Coverage Measurement on 5G NR Network

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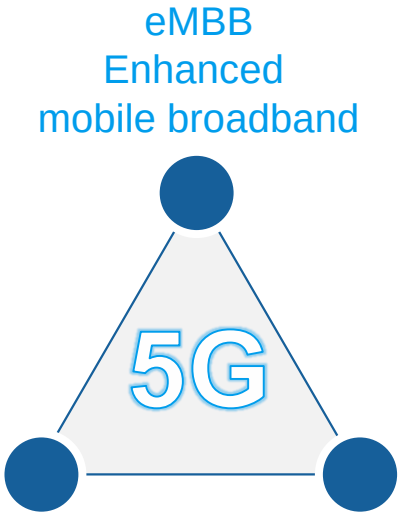
ROHDE&SCHWARZ

What is 5G NR?

Triangle of use-cases

Massive IoT

- A diverse ecosystem (operators, manufacturers, local authorities, certification only for some technologies)
- Mix of technologies (GSM, Lora, Zigbee, Cat M, NB-IoT,…)
- **It's all about cost efficiency and massive connectivity**



eMBB – the known playground

- Established ecosystem (operators, manufacturers, certification of devices)
- Evolution from existing technologies (LTE-A, 802.11 ad) and revolutionary additions (cm- / mm-wave)
- **It's all about data (speed and capacity)**

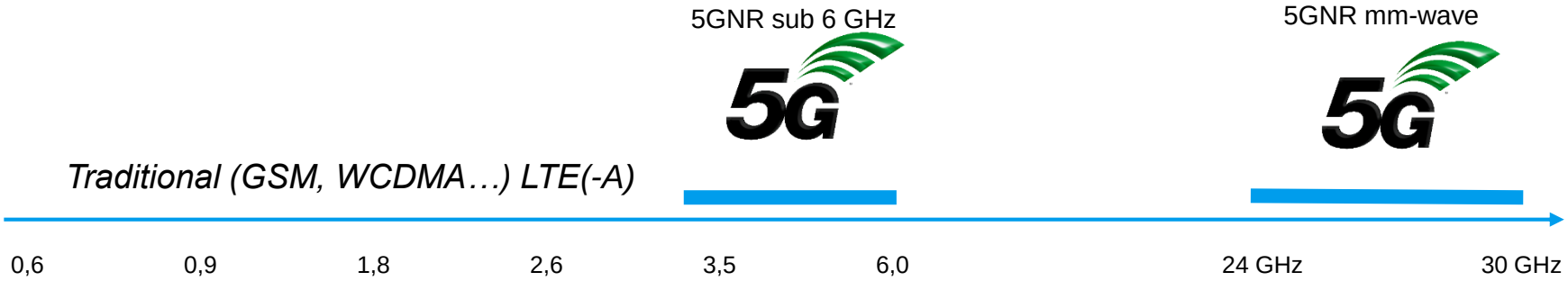
URLLC

- A significantly enhanced and diverse ecosystem (operators, manufacturers, verticals, certification not existing (yet))
- Existing technologies do not provide sufficient performance
- **It's all about reliability and security (data and capacity)**

The spectrum challenge…

- Especially eMBB (enhanced mobile broadband) and Massive IoT needs new spectrum for to cope with the increasing data comsumption and number of connected devices

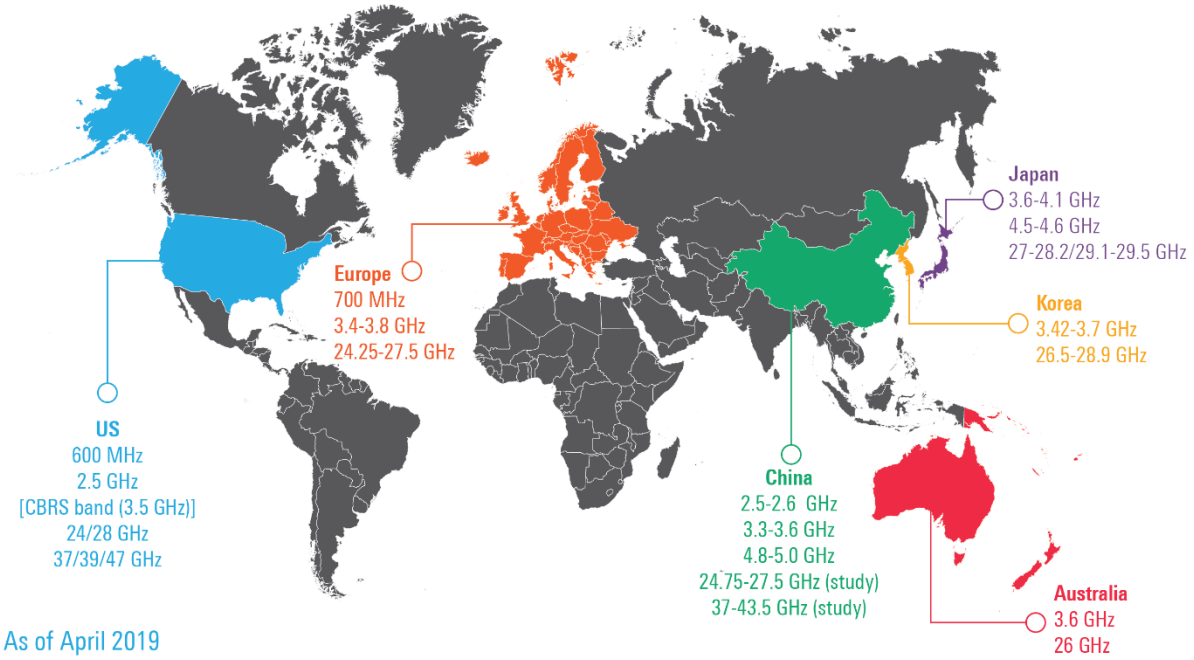
- 5GNR is devided in sub 6 GHz and mm-wave band



Frequency trends for 5G

NR frequency range 2 Reserved numbers 257-512		
	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	n/a	n/a
n260	37 – 40 GHz	37 – 40 GHz

NR frequency range 1 reserved numbers 65-256		
	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

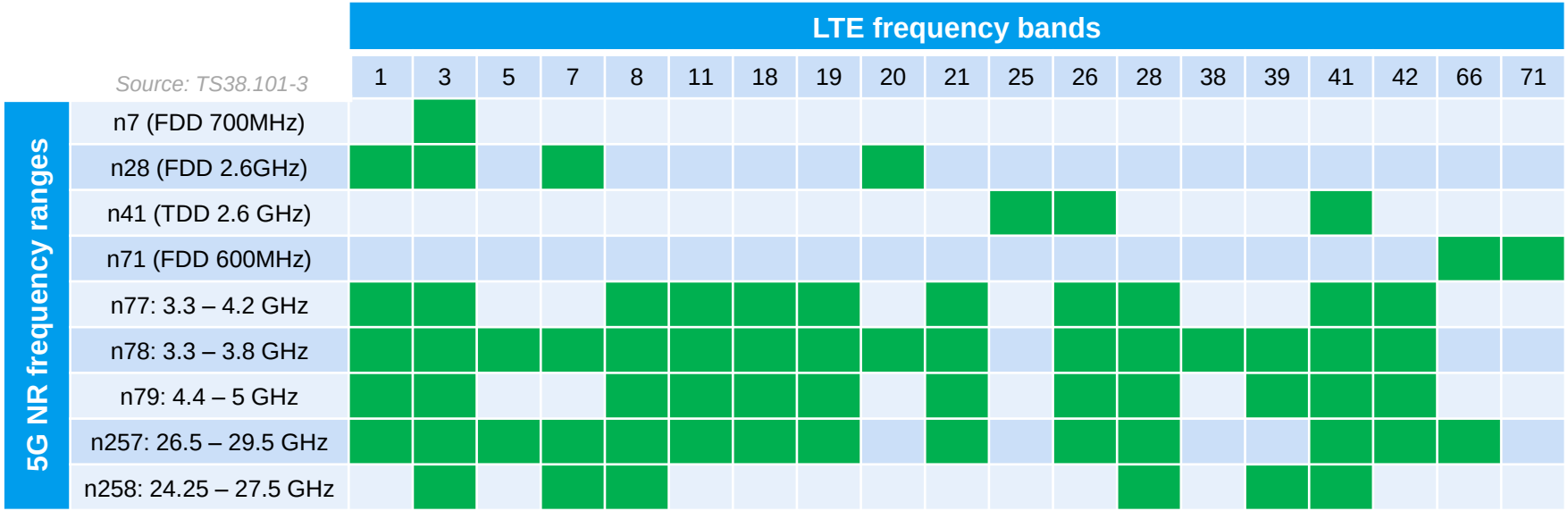


As of April 2019

5G NR spectrum utilization

Dual connectivity, for Non-Standalone (NSA) mode operation

- Two band combinations (2CC) of 1CC in NR band and 1CC in LTE band
- Additional tables for three band (3CC), four band (4CC) and five band (5CC) in TS38.101-3



5G New Radio (NR) offers a flexible air interface

Summary of key parameters

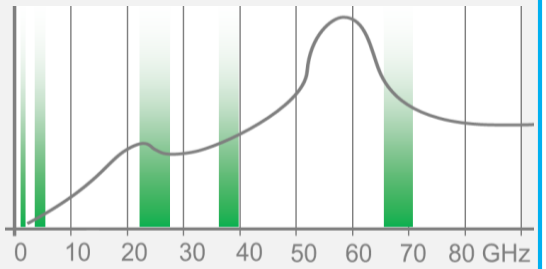
Changed to 7.125 GHz

Parameter	FR1 (450 MHz – 6 GHz)	FR2 (24.25 – 52.6 GHz)
Carrier aggregation	Up to 16 carriers	
Bandwidth per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 (not for data) kHz
Max. number of subcarriers	3300 (FFT4096 mandatory)	
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM; uplink also supports π/2-BPSK (only DFT-s-OFDM)	
Radio frame length	10ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	Max. 2 codewords mapped to max 8 layers in downlink and to max 4 layers in uplink	
Duplex mode	TDD, FDD	TDD
Access scheme	DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM	

Managing the key challenges related to 5G NR RAN

New spectrum

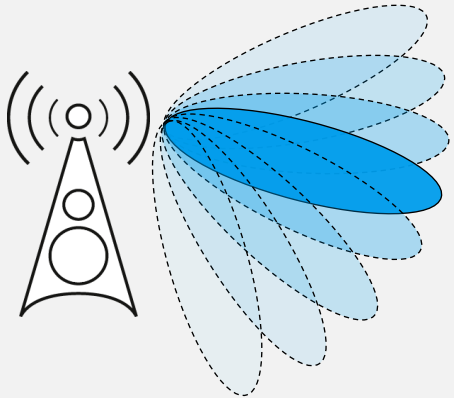
- Even 3.5 GHz is different from today's frequencies



- What about coverage?
- Spectrum clearance?

Beamforming and massive MIMO

- How many beamforming ?



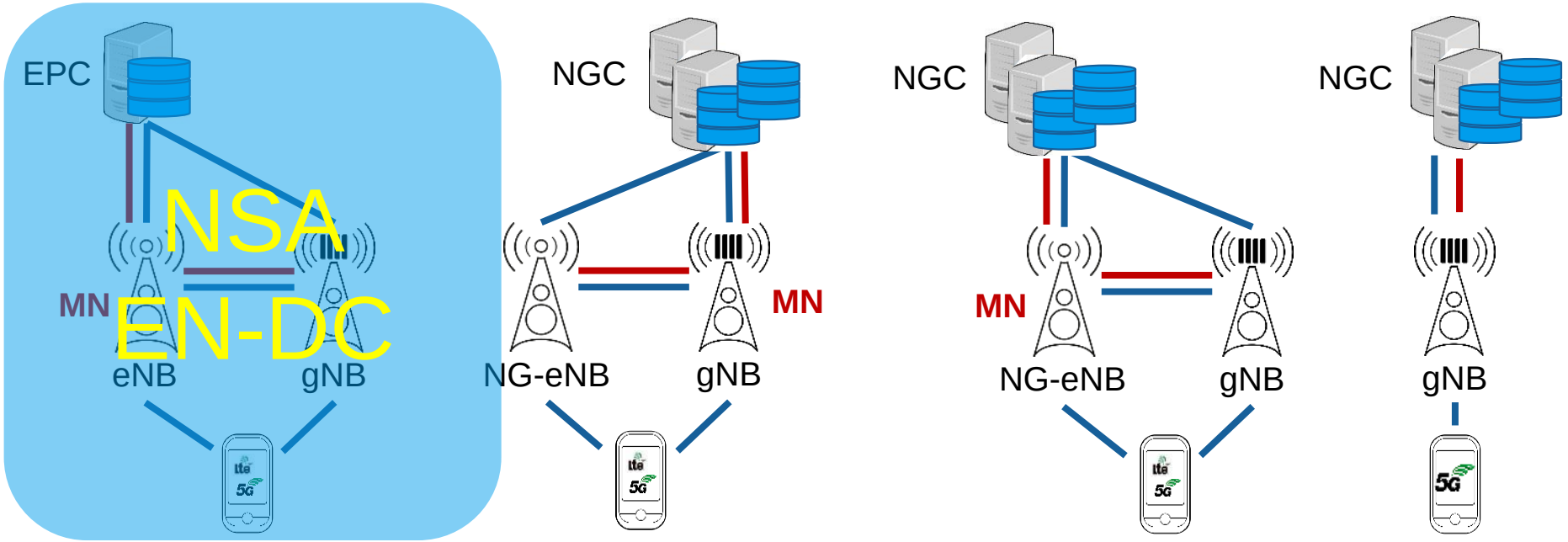
Flexibility of air interface and gNB configuration

- Bandwidth:
  5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz (FR1)
  50, 100, 200, 400 MHz (FR2)
- Subcarrier Spacing:
  15, 30, 60 kHz (FR1)
  60, 120, (240) kHz (FR2)
- Mapping onto antenna ports:
  single beam / multi beam sweeping

➢ **New technology elements drive the need for (and complexity of) 5G NR network measurements**

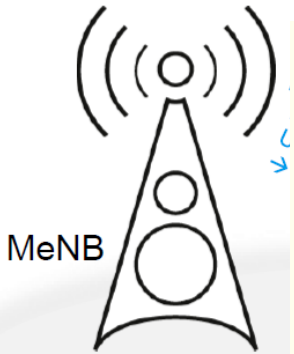
Architecture Evolution – DC Options

Option 3 is priority 1 in 3GPP, followed by Option 2



How will the 5G UE (NSA mode) get the SSB?

Network instructs UE to carry out signal quality measurements



DL DCCH Message
- _DL_DCCH_Message message: c1
  - rrcConnectionReconfiguration 2
    - rrc_TransactionIdentifier 1
    - criticalExtensions c1: rrcConnectionReconfiguration_r8
      - measConfig: 18
        - measObjectToAddModList 2
          - _MeasObjectToAddMod
            - measObjectId 1
            - measObject measObjectEUTRA: 16
              - carrierFreq 547
              - allowedMeasBandwidth (0) mbw6
              - presenceAntennaPort1 (0) false
              - neighCellConfig (0x02) '10'B
              - neighCellConfig[] (2) The MBSFN subframe allocations of all neighbour cells are identical to or subsets of that in the serving c
          - _MeasObjectToAddMod
            - measObjectId 2
            - measObject measObjectNR_r15: 10
              - carrierFreq_r15 647040
              - rs_ConfigSSB_r15 (2) _RS_ConfigSSB_NR_r15
                - measTimingConfig_r15 (2) _MTC_SSB_NR_r15
                  - periodicityAndOffset_r15 sf20_r15: 18
                  - ssb_Duration_r15 (4) sf5
                - subcarrierSpacingSSB_r15 (1) kHz30
              - quantityConfigSet_r15 1
              - Extension_Addition_Group : bandNR_r15
                - setup 78

```
-- ASN1START
MeasObjectNR-r15 ::=
    carrierFreq-r15
    rs-ConfigSSB-r15
    threshRS-Index-r15
    ...
    offsetFreq-r15
    blackCellsToRemoveList-r15
    blackCellsToAddModList-r15
    quantityConfigSet-r15
    ...
}
```

Let's see what's around?

...ed via LTE RRC

... carry out signal

...urement on

...5G NR carriers

...ity measurements

... Synchronization

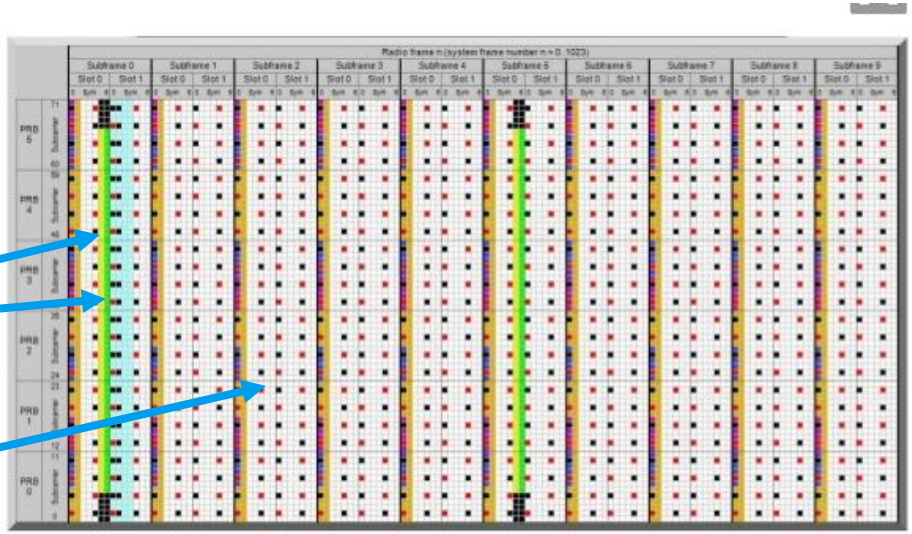
...B)

... SSBs?

...configuration?

What did we measure in LTE?

Synchronization and reference signals („LTE narrowband“)



Sync signals

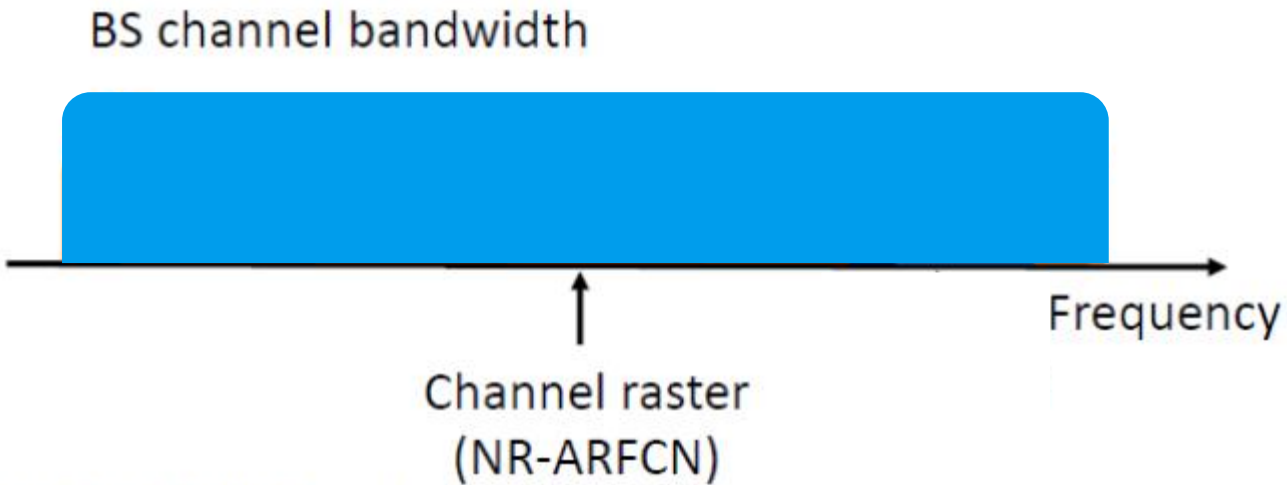
Reference signals

6 PRBs

Time domain

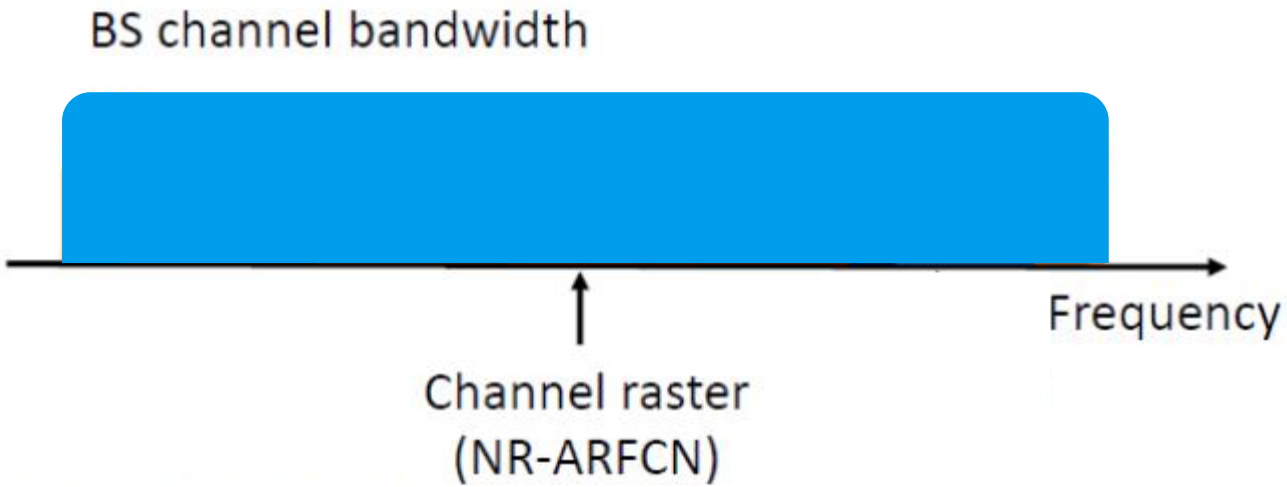
1SF = 1 ms

5G NR ARFCN as in LTE…..



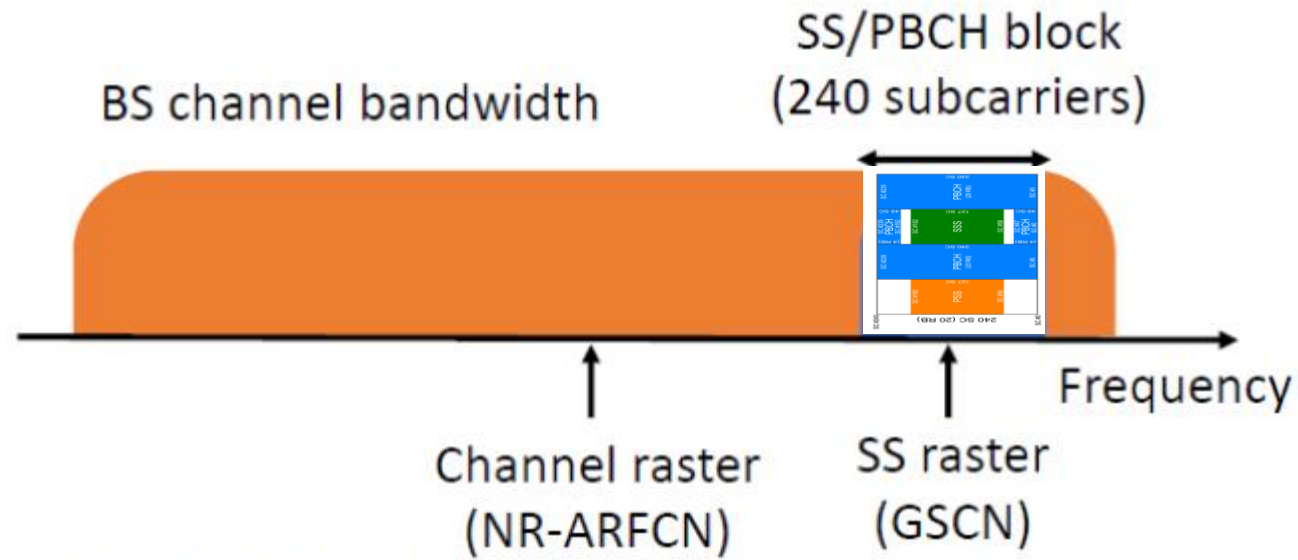
NR-ARFCN: NR absolute radio frequency channel number

5G NR ARFCN as in LTE…..BUT not so simple……. ☺



NR-ARFCN: NR absolute radio frequency channel number

5G NR channel raster vs SSB raster



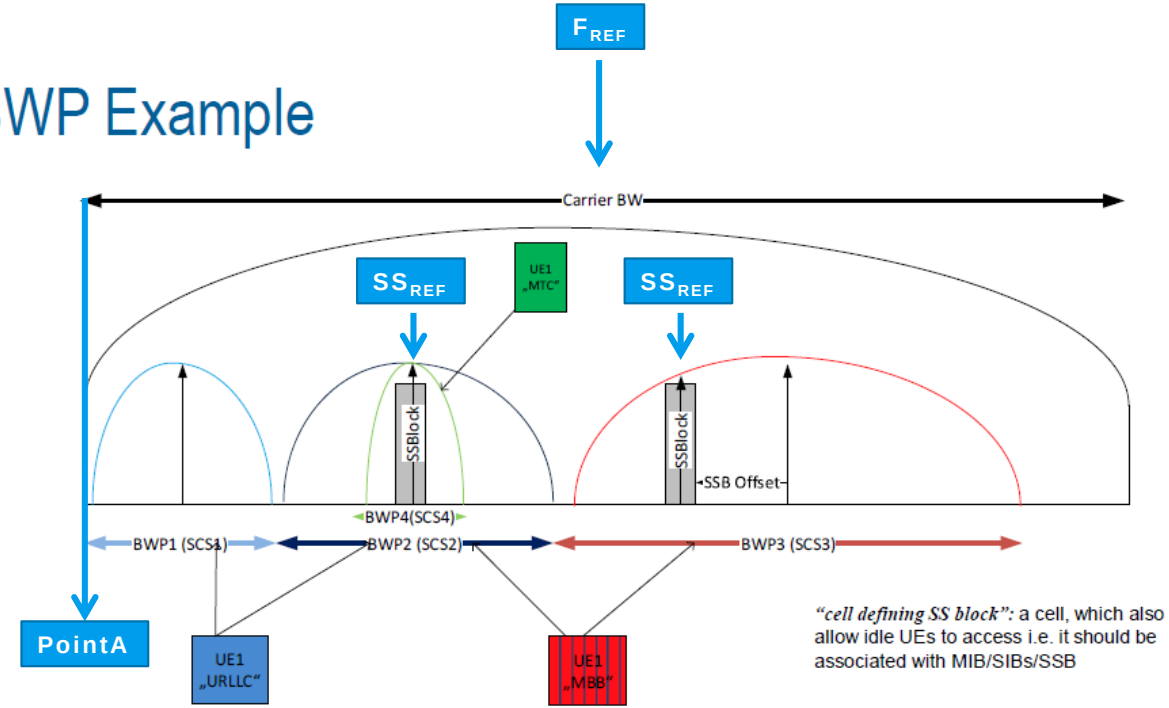
GSCN: Global synchronization channel number

NR-ARFCN: NR absolute radio frequency channel number

What can we measure?

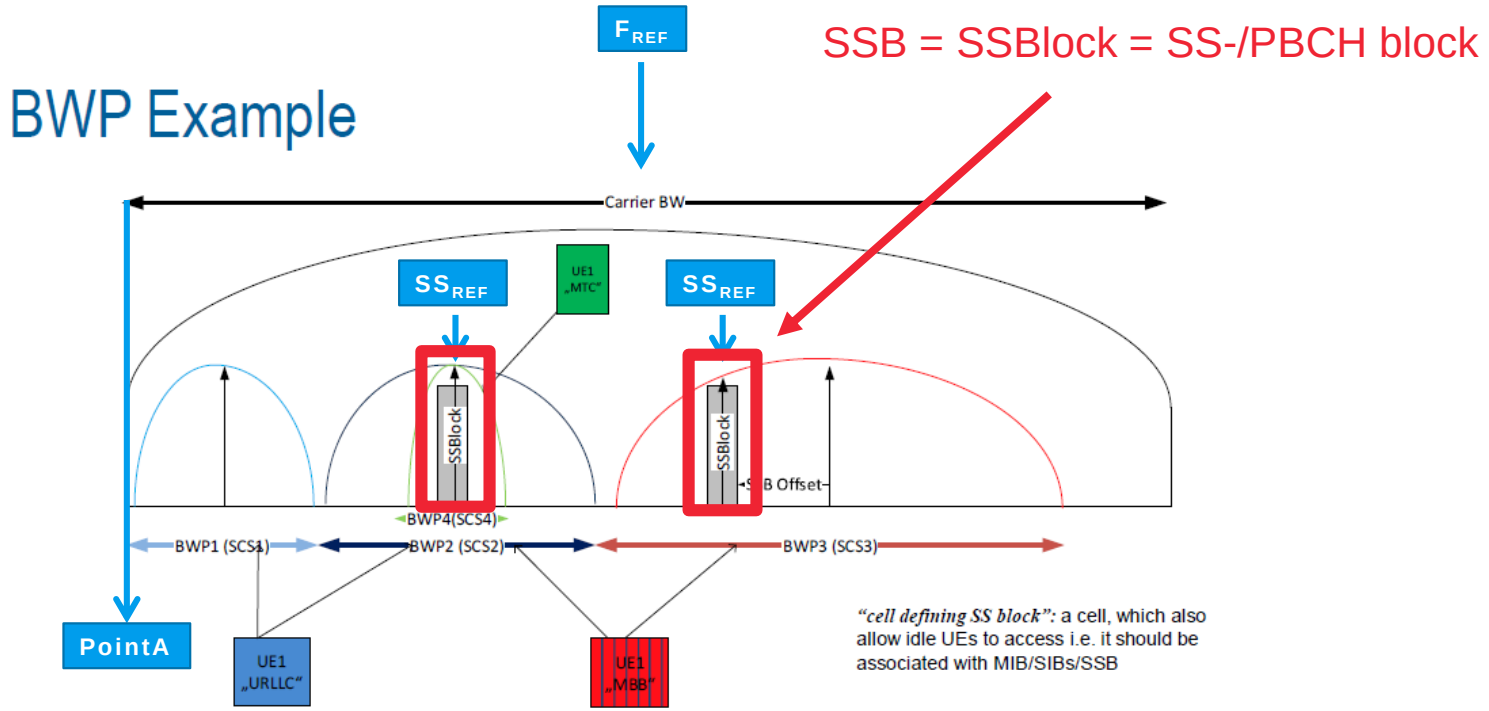
5G NR carrier overview

BWP Example



What can we measure?

5G NR SSBlocks



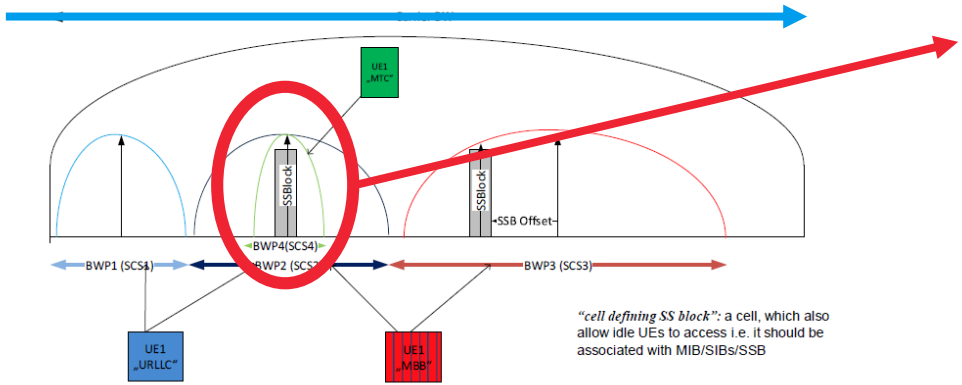
Why are SSB measurements essential?

- The UE / CPE uses the SSB for 5G NR cell search and synchronization
- The UE measurements on the different SSBs are essential to determine the right beam configuration for data transmission (based on an UE / CPE / gNB internal algorithm)
- The SSB is always there (at least once per 5G NR carrier) and the sequence is known
- Therefore it‘s perfect for
  - coverage measurement
  - CIR measurement
  - Interference measurement
  - Beamforming evaluation

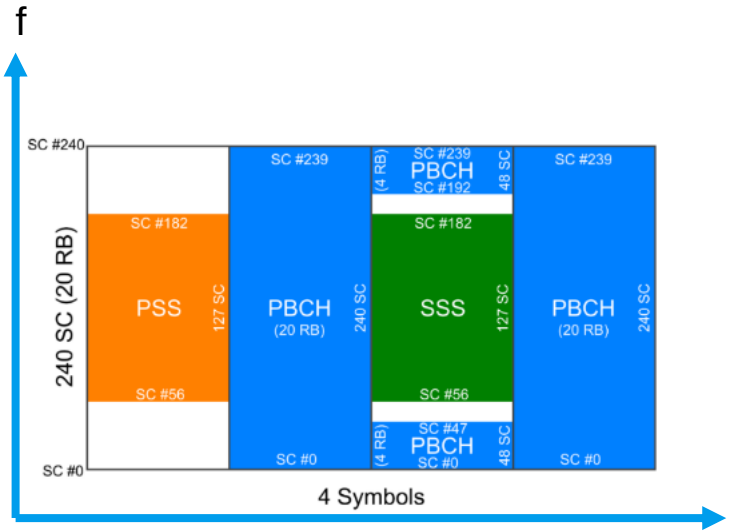
Let‘s zoom into a SSB…

Zoom factor 1

Total 5G NR carrier bandwidth



“cell defining SS block”: a cell, which also allow idle UEs to access i.e. it should be associated with MIB/SIBs/SSB



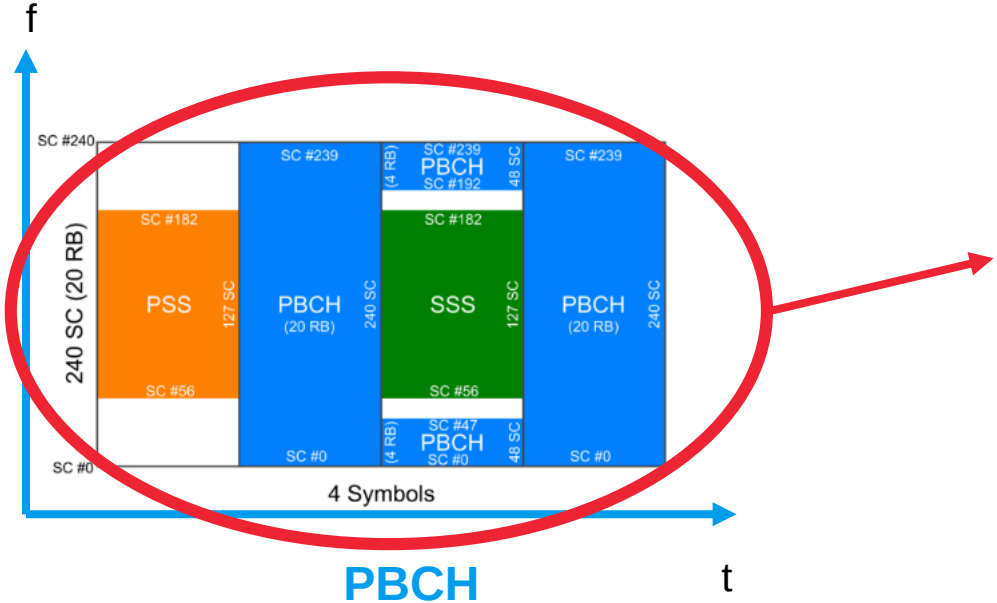
PBCH

PSS PBCH SSS PBCH

PBCH

Let‘s zoom into a SSB

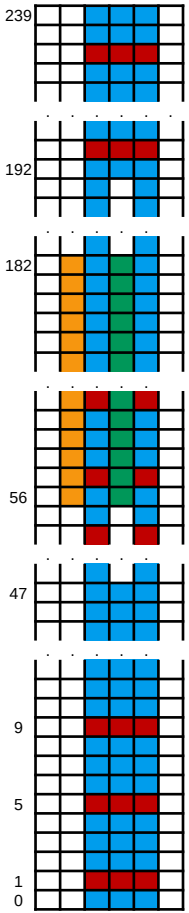
Zoom factor 2



PBCH

PSS PBCH SSS PBCH

PBCH



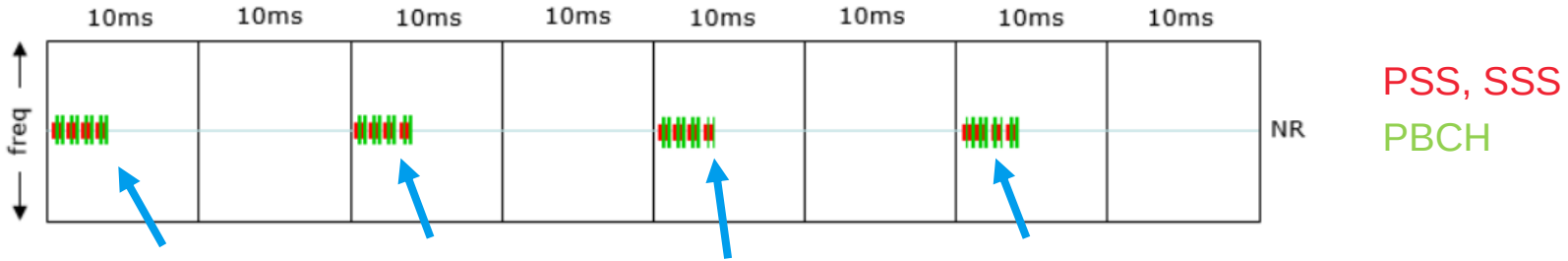
DM-RS PBCH

PSS PBCH SSS PBCH

DM-RS PBCH

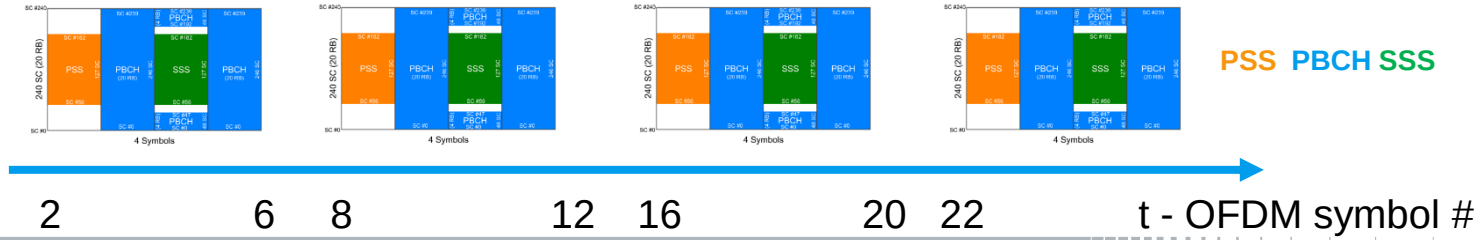
How often is the SSB block transmitted (time domain)?

- SSB Transmission time domain pattern: **SSB periodicity**



- **Let‘s zoom into the picture…**

Case A
Below 3 GHz
SCS= 15 kHz
L=4



What is a „case“?

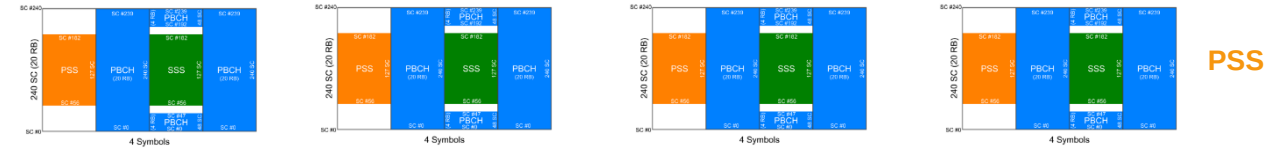
- A „case“ defines the max. number of SSB transmissions (L) and the SSB subcarrier spacings for several 5G NR bands
- It also defines the start-OFDM symbols of each SSBlock
- 3GPP includes a look-up table, which might change from release to release

SSB Mapping TS 38.213

Subcarrier Spacing	OFDM Symbol (s)	f ≤ 3 GHz	3 GHz < f ≤ 6 GHz	6 GHz < f
Case A : 15 kHz	{2,8} + 14n	n = 0,1 s = 2,8,16,22 L = 4	n = 0,1,2,3 s = 2,8,16,22,30,36,44,50 L = 8	
Case B : 30 kHz	{4,8,16,20}+28n	n = 0 s = 4,8,16,20 L = 4	n = 0,1 s = 4,8,16,20,32,36,44,48 L = 8	
Case C : 30 kHz	{2,8} + 14n	n = 0,1 s = 2,8,16,22 L = 4	n = 0,1,2,3 s = 2,8,16,22,30,36,44,50 L = 8	
Case D : 120 kHz	{4,8,16,20} + 28n			n=0, 1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18 L = 64 s=4,8,16,20,32,36,44,48,60,64,72,76,88,92,100, 104,144,148,156,160,172,176,184,188,200,204, 212,216,228,232,240,244,284,288,296,300,312, 316,324,328,340,344,352,356,368,372,380,384, 424,428,436,440,452,456,464,468,480,484,492, 496,508,512,520,524

Subcarrier Spacing	OFDM Symbol (s)	f ≤ 3 GHz	3 GHz < f ≤ 6 GHz	6 GHz < f
Case E : 240 Khz	{8, 12, 16, 20, 32, 36, 40, 44} + 56n			n=0, 1, 2, 3, 5, 6, 7, 8 L = 64 s=8,12,16,20,32,36,40,44,64,68,72,76,88,92, 96,100,120,124,128,132,144,148,152,156,176,180, 184,188,200,204,208,212,288,292,296,300,312, 316,320,324,344,348,352,356,368,372,376,380, 400,404,408,412,424,428,432,436,456,460,464, 468,480,484,488,492

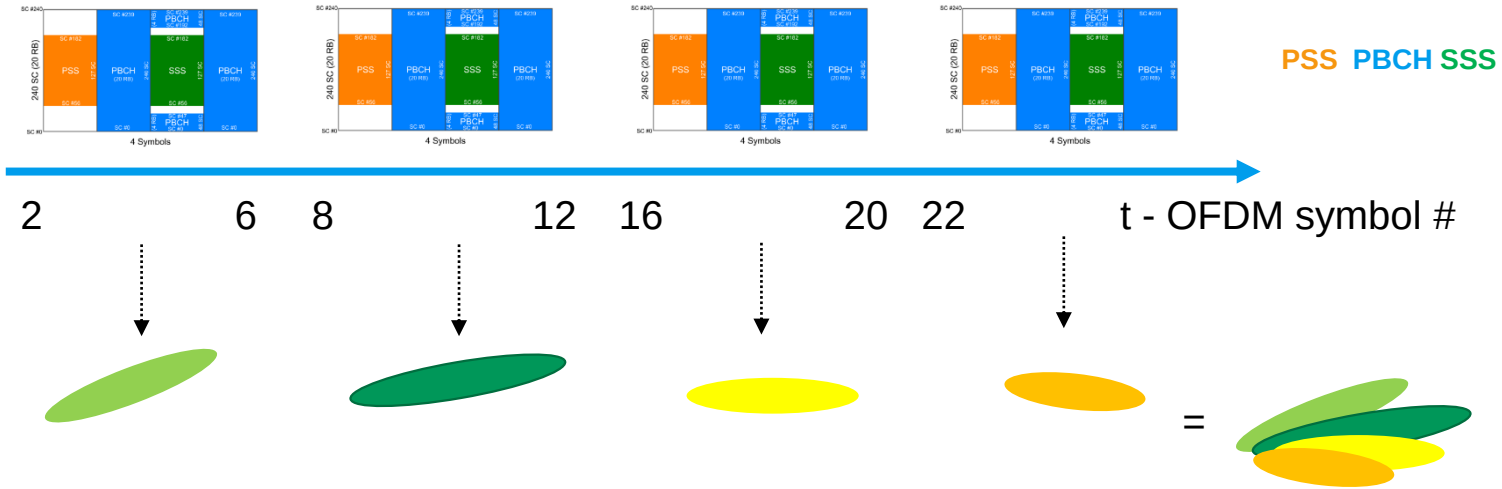
Case A
Below 3 GHz
SCS= 15 kHz
L=4



PSS PBCH SSS

What happens in the field?

Case A
Below 3 GHz
SCS= 15 kHz
L=4



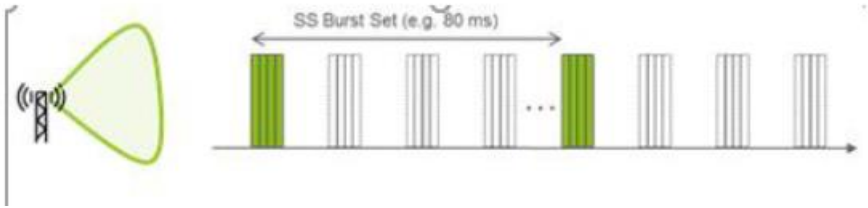
- Each SSB transmission in the time domain means „switching the SSB index / switching beams“ if configured by the network

- **Each SSB has a SSB index**

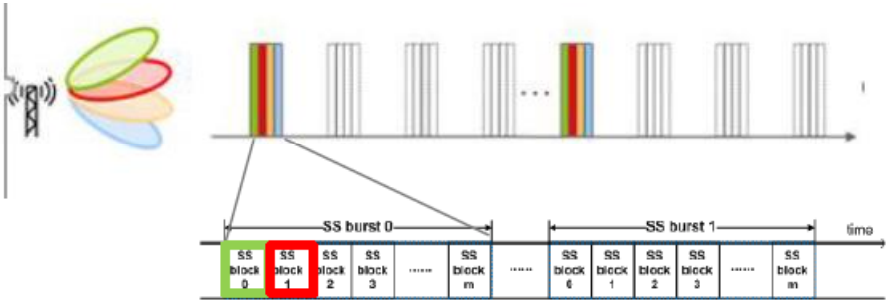
Signals for Beamforming

- **Single Beam** and **Multi Beam** scenarios supported in 5G NR
- SS Block Index is used to separate SSB transmission on different Beams
- Mapping of Antenna ports and Physical Beams to the SSB Index is implementation specific, e.g. will/can differ between vendors

Single Beam



Multi Beam

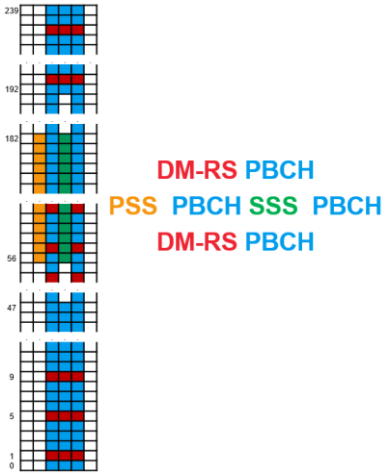


Which parameters do we get from the 5G NR SSB ?

- Cell / SSB identification
  - PCI
  - SSB index
  - GSCN (from configuration)
  - SSRef (from configuration)
- RSSI measurements
  - Inband Power / SSB RSSI
- Secondary sync measurements
  - SSS-RSRP
  - SSS-RSRQ
  - SSS-SINR
  - SSS-Pathloss (if configured!!)
- Primary sync measurements
  - PSS-RSRP
  - PSS-SINR
  - PSS-Pathloss (in configured!!)

- DM-RS measurements (DM-RS included in PBCH)
  - DM-RS-RSRP
  - DM-RS-SINR
  - DM-RS-Pathloss (if configured!!)
- PBCH measurements
  - PBCH-RSRP
  - PBCH-SINR
  - PBCH-Pathloss (if configured!!)
- Secondary sync and PBCH measurements
  - SSS-PBCH-RSRP
  - SSS-PBCH-SINR
  - SSS-PBCH-Pathloss (if configured!!)
- Primary and secondary sync and PBCH measurements
  - xSS-PBCH-RSRP
  - xSS-PBCH-SINR
  - xSS-PBCH-Pathloss

- CIR parameters based on SSS
- Max. delay of the peaks Time delta between first and last arrived peak
  - Power
  - Ptotal



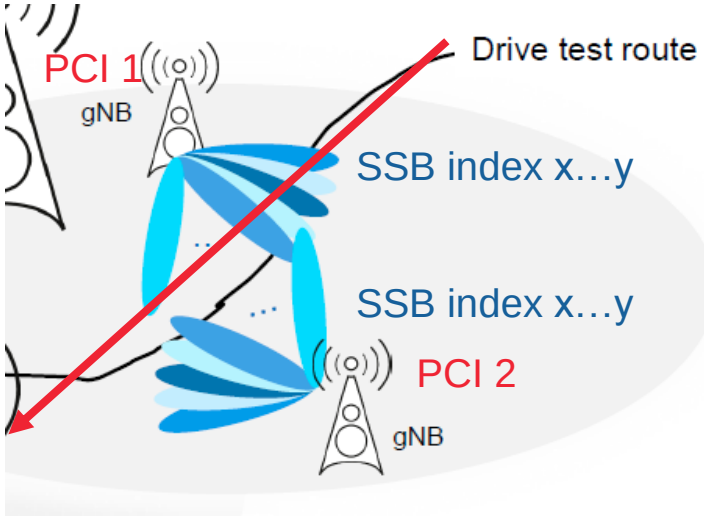
Coverage Measurement on 5G NR Network

- What do we measure ??

What happens during a drive test?

- **During a drive test we cross several PCIs and several SSB indices belonging to certain PCIs**

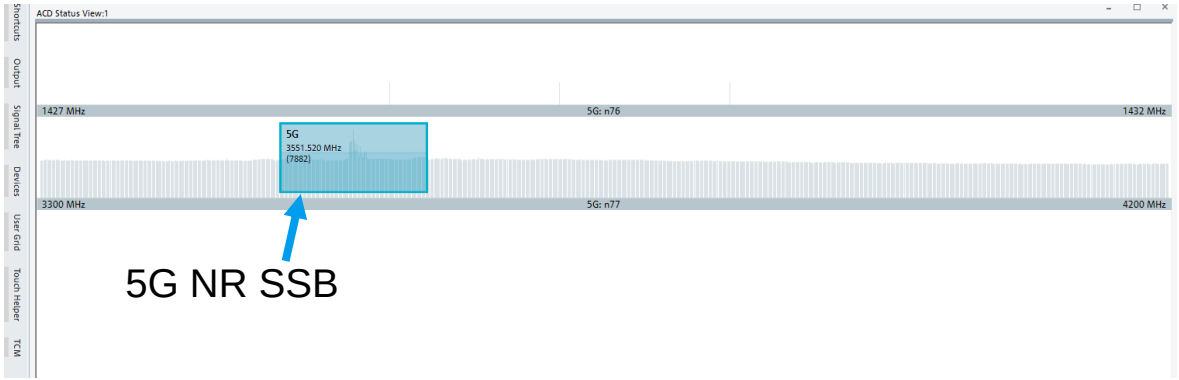
- **Each beam / SSB is described by a SSB index and PCI**



5G NR ACD Helpful Tools

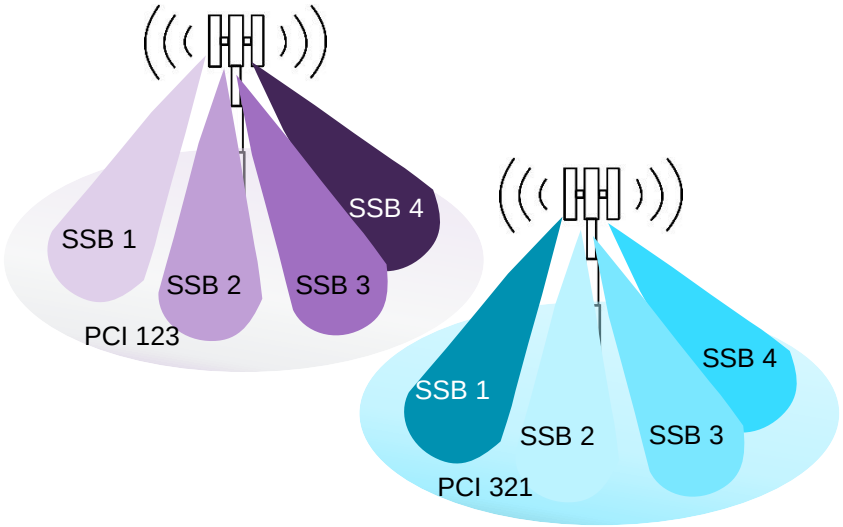
supports sub 6 and mm-wave frequency bands

- The 5G NR ACD starts with a fast spectrum sweep (grey lines in the ACD view) a 5G NR SSB is visualized using a blue marker in the ACD view



ROMES Top N PoolBasics

5G NR Scanner TEC settings



Beam specific Top N Pools

Beam Quality Ranking

- Top 1 SSB Index @ PCI
- Top 2 SSB Index @ PCI
- Top 3 SSB Index @ PCI
- …

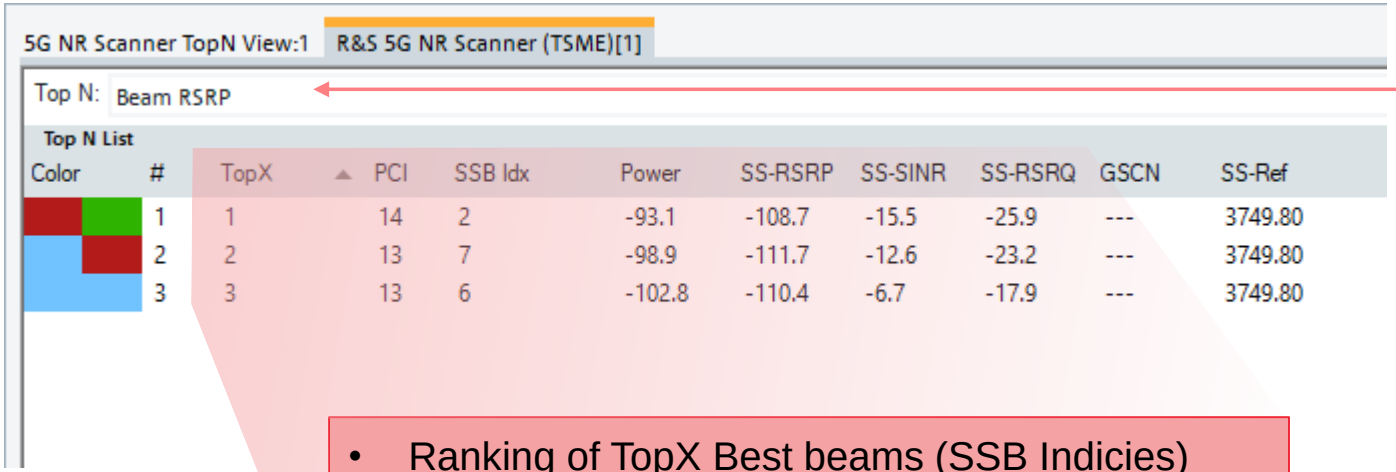
Cell specific Top N Pools

Cell Quality Ranking

- Top 1 PCI
- Top 2 PCI
- …
- …

5GNR Scanner Top N View

Beam specific Top N Pool



Color	#	TopX	PCI	SSB Idx	Power	SS-RSRP	SS-SINR	SS-RSRQ	GSCN	SS-Ref
	1	1	14	2	-93.1	-108.7	-15.5	-25.9	---	3749.80
	2	2	13	7	-98.9	-111.7	-12.6	-23.2	---	3749.80
	3	3	13	6	-102.8	-110.4	-6.7	-17.9	---	3749.80

Beam specific Top N Pools

- Ranking of TopX Best beams (SSB Indicies)
- Example of TopN Pool rank based on SS-RSRP
- TopX Beams can belong to different PCIs!

5GNR Scanner Top N View

Cell specific Top N Pool

5G NR Scanner TopN View:1 | R&S 5G NR Scanner (TSME)[1]

Top N: Cell RSRP

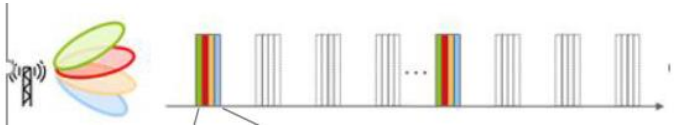
Top N List

Color	#	TopX	PCI	SSB Idx	Power	SS-RSRP	SS-SINR	SS-RSRQ	GSCN	SS-Ref
	1	1	1005	1(-77);2(-82);	-76.4	-79.0	17.9	-5.2	7900	3577.44
	2	2	892	**6(-77);**7(-84);**0(-88);	-78.5	-80.9	16.4	-5.5	7900	3577.44
	3	3	449	-(-80);	-76.9	-80.2	16.0	-5.4	7900	3577.44
	4	4	779	-(-80);-(-81);	-78.8	-80.7	14.8	-4.7	7900	3577.44
	5	5	1005	0(-81);	-78.5	-81.0	15.9	-5.2	7900	3577.44
	6	6	336	1(-79);2(-82);3(-91);	-79.5	-81.7	13.2	-4.2	7900	3577.44
	7	7	449	-(-78);-(-83);	-77.8	-80.2	18.7	-5.3	7900	3577.44

Cell specific Top N Pools

- Ranking of TopX Best Cells
- SSB Index for qualified Beams used in the Cell Quality averaging
- SS-RSRP, SS-SINR and SS-RSRQ values are cell averages

Multi Beam Example in ROMES



5G NR Scanner TopN View:1 | R&S 5G NR Scanner (TSME)[1]

Top N: SSB RSRP | Auto Width

Top N List

Color	#	TopX	PCI	SSB Idx	Power	SS-RSRP	SS-SINR	SS-RS...	GSCN	SS-Ref
	1	1	15	0	-65.3	-75.0	-9.1	-19.9	---	3749.80
	2	2	15	2	-67.1	-76.6	-9.0	-19.9	---	
	3	3	15	3	-77.7	-89.0	-10.9	-21.5	---	
	4	4	13	7	-87.7	-96.5	-8.2	-19.2	---	
	5	5	15	1	-83.6	-96.8	-12.9	-23.5	---	
	6	6	15	4	-82.6	-94.4	-11.6	-22.2	---	
	7	7	13	6	-86.5	-95.9	-8.8	-19.6	---	
	8	8	15	5	-83.4	-97.4	-13.8	-24.3	---	

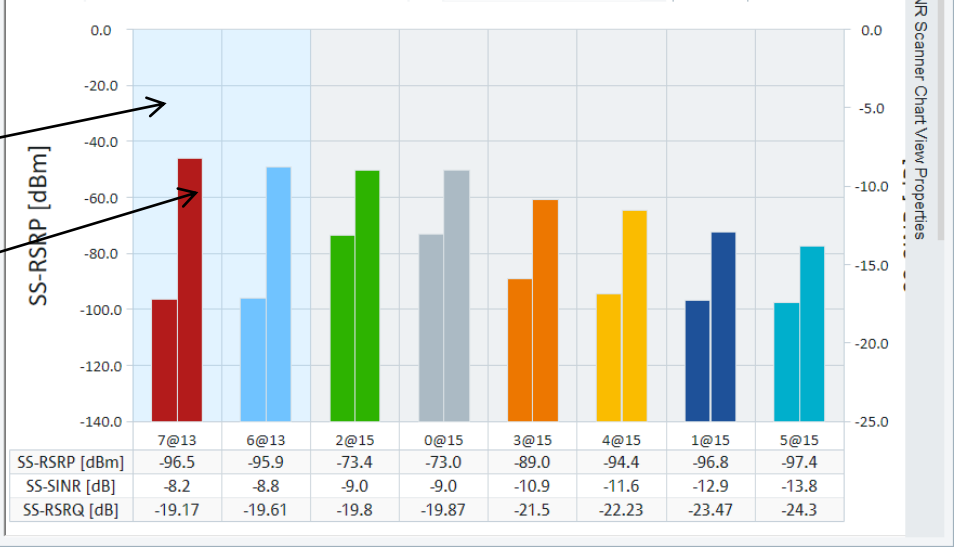
Top N Chart (Click to open)

Cell Color by PCI

Beam Color by SSB Index

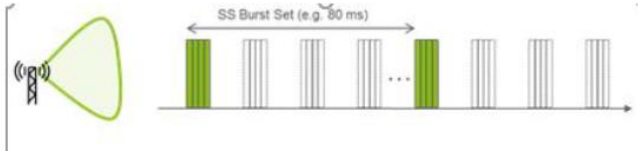
5G NR Scanner Chart View:1 | R&S 5G NR Scanner (TSME)[1]

PCI Filter: [Beam@]PCI;[Beam@]PCI;... | @ Any Frequency | Clear



	7@13	6@13	2@15	0@15	3@15	4@15	1@15	5@15
SS-RSRP [dBm]	-96.5	-95.9	-73.4	-73.0	-89.0	-94.4	-96.8	-97.4
SS-SINR [dB]	-8.2	-8.8	-9.0	-9.0	-10.9	-11.6	-12.9	-13.8
SS-RSRQ [dB]	-19.17	-19.61	-19.8	-19.87	-21.5	-22.23	-23.47	-24.3

Single Beam Example



5G NR Scanner TopN View:1 | R&S 5G NR Scanner (TSME)[1]

Top N: SSB RSRP | Auto Width

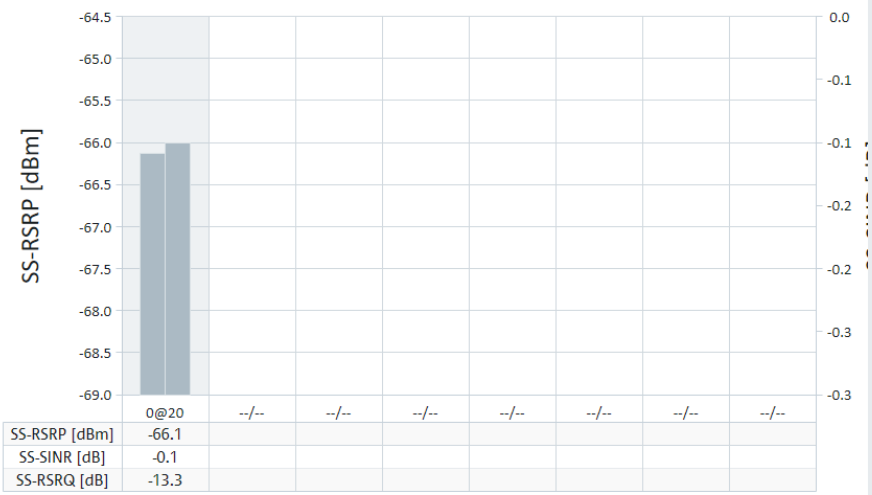
Top N List

Color	#	TopX	PCI	SSB Idx	Power	SS-RS...	SS-SI...	SS-RS...	GSCN	SS-Ref
	1	1	20	0	-63.1	-66.1	-0.1	-13.3	---	3500....

Top N Chart (Click to open)

5G NR Scanner Chart View:1 | R&S 5G NR Scanner (TSME)[1]

PCI Filter: [Beam@]PCI;[Beam@]PCI;... | @ 3.500000 GHz | Clear



	0@20	--/--	--/--	--/--	--/--	--/--	--/--	--/--
SS-RSRP [dBm]	-66.1							
SS-SINR [dB]	-0.1							
SS-RSRQ [dB]	-13.3							

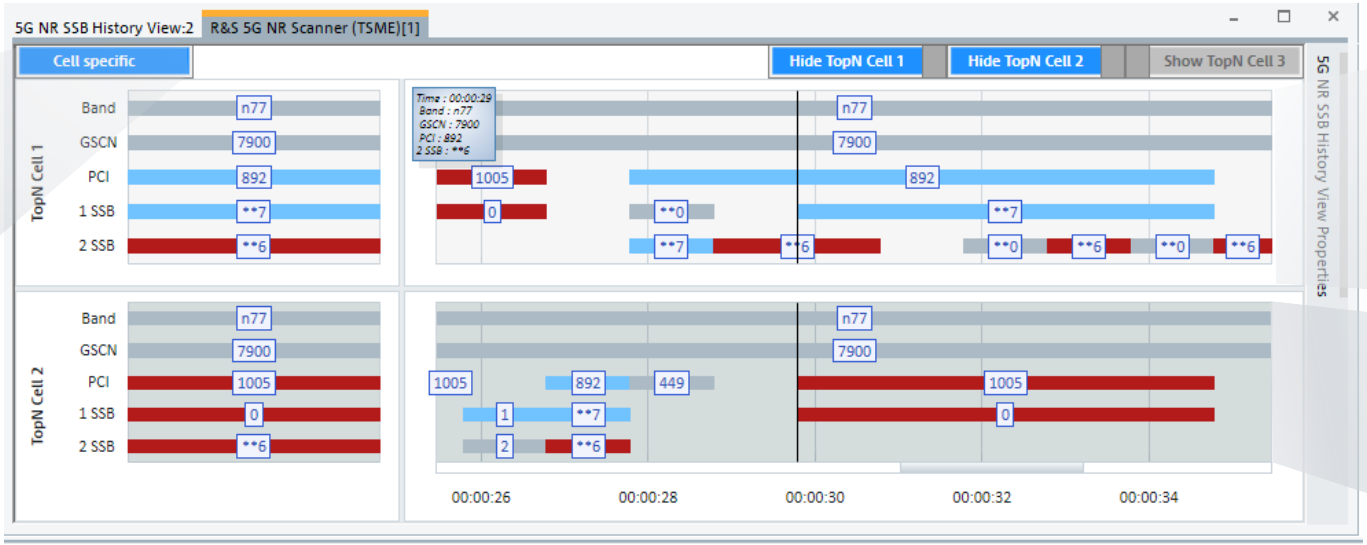
One PCI and SSB index detected

5G NR scanner SSB History View

Cell specific Top N Pools

History of TopN [1..X] Cell and [1..Y] Beam (SSB Idx) identies over time

Configured Top N Pools



1st Best cell

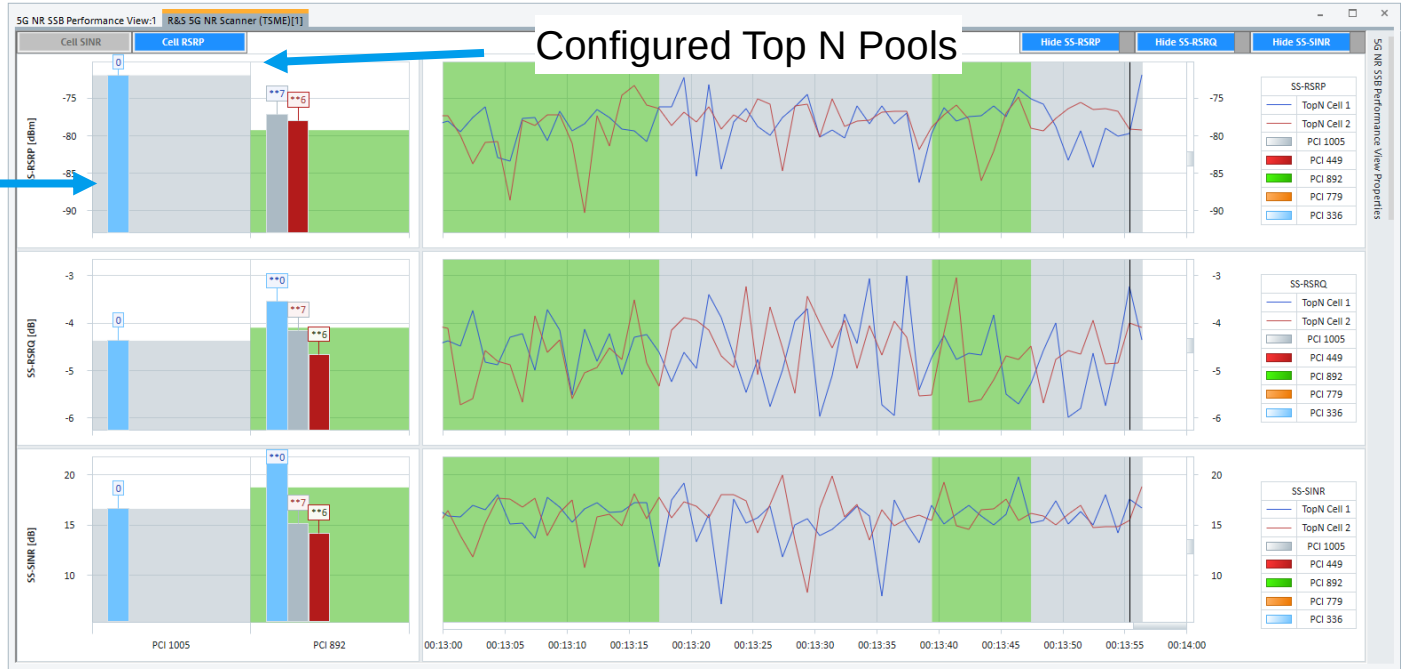
2nd Best cell

5G NR scanner SSB performance view

Background color: PCI

Bar color: SSB index

By default: 1st best and 2nd best cell is shown



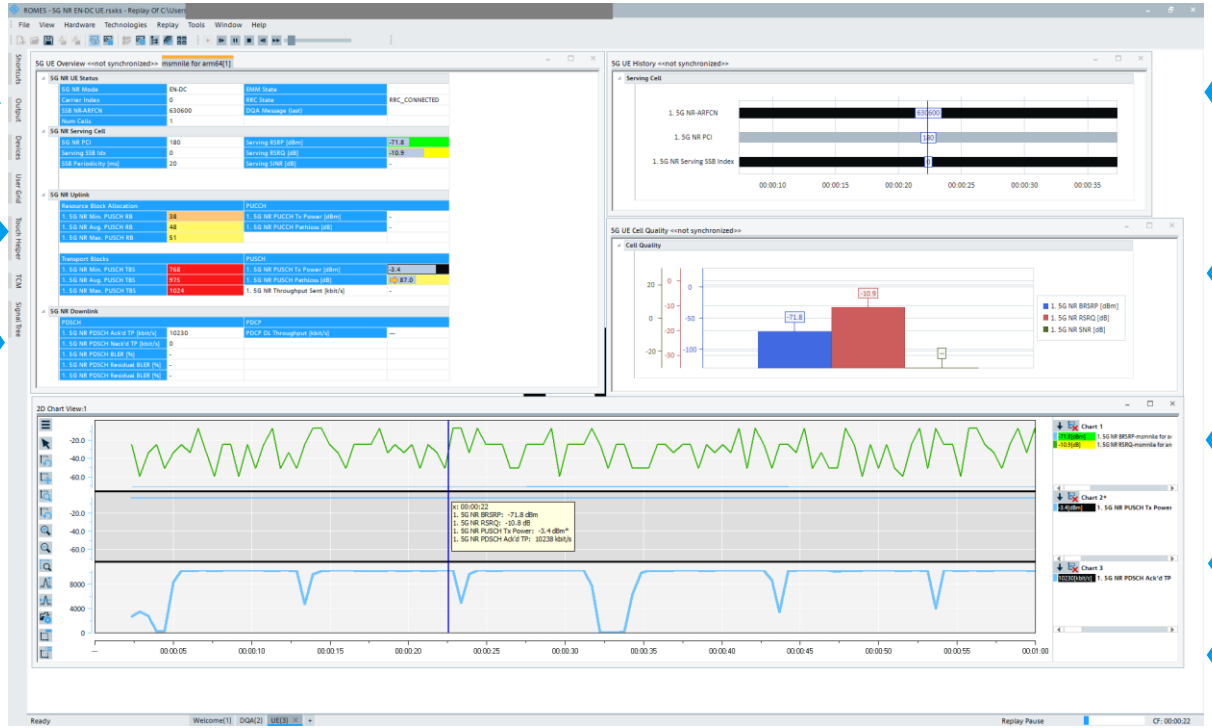
- Most detailed view to analyze cell and SSB coverage over time
- Compare with UE: was the UE on the best channel/cell/beam when doing RACH?
- When driving through the beam coverage of a cell: Are all beams transmitted as expected?

5G NR UE Measurement

5G NR Cell

5G NR Uplink

5G NR Downlink



5G NR Cell History

5G NR Cell Quality

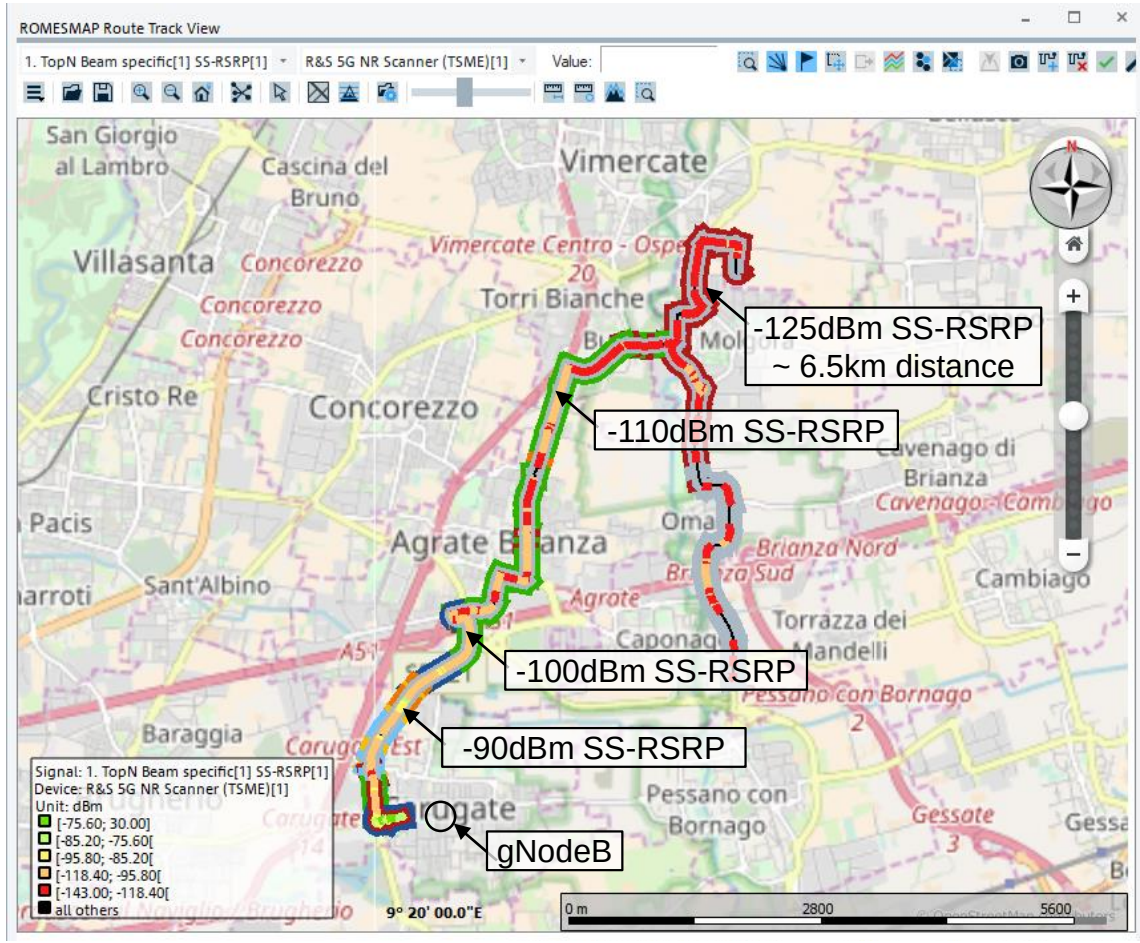
RSRP, RSRQ

Tx Power

DL Thp

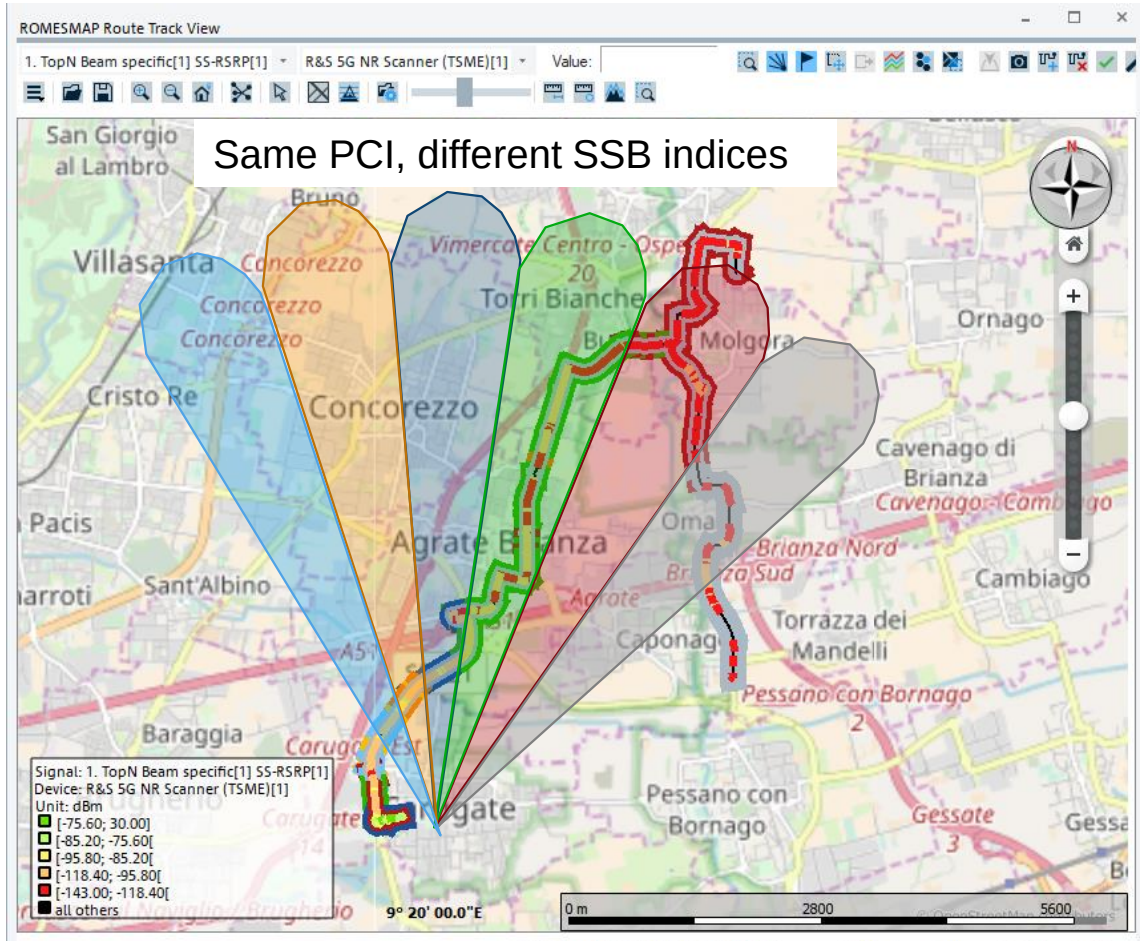
Coverage

- **Expected UE sensitivity: ~ -120 dBm (SS-RSRP)**
- **Surprisingly good SSB coverage in suburban area**



SSB / beam ranking

- **SSB / beam index visualized on the map**



Coverage Measurement on 5G NR Network

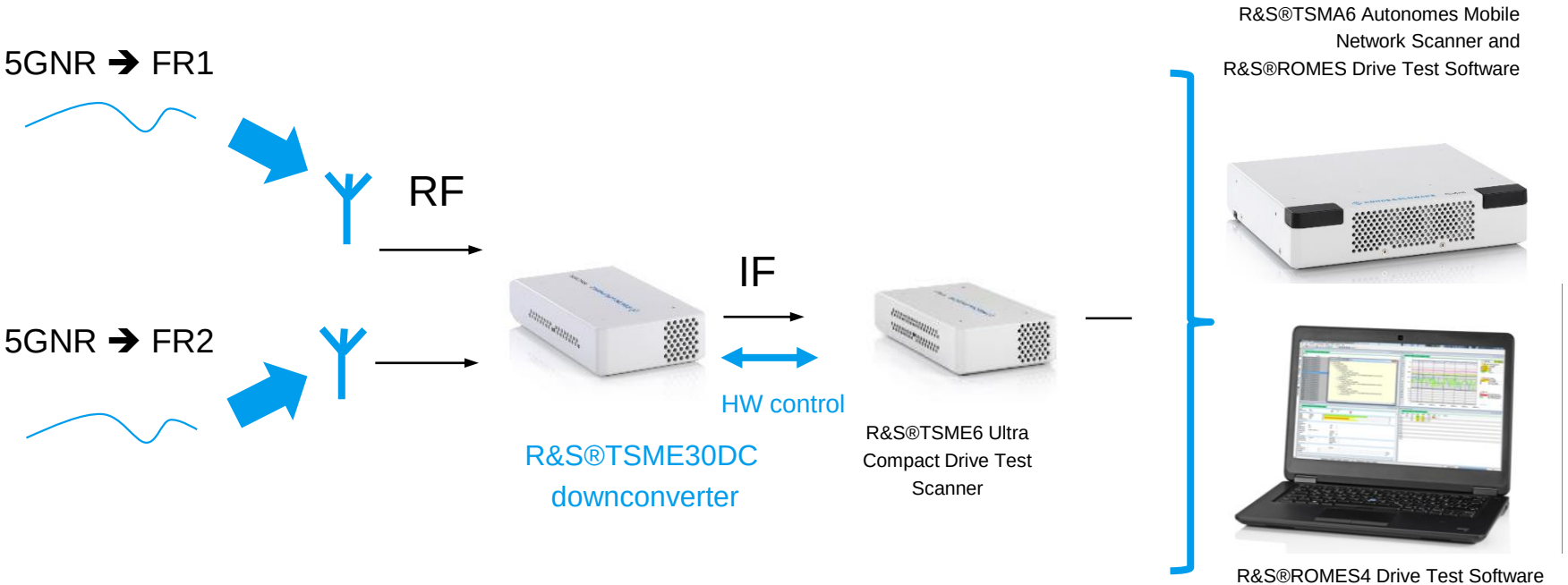
- How do we measure ??

ROMES Solution for 5G NR Measurement

- ROMES based on TSME6 / TSMA6 Scanner + 5G NR UE
- Laptop / Shoulder bag / Backpack

Setup for 5G NR measurements including Sub6 and mmW

Setup for a Sub6 and mm-Wave measurement



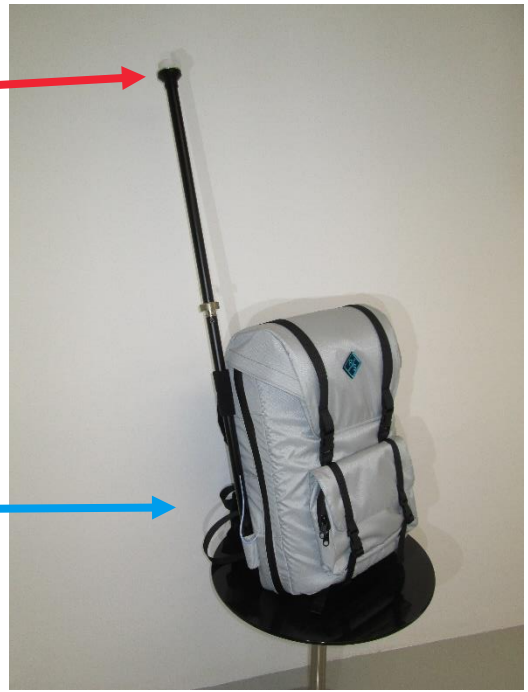
5G NR measurements – use cases and antennas

mm-wave measurement with FR4 backpack

TSME-Z20: omnidirectional mm-wave antenna

Frequency	26 to 40 GHz
Connector type	K type jack
Power Handling	10 Watt c.w.
VSWR	< 2.0:1
Gain	2 to 4 dBi
Azimuth Ripple	+/- 1 dB worst case, generally < +/- 0.5 dB
Weight	40 g
Size- max.	46 mm diameter
Mounting	Three M2.5 screws equispaced on 39.5 mm pitch circle diameter.
Construction	Aluminium and Engineering plastics

FR4 backpack



Thank you