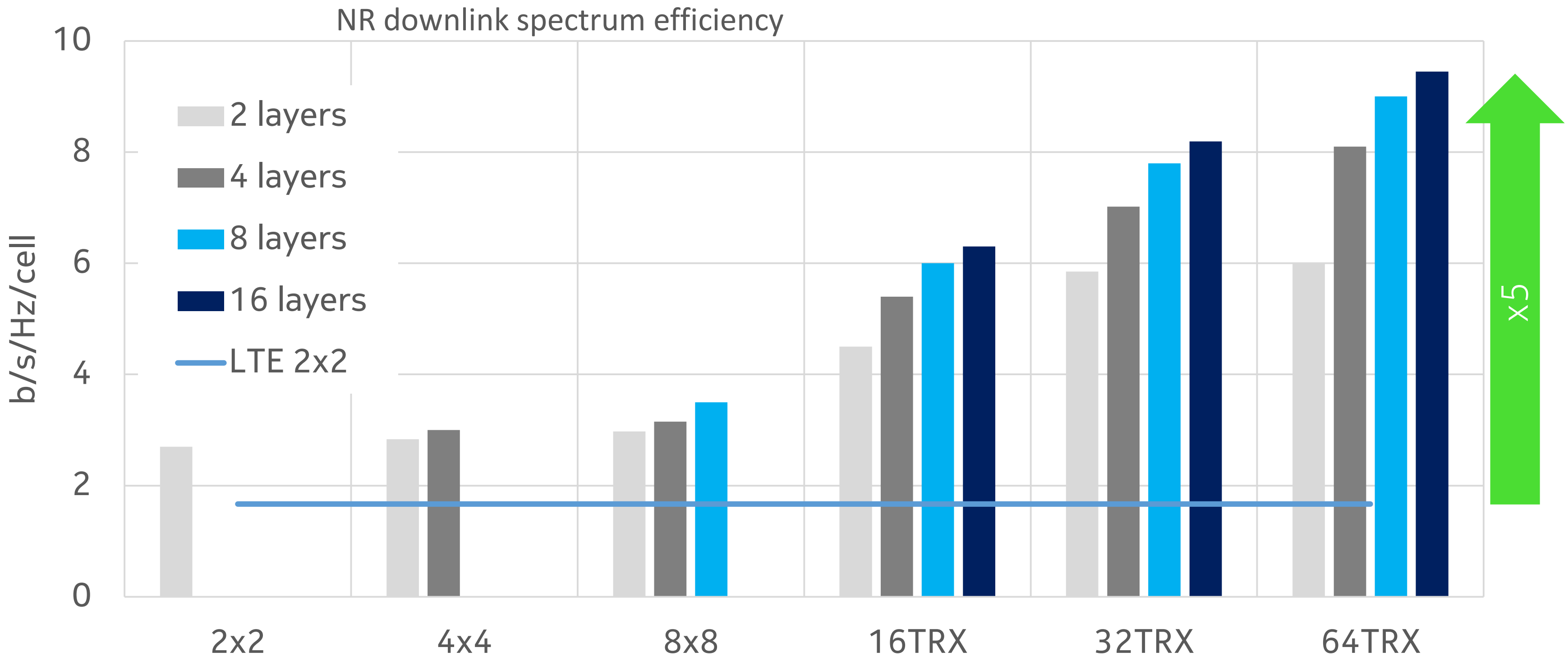
Massive MIMO
Performance estimation



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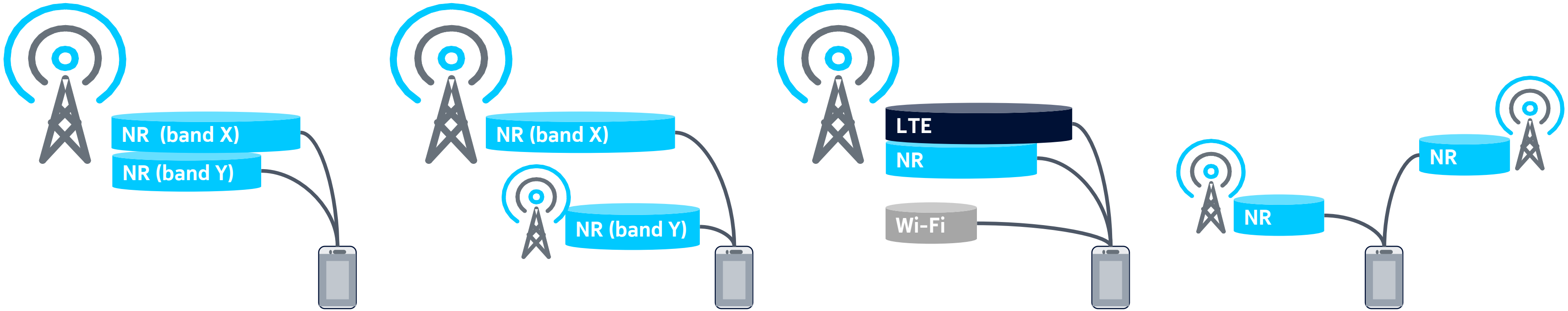
Multi-connectivity and aggregation

Re-using LTE techniques to go beyond handover



Carrier aggregation

Combining carriers intra and inter site

Dual-connectivity between layers

Combining macro and small cells

Dual-connectivity between radios

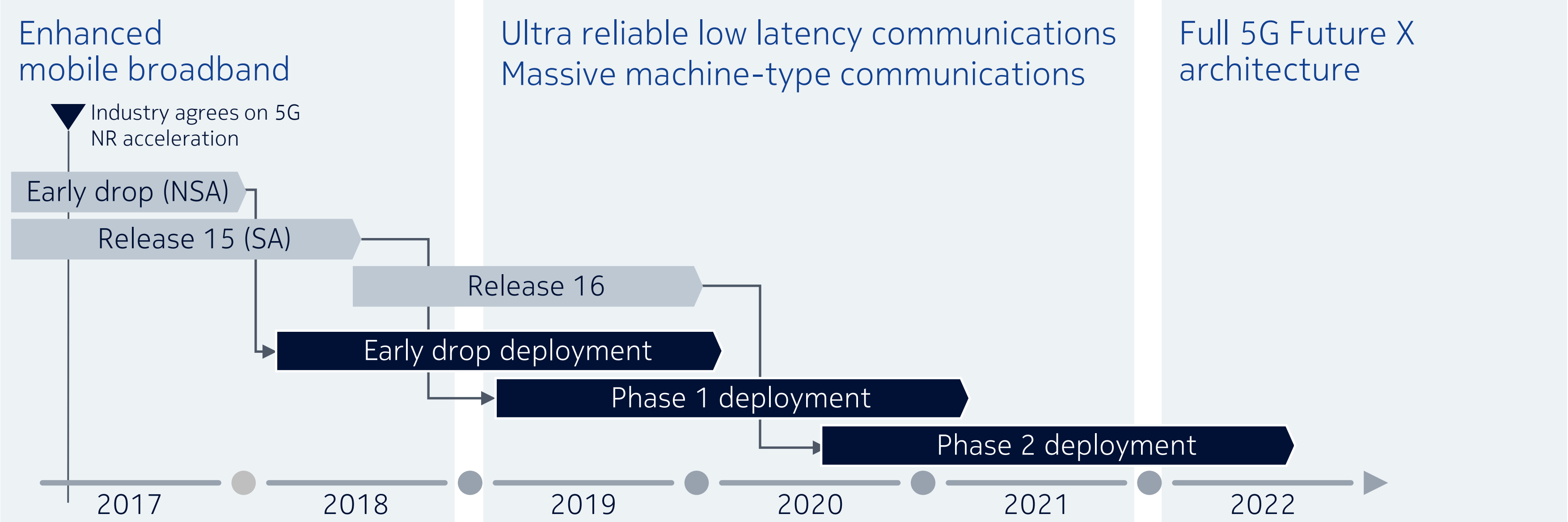
Combining across radio technologies

Coordinated Multi-Point (CoMP)

Combining between cell sites

3GPP standardization timeline

Accelerating 5G NR



Release 15
- 5G Non-Standalone (NSA, option 3) and 5G core (5GC) stage 2 completed Dec. 17, with ASN.1 completed March 18 and key corrections agreed in June, Sept and Dec. 18
- 5G Standalone (SA, option 2), eLTE (option 5), 5GC stage 3 completed June 18 with ASN.1 completed Sept. 18, key cor. agreed in Dec. 18
- “Late Drop” for 5GC NSA solutions (options 4&7) and NR-NR dualco now due March 19 with ASN.1 in June 2019

Release 16 studies completed in 2018, rel. 16 completion due March 2020 with ASN.1 due June 2020

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5G equipment examples

Devices

Gateway box

Small cells

Macros

Macros including beamforming

Backhaul

RF-EMF exposure assessment methods

One worldwide applicable international standard – IEC 62232:2017

Frequency range: 110 MHz to 100 GHz

Single standard including methods for

- Product compliance
- Product installation compliance
- In-situ RF exposure assessment

Simplified rules

- Low power exclusion for product compliance
- Product installation classes
- In-situ RF exposure

Uncertainty

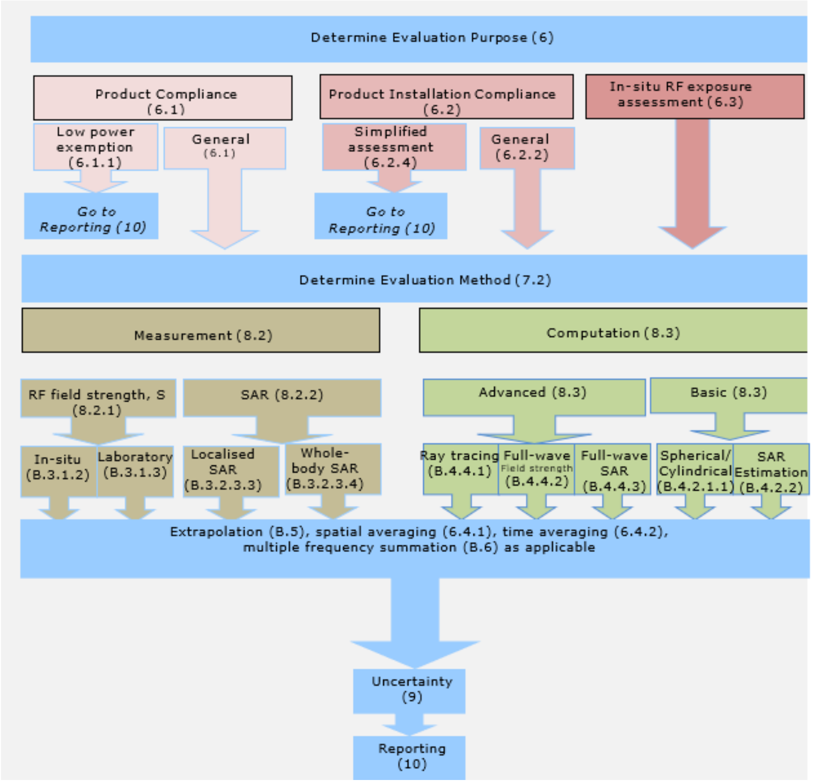
- Target value (best ind. practice) & maximum value

Annex B (normative):

- All details of evaluation methods (measurements & calculations)

Annex F (informative):

- Technologies
- Introduction of compliance based on actual max power



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One practical implementation guide – IEC TR 62669:2019

Uses cases and introduction of compliance based on actual service

§	Base station type	Evaluation type	Evaluation method
6	Small cell (indoor local area BS)	Product compliance (6.1)	SAR measurements (B.3.2)
7	Small cell (outdoor medium range BS)	Product compliance (6.1)	SAR measurement (B.3.2)
8	Small cell	Product installation compliance (6.2)	Field strength computations (B.4)
9	Small cell	In-situ RF exposure assessment (6.3)	Field strength measurements (B.3.1)
10	Street cell	Product compliance (6.1)	SAR (B.3.2) and field strength (B.3.1) measurements
11	Macro site	In-situ RF exposure assessment (6.3)	Field strength measurements (B.3.1)
12	Macro site (inspection with drone)	In-situ RF exposure assessment (6.3)	Field strength measurements (B.3.1)
13	All types of BS	Compliance using the actual maximum transmitted power or EIRP	Field strength measurements (B.3), computations (B.4) & actual max (B.5)
14	Macro (massive MIMO)	Product compliance (6.1)	Field strength computations (B.4)
15	Macro and small cell (massive MIMO)	Product installation compliance (6.2)	Field strength computations (B.4)
16	Small cell (massive MIMO)	Product installation compliance (6.2) and in-situ RF exposure assessment (6.3)	Field strength measurements (B.3) and computations (B.4)
17	Wireless link using parabolic dish antenna	Product compliance (6.1)	Field strength computations (F.11)

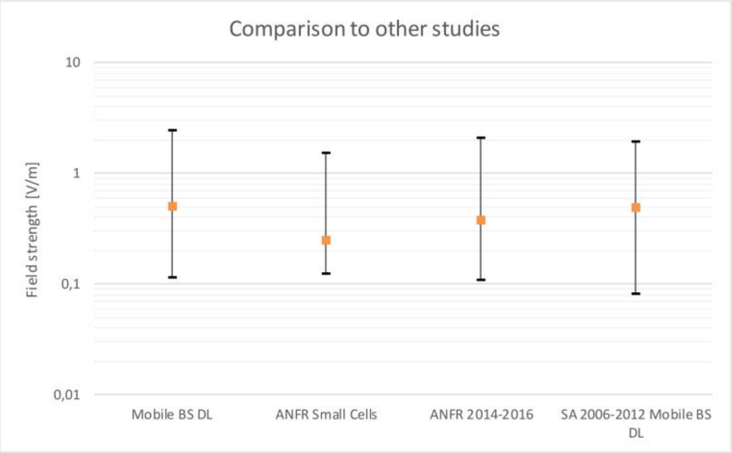
Example: small cells in-situ measurement campaigns
(from IEC TR 62669:2019 – Clause 9)

Measurement campaign A

- Measurements according to IEC 62232:2017 + uplink/downlink statistics
- 9 outdoor sites with medium range small cells in urban furniture

Measurement campaign B

- Measurements according to IEC 62232:2017
- 295 measurement points on 98 sites
- South Africa (80), Amsterdam (16) & Turin (2)
- Indoor (47), Outdoor 2 m to 4 m (30) and Outdoor > 4 m (21)



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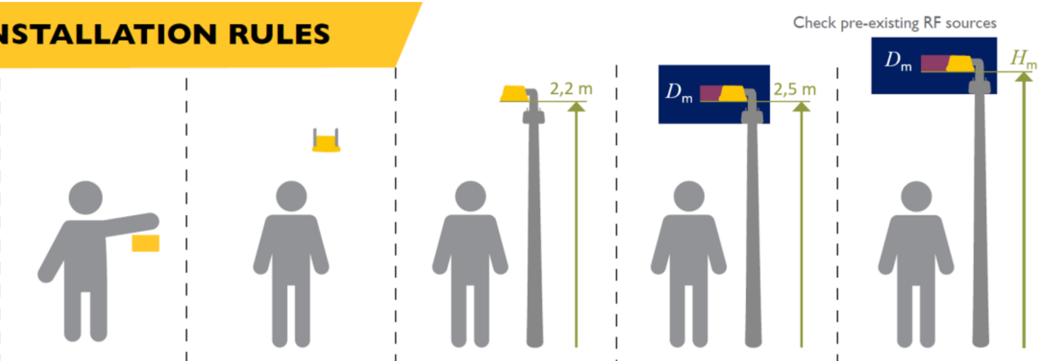
Example: small cells simplified installation classes

(from IEC TR 62669:2019 – Clause 8)

SIMPLIFIED INSTALLATION RULES

From IEC 62232:2017

Installation shall be done according to instructions from the manufacturer or entity putting into service



Installation class	E0	E2	E10	E100	E+
Total EIRP	N/A	≤ 2 W	≤ 10 W	≤ 100 W	No limit
Minimum height above walkway	None	None	2,2 m	2,5 m	H_m (calculation)
Exclusion zone	None, touch compliant	Provided in manufacturer's instructions Small D_m not shown on the picture		Provided in manufacturer's instructions D_m in main lobe direction	
Check pre-existing RF sources	N/A	N/A	N/A	$5D_m$ in main lobe direction D_m in other directions	

→ Confirmed by in-situ measurement campaigns presented in Clause 9

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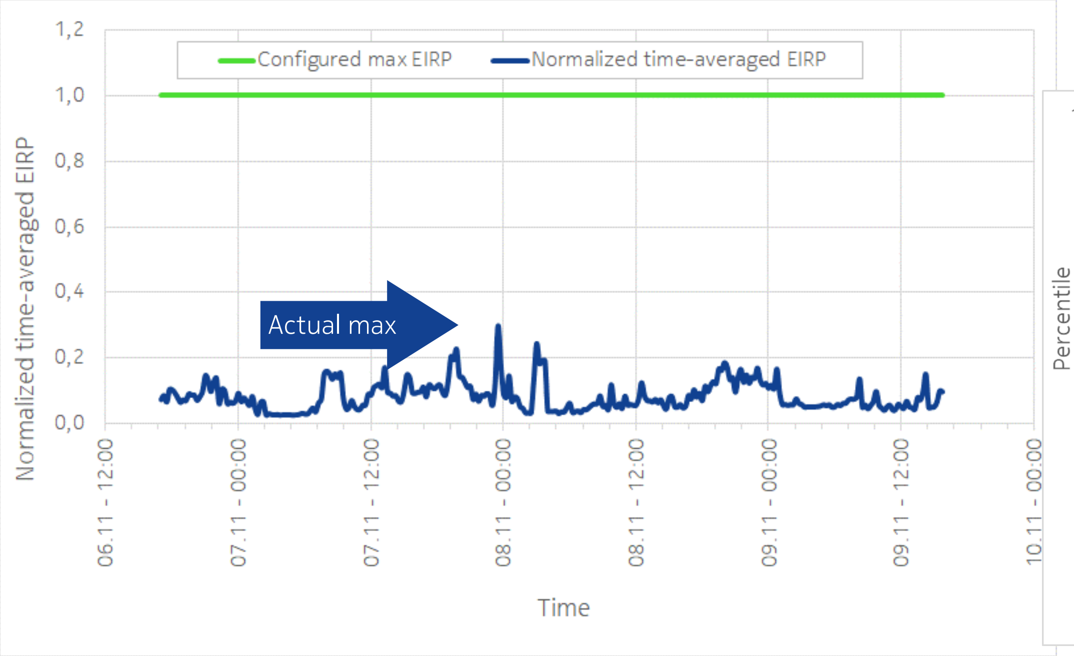
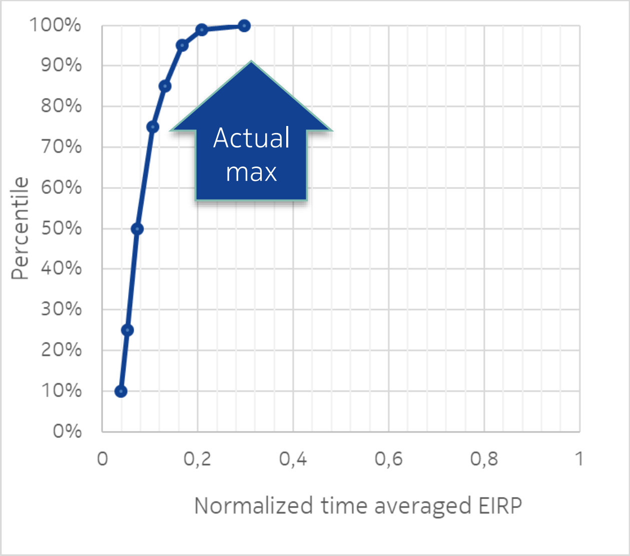
Towards compliance based on actual service

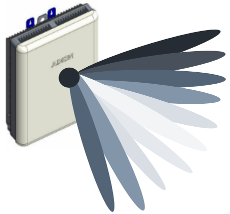
Example of time-averaged EIRP of a 4G cell

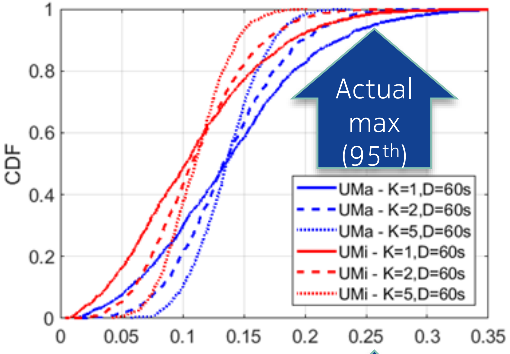




What do we know about new technologies (beamforming) ?

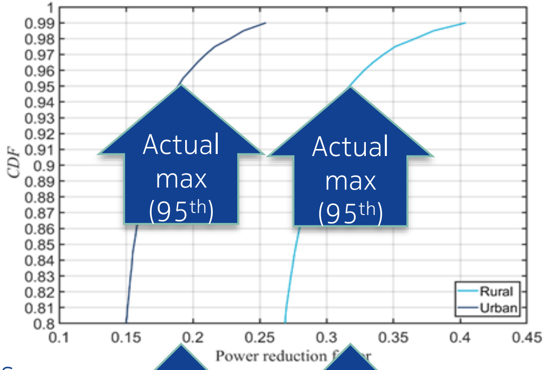
Time & space variation of RF transmitted power with 5G massive MIMO





Source:
IEC TR 62669:2019,
Nokia Bell Labs,
modelling

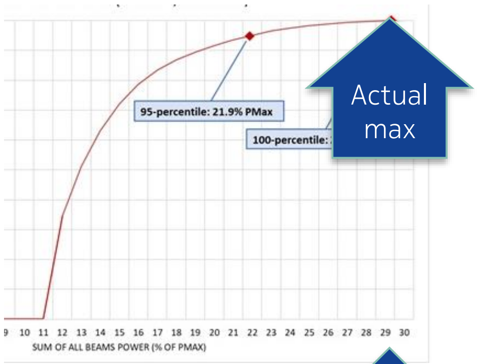
6.0 dB



Source:
IEC TR 62669:
Ericsson,
modelling

7.2 dB

5.0 dB



Source:
IEC TR 62669:2019,
Vodafone,
measurements

5.2 dB

→ The actual transmitted power (time-avg) does not exceed a threshold (= actual maximum threshold)

→ Power reduction factors (actual max threshold/configured max) vary from 5 to 7 dB

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Modelling of the novel compliance approach (from IEC TR 62669:2019)

EIRP is a key parameter of the base station influencing RF exposure level

The time-averaged EIRP is calculated using Equation (1):

$$\mathrm{EIRP}(\theta, \phi) = P_{\mathrm{TXM}} \times F_{\mathrm{TDC}} \times G_{\mathrm{MLB}} \times F_{\mathrm{PDL}}(\theta, \phi) \times F_{\mathrm{G}}(\theta, \phi)$$

Base station installation parameters (fixed configuration) ($P_{\mathrm{TXM}} \times F_{\mathrm{TDC}} \times G_{\mathrm{MLB}}$)

P_{TXM}: maximum configured transmitted power

F_{TDC}: scaling factor representing the technology

G_{MLB}: gain in the main lobe of the antenna

$F_{\mathrm{PDL}}(\theta, \phi)$: Parameter representing the variation of transmitted power due to the traffic

$F_{\mathrm{G}}(\theta, \phi)$: Parameter representing the variation the antenna gain due to beam steering

Implementation of the novel compliance approach (from IEC TR 62669:2019)

Principles

General principle for RF compliance based on actual max power:
[from IEC TR 62669:2019 §13.1.2]

- The real time-averaged transmitted power by BSs during service, called actual transmitted power, is generally below the time-averaged maximum transmitted power.
- Therefore, as a conservative approach, the actual maximum transmitted power can be used to determine the RF compliance boundary provided that the operator is implementing tools ensuring this threshold is not exceeded over time during service.
- These tools can be based on BS counters and features developed by manufacturers to monitor and control the RF transmitted power or EIRP and other relevant characteristics of the BS.
- This applies to all types of BS, whether they are using fixed beams or steerable beams like with mMIMO.

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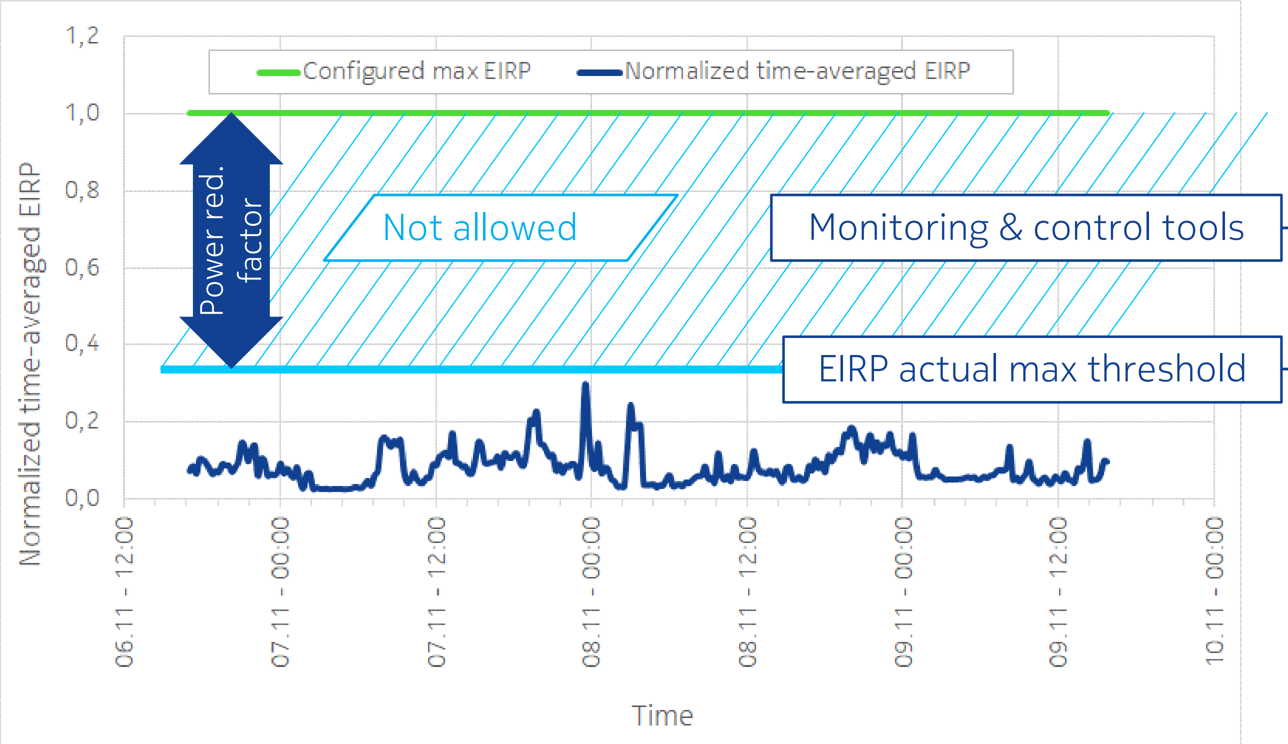
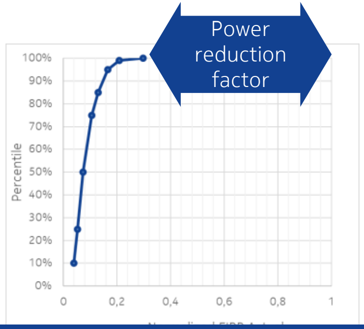
Implementation of the novel compliance approach (from IEC TR 62669:2019)

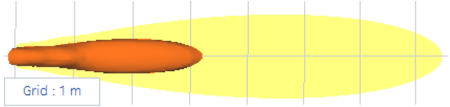
Example with current radio technologies (non beamforming)





Proof points available upon request

EMF compliance boundary assessment and site declaration/approval



Implementation of the novel compliance approach (from IEC TR 62669:2019)

Flow chart applicable to a BS site sector or site sector sub-division

a) Specify the actual max threshold

a) 1) use the maximum value of the measured time-averaged transmitted power or EIRP from measurements taken on a single operational BS

a) 2) use a percentile derived from measurements taken on a larger number of representative BS sites

a) 3) otherwise use a percentile derived from computation models on BS sites with similar config. & env.

b) Before putting into service

b) 1) Evaluate the RF compliance boundary using the actual maximum transmitted power or EIRP threshold

b) 2) Configure the BS and implements tools ensuring that the time-averaged transmitted power or EIRP does not exceed the time-averaged actual maximum transmitted power or EIRP threshold over time

c) During service

c) 1) Record periodically the CDF of the time-averaged transmitted power or EIRP

c) 2) Record BS actual maximum transmitted power or EIRP threshold CDF in the assessment reports

d) 3) In case of threshold change (config. or perf.)

IEC 62232 next edition development with TC106 MT3

Same structure with enhanced content

	Domain	Technical topic	Clauses & sub-clauses
New	Actual max approach	Process	Process in §6.1, 6.2 and 6.3
	Actual max approach	Monitoring & control specification	Methods in new §8.4
	Beamforming (including mMIMO)	Product compliance	6.1
	Actual max & beamforming	In-situ measurements (including extrapolation)	6.3
	Power density assessment	Include power density measurements (63195) & computations (62704-5)	6.1, 8.2 and 8.3
	Frequency range & dish antennas	Extension of higher frequency & inclusion dish antenna formulas	All, 6.1 and Annex B
	Meas. using drones	In-situ meas. process	6.3 and 8.2
Maint.	Technology annex	Update (NR) & simplify	Annex F and main body
	Table 2	Update and more didactic	6.2
	Multiple sources	Include missing formulas & align with others (e.g. 62311)	New 8.5 and references in 6.1, 6.2 and 6.3
	Uncertainty	Clarification from remaining NC comts	9 and Annex E
	Consistency with ICNIRP rev	Review & update if/where necessary	5, 8 and Annex B

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Implementation of the novel compliance approach

From IEC TR 62669:2019 guidelines to the next edition of IEC 62232 standard

Jul'17
Global RF exposure assessment standard IEC 62232:2017

Apr'19
Implementation guide IEC TR 62669:2019
→ novel approach (rationale and principles for RF compliance based on actual max service)
→ adopted in ITU-T K.Sup16

Dec'19
Introduction of the novel compliance approach in IEC 62232
→ 1st consolidated draft (committee draft)

Dec'20
IEC 62232 next edition
→ technical freeze (committee draft for vote)

National authorities update RF compliance regulations for early 5G deployments

IEC 62232 next edition publication target 2021

Thank you!