5G NR network measurements using network scanners and advanced data analytics

Application Note

Products:

- R&S®TSME6
- R&S®TSMA6
- R&S®TSMx6-K50
- R&S®ROMES4
- R&S®ROMES4ACD
- R&S®TSMx6-K40
- R&S®ROMES4NPA, ROMES4N18
- R&S®SmartAnalytics
- R&S®TSME30DC

This document describes the highlights of 5G NR network analysis from pre-commercial trials and early deployments and introduces 5G NR scanning use cases and the functionality of the R&S®TSMx6 mobile network scanner family together with R&S®ROMES4 and R&S®SmartAnalytics software.

5G NR is expected to become the major cellular radio access technology during the coming years. With the use of higher frequencies associated with 5G NR, particularly FR2, several new technologies such as beamforming are employed to overcome the increasing path loss. During the whole chain of lab testing, field trials, network rollout, optimization and benchmarking, measurement tools are required which characterize the RF conditions and network coverage in the field precisely to understand the operation of features such as beamforming and their impact on the coverage area. Passive measurement tools such as scanning receivers have the advantage that they are not limited to specific operators, bands or signal components and with their multi-technology measurement capability, they are also prepared for 5G NR non-stand-alone (NSA) measurements.

The following Application Note highlights where users of network scanners will benefit and what can be analyzed.

A description of UE-based 5G NR measurements will be added in the next version of this document.

Note:

Please find the most up-to-date document on our website: http://www.rohde-schwarz.com/mnt-5G.

Application Note

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4.2019 – Version 2.0

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1 Introduction

1.1 5G NR - new use cases for wireless mobile communication

5G NR is expected to become the major cellular radio access technology for mobile networks during the coming years. It is specified by 3GPP in Release 15 and subsequent releases and it is based on requirements which arise from several well-defined use cases.

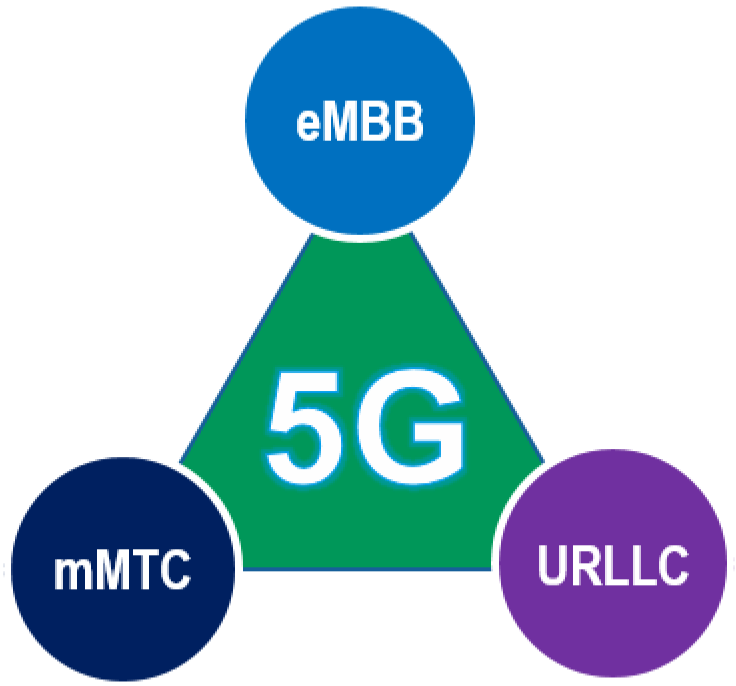


Figure 1: The triangle of 5G NR use cases

The triangle of use cases includes:

eMBB: enhanced Mobile Broadband, which can be seen as an evolution from existing mobile technologies combined with revolutionary developments in the RAN such as using mm-Wave frequencies (mm-wave) and much wider channel bandwidths. It is all about providing ultra-high data rates for connectivity, high-resolution videos, audio and apps used by a massive number of subscribers per square km. The eMBB ecosystem is already well established; manufacturers, operators and other parts of the industry are well known from legacy technologies like WCDMA and LTE.

URLLC (Ultra Reliable and Low Latency Communication) is a completely new field and leads to a diverse eco system. The focus is on a very short latency (~ 1 ms) and high reliability, which is mandatory for critical applications such as healthcare, industry and manufacturing and automotive, e.g. for controlling driverless cars.

mMTC (massive Machine Type Communication) is an evolution from existing cellular developments and a mix of existing IoT technologies like NB-IoT, LTE-M, Wi-Fi, GSM, Bluetooth and LoRa that already today connect things to the internet. However, the massive number of connected devices, which are expected for the future, will require a new radio access technology to serve all demands.

1.2 5G NR - technical aspects

These diverse use cases necessarily lead to an ultra-flexible technology with a high degree of freedom for different network configurations. The 5G NR specification leaves space for optimization to reduce the latency significantly as well as increase the data rate by a factor of 10. Those optimizations require many new technology components including new spectrum, higher OFDMA subcarrier spacing, shorter transmission time intervals and multi-connectivity that allow combining 5G network elements with LTE.

1.2.1 New frequency ranges, beamforming, bandwidth parts and multi-connectivity

One method to increase the data rate is to use wider bandwidth carriers and 5G NR is expected to provide carrier bandwidths up to 400 MHz. Broadband carriers require a free and contiguous spectrum without gaps. Legacy technologies - especially GSM - will remain as a basic service for voice, which means that new spectrum has to be allocated for 5G NR. For the sub 6 GHz band, also known as FR1, 3.5 and 5-6 GHz are the preferred frequencies. Additionally, in most countries, mm-wave frequencies (24 - 44 GHz) are allocated or under consideration for 5G NR. Using higher frequencies for wireless transmissions becomes more difficult, particularly the increasing path loss, which requires new technical components. To overcome the path loss, beamforming is one of the main pillars in 5G NR. Antenna arrays with for example 64 x 64 antenna elements or even more concentrate the power with pencil beams in three dimensions to a small geographical area where it is required. This leads to a significantly higher SINR, which increases the channel capacity.

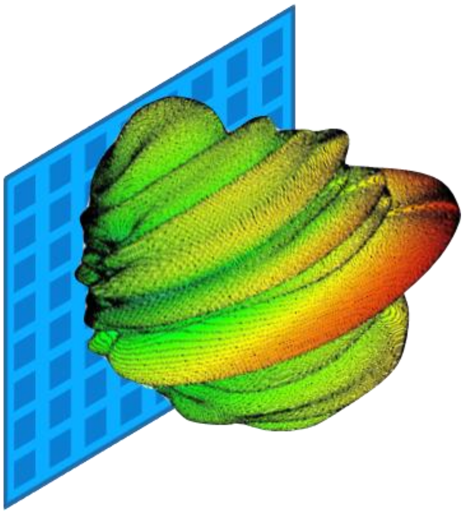


Figure 2: Beamforming using an antenna array with phase shifting between antenna elements

Traditional antennas with a half-power beam width of 65° radiate their power across the whole sector and therefore "waste" a huge part of the power, delivering it where it is not used.

Native support for beamforming requires the possibility to distinguish between different beams applied in the transmit direction. 5G NR provides this feature by a specific design of synchronization signals/PBCH blocks (SSBs).

Another main pillar of 5G NR is multi-connectivity. The possibility of the same core network connecting with various radio access networks results in several connectivity scenarios. UEs can be connected over LTE or over NR base stations to the new 5G core network (5GC). Moreover, connectivity involving the cellular technologies has been further evolved with an option of the connection going through more than one access technologies at the same time (Non-Standalone Connectivity Options).

In 3GPP Release 15, dual connectivity can involve two 5G NR base stations (NR-DC) or one 5G NR and one LTE base station (Multi-RAT-DC or MR-DC). Only LTE is considered as possible Multi-RAT connectivity with NR. Other technologies such as GSM and WCDMA cannot be combined in DC with 5G NR.

In dual connectivity mode, one of the two base stations takes the master node (MN) function and the other the secondary node (SN). The MN is the one in charge of the signaling connection while the secondary node is responsible for the additional user data connection. In the first wave of network roll-outs, the LTE acts as MN and conducts all the control signaling to the core network and 5G NR is added to enable a high data rate over the air interface which transports only the user plane data connected to LTE Core Network EPC. This is defined by 3GPP as Option3, and is named EN-DC in the specifications.5G NR in stand-alone mode (5G NR only) is expected to be deployed later this year.

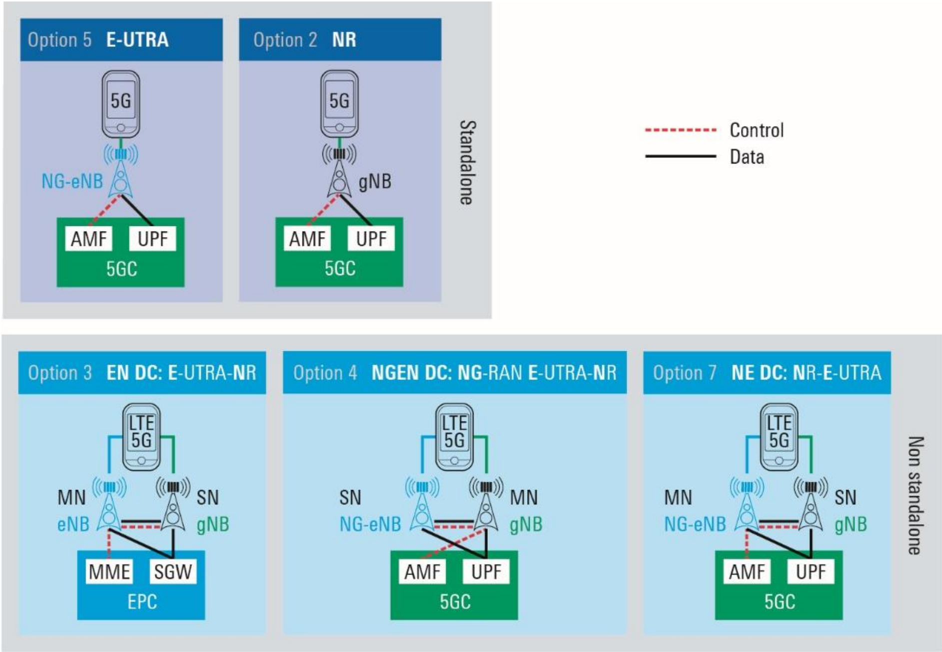


Figure 3: Multi connectivity options of a UE (eNB - LTE / gNB - 5G NR)

Beamforming and multi-connectivity in themselves do not guarantee the low latency required by the URLLC use cases.

To address the different nature of services, the design of the physical layer needs to offer very high configuration flexibility. Although the waveform is still OFDM-based as used in LTE, there are fundamental differences, which enable this required flexibility. A key difference to existing OFDM-based access schemes is the introduction of a so-called "flexible numerology", that allows multiple different subcarrier spacings (SCS) being used. In contrast to a fixed SCS of 15 kHz in LTE, 5G NR allows 15, 30, 60, 120 and 240 kHz SCS. This results into different symbol time durations, since the SCS is inversely proportional to the symbol duration. Likewise, the number of symbols in a fixed time duration, e.g. the number of symbols within a 10 ms radio frame, becomes a variable. The flexible numerology is a key component in enabling a configurable air interface.

The 5G NR carrier is split up in different bandwidth parts (BWP), where each part can have its own subcarrier spacing optimized for a certain use case. Each bandwidth part can have its own SS/PBCH block (SSB) and is allocated to UEs/devices according to their QoS requirements (eMBB, URLLC, mMTC).

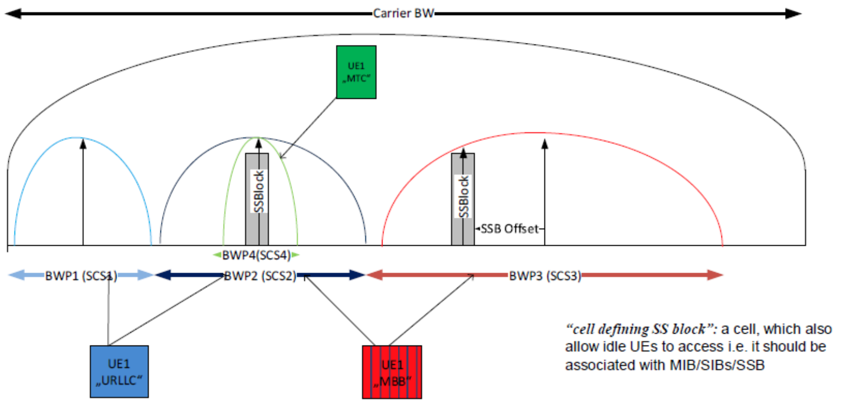


Figure 4: 5G NR component carrier divided in bandwidth parts with own synchronization blocks

Reserving dedicated bandwidth parts e.g. for URLLC increases the reliability significantly.

1.2.2 5G NR specific signals - a new approach

In previous cellular technologies, the UE measurement relies on always-on signal parts transmitted within a cell. For LTE networks, power measurements are executed and channel and timing feedback is provided based on the cell specific reference symbols. In 5G NR there are no cell specific reference symbols, which could serve as basis for these measurements. Therefore, it was decided to provide UE measurements based on the secondary synchronization (SS) signals and only among the reference signals corresponding to SS/PBCH blocks (SSB) with the same SSB index and the same physical-layer cell identity (PCI).

A 5G NR component carrier (CC) can have several SSBs allocated in different bandwidth parts, with one of them defined as the cell-defining SSB (CD-SSB).

Figure 4 visualizes different bandwidth parts and their synchronization blocks. In this example, the BWP 1 does not have its own synchronization block (SSB), which is possible according to 3GPP. An end user device will learn about bandwidth parts allocation through RRC Layer 3 signaling.

SSBs are cell-specific signals, which means that they are "always-on" and have a specific structure. As shown in Figure 5, each SSB occupies 240 subcarriers (frequency domain) and 4 symbols (time domain) and contains primary and secondary synchronization signals (PSS and SSS) and the physical broadcast channel (PBCH).

As we are familiar with from LTE, also in 5G NR the PSS and SSS represents the physical cell identity (PCI) and the PBCH carries the Master Information Block (MIB) plus a few additional payload bits.

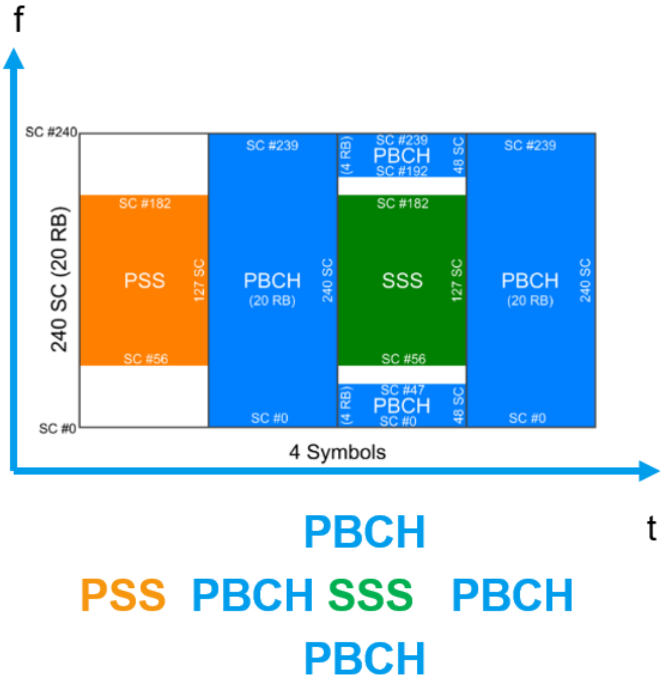


Figure 5: 5G NR synchronization block

If we zoom into the subcarriers (Figure 6), we can also see DM-RS (demodulation reference signals). The DM-RS are used by the UE for channel estimation to demodulate the PBCH. The positions of the DM-RS signals across the PBCH is determined by the PCI.

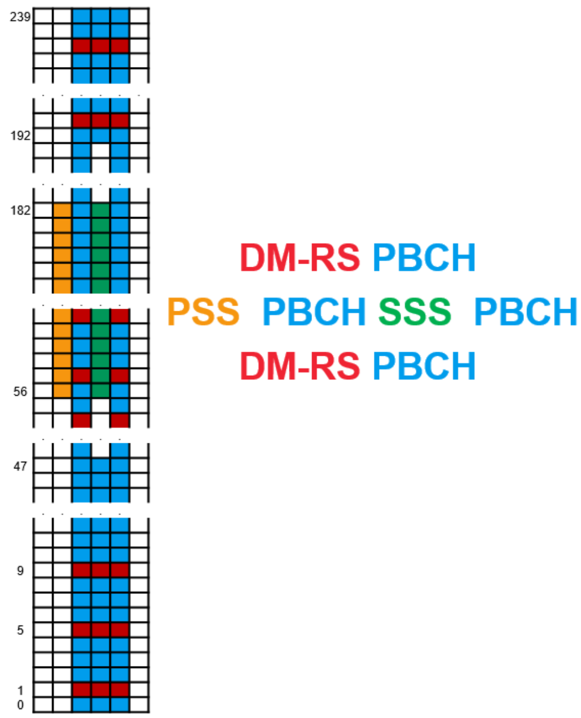


Figure 6: 5G NR synchronization block with increased zoom factor

SSBs are transmitted periodically from each cell and 3GPP have defined five transmission patterns named Case A, Case B ..Case E. The frequency range, the maximum number of SSB transmissions, the subcarrier spacing and the start-OFDM symbols define the cases.

SSBs are organized in burst sets, where a burst set is composed of one or multiple SSBs. Lmax denotes the maximum number of SS/PBCH blocks, which can be configured for the different cases. For higher frequencies, the number is significantly higher (Lmax = 64) than for the below 1 GHz frequency range (Lmax = 4), which reflects the need for more and smaller beams in the cm-/mm wave spectrum. Each SS/PBCH block has an index with increasing number from 0 to Lmax-1.

The periodicity (Figure 7 shows 20 ms) can vary between 5 ms and 160 ms (5, 10, 20, 40, 80, 160 ms). The 3GPP standard recommends using 20 ms periodicity for cell-defining SSBs. Higher periodicities like 80 or 160 ms are used preferably for SSBs in mm-wave networks to allow more time to transmit a higher number of SSBs in case D and E.

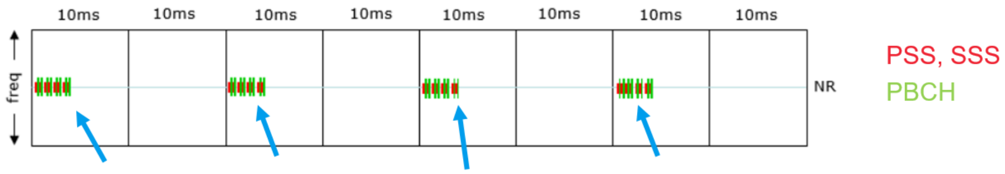


Figure 7: Periodically broadcasted synchronization blocks

As explained in chapter 1.2.1, beamforming is an essential method to overcome the increasing path loss when using higher frequencies. This is also used for the SSBs that can be beam-formed individually and preferentially cover a certain geographical area.

In the following example (Figure 8) a cell is transmitting six SSBs (L=6), meaning the SSB is transmitted six times, each time with a different value of the SSB index. If SSB beamforming is enabled, each SSB is transmitted on different spatial beams (here color-coded).

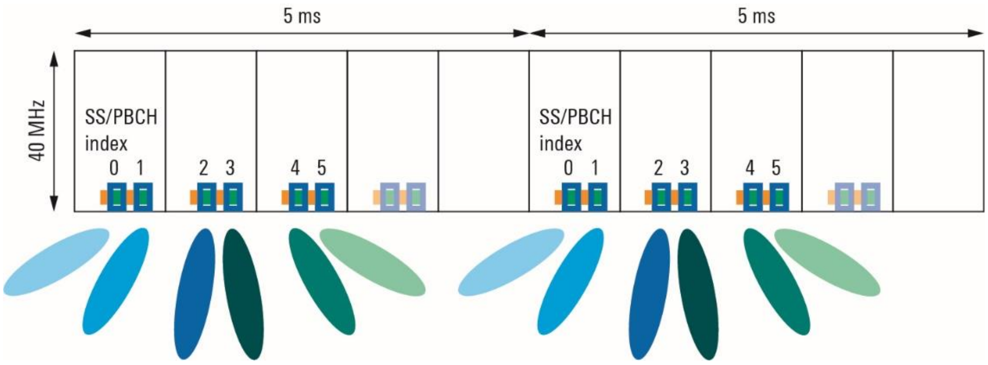


Figure 8: Example of SSB transmissions

3GPP gives the infrastructure vendors total freedom on how the beams shapes can look like and how they are mapped onto the SSBs. In theory, all SSBs could also be transmitted with the same spatial beam.

In Figure 9 a typical drive test scenario is depicted for a 5G NR network where SSBs are beam-formed individually along the route.

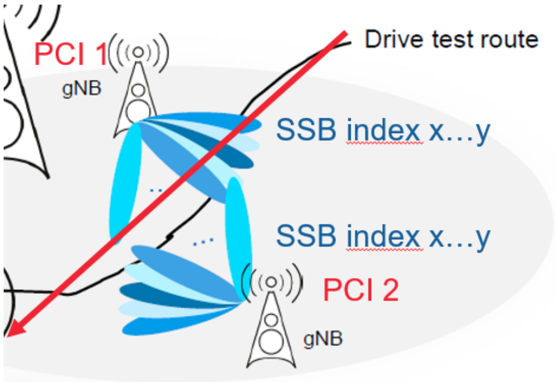


Figure 9: Drive test crossing several SSBs and PCIs

It is expected that infrastructure vendors and operators will optimize the beam forming according to the specific use case. The UE is involved in the beamforming procedure to acquire and maintain a set of gNB and/or UE beams for DL and UL transmissions, including measurement reporting of the different SSBs / beams. The beamforming management procedure is highly flexible and completely depends on the system vendors' implementation and configuration.

2 5G NR cell specific signal measurement

2.1 How to find 5G NR SSBs

In LTE, the PSS/SSS and PBCH signals are always transmitted around the center frequency of the carrier with fixed periodicity. However, in 5G NR the transmission characteristics of the SS/PBCH block are much more flexible which creates many new challenges when it comes to configure a 5G NR scanner.

Accessing or measuring a 5G NR carrier starts with discovering the SSBs. Each SSB's structure is unique but with different transmission cases and periodicities, their appearance over time is ambiguous. Furthermore, a single SSB only appears for a very short time (4 symbols) and it is hard to detect them with a traditional swept-tuned spectrum analyzer. To set up a scanner for 5G NR measurements, the frequency, transmission case and periodicity has to be known. The correlation between frequency and transmission case can be found via 3GPP tables but the SSB can be located almost everywhere in the spectrum.

The 3GPP standard defines a frequency raster for the appearance of SSBs (GSCN or NR-ARFCN depending on the deployment mode) but the raster is very narrow and there are hundreds of possibilities within a 5G NR carrier. Therefore, it is almost impossible to find the correct SSB frequency in the field without having detailed information about the SSB center frequency. To avoid time-consuming spectrum scans, wrong scanner configuration and guessing, the correct SSB center frequency (SSRef), R&S®ROMES4 with R&S®TSME6 / TSMA6 is able to detect the SSRef using a feature called Automatic Channel Detection (ACD). It runs automatically an internal spectrum scan and searches for SSBs in the frequency domain with a smart algorithm. It delivers the correct SSRef (and the corresponding case from a look-up table) within seconds and the scanner starts to measure the 5G NR specific signals.

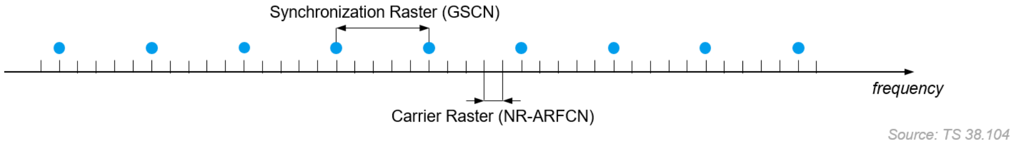


Figure 10: GSCN and NR-ARFCN frequency raster

With the benefit of ACD, the user just has to specify a band or a frequency range where a 5G NR SSB shall be detected. This is helpful especially for analyzing competitor networks, when parameters are completely unknown. The result of the ACD is shown in the ACD view contained in the Figure below. Grey lines show the internal spectrum scan and a blue box indicates at which frequency a 5G NR SSB was found.

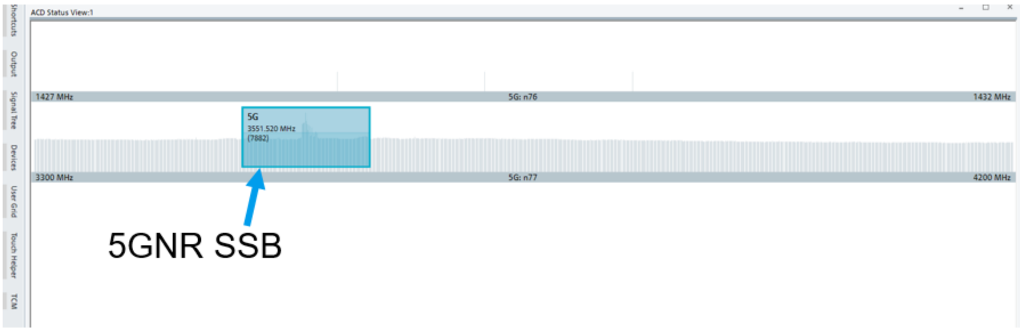


Figure 11: 5G NR ACD result in the ROMES4 ACD view

The ACD expects a 3GPP compliant 5G NR SSB transmitted on multiple frames with an increasing system frame number. Internally, the ACD uses the 3GPP band table to select the SSB transmission case for the selected frequency bands. This accelerates the ACD and avoids checking the algorithm for unnecessary cases (e.g. Case E for band n1). ROMES4 includes several band table versions, which can be set in Technology / TEC settings of the 5G NR scanner in the section Settings -> 'Band Version'. The GSCN raster is also defined by the band table version.

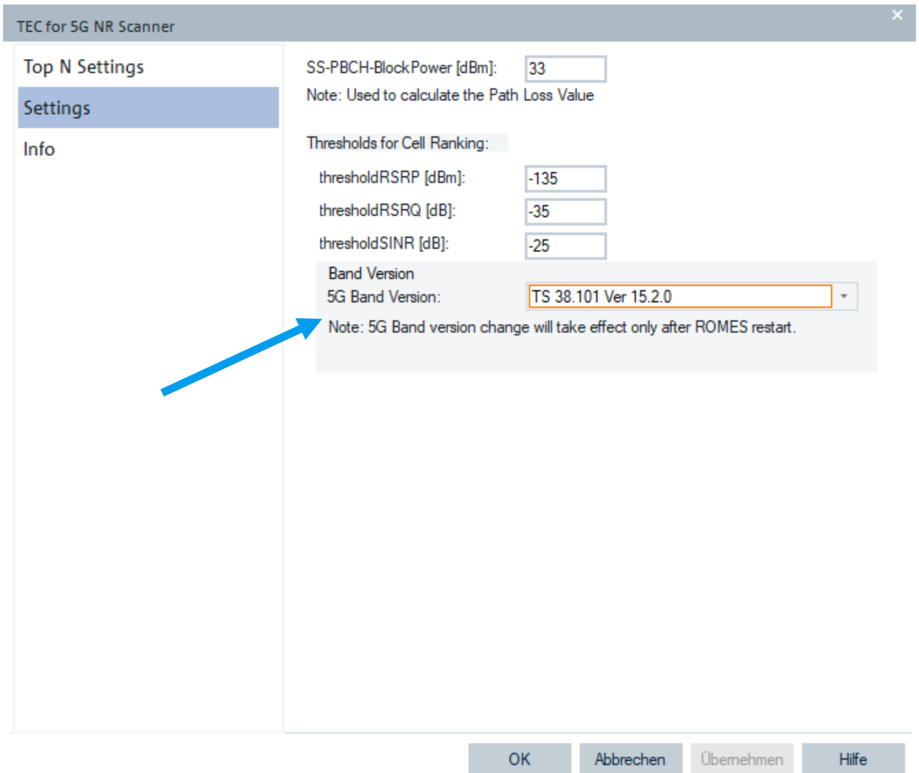


Figure 12: Selecting the band table version in ROMES4.

ACD tests using a signal generator might be not successful as signal generators transmit just a few frames when using their default settings. It is recommended to increase the number of frames in signal generator configuration.

2.2 SSB measurements for cell and beam quality evaluation

As described in 1.2.2, the synchronization signals are transmitted as several SSBs consisting of primary, secondary sync signals and the PBCH. SSBs are transmitted in burst sets with a certain pattern and periodicity.

In 5G NR the UE measurement reference signals corresponds to SS/PBCH blocks (SSB) with the same SSB index and the same physical-layer cell identity (PCI) and the measurement results will be used for evaluating and reporting both beam and cell quality. The random access procedure at initial access is based on beam measurements, where the UE will select an SSB for the preamble transmission among all the detected SSBs that fulfill certain criteria. The cell reselection and handover procedures are based on cell quality evaluation where the cells are ranked based on the resulting average of the SSB measurement results per cell.

The unique Top N pool concept in ROMES4 enables analysis and visualization of both beam and cell quality results based on scanner measurement data in parallel.

Beam measurement analysis

As each SSB can be beam formed individually, it is required to obtain beam quality measurement results for each SSB per PCI. An example of a list of several received PCIs with several SSBs captures by an R&S®TSMx6 can be found in Figure 13.

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

Top N: Beam specific

Top N List

#	T	PCI	SSB Idx	SSS-RSRP	SSS-SINR	SSS-RSRQ
1	1	20	2	-77.8	3.4	-11.9
2	2	20	3	-83.2	3.5	-11.9
3	3	20	1	-88.3	-0.5	-13.6
4	4	19	6	-94.0	-3.7	-15.5
5	5	20	0	-95.0	-0.3	-13.5
6	6	20	4	-96.0	0.4	-13.1
7	7	20	7	-97.0	-2.6	-14.8
8	8	19	5	-99.0	-4.7	-16.3
9	9	19	7	-98.8	-5.2	-16.6
10	10	20	5	-98.1	-3.5	-15.4

Figure 13: Beam / SSB specific Top N Pool with RF results for each received SSB index.

This type of Top N Pool is called Beam or SSB specific Top N Pool. It can be configured to average and rank SSBs by either SSS-RSRP, -SINR or RSRQ. In this case, the scanner received two PCIs (19, 20) with several SSB indices from each PCI. In this example, a Beam specific pool is selected in the Top N view and it ranks the SSB Index according to their SSS-RSRPs. Top N Pool settings can be changed in ROMES4 Technology / TEC settings of the 5G NR scanner, menu: Top N Settings -> Top N Pool -> Manual Pool configuration -> Properties.

ROMES4 Signal Tree displays the Top N Pool signals indexed by their ranking order. The automatic coloring of the PCI and SSB index signals that are enabled by default and displayed at the left edge of the Top N Pool. The Signal color settings are consistent in all 5G NR related Scanner Views as well as on the ROMES4 Map and if used in the customizable Basic Views.

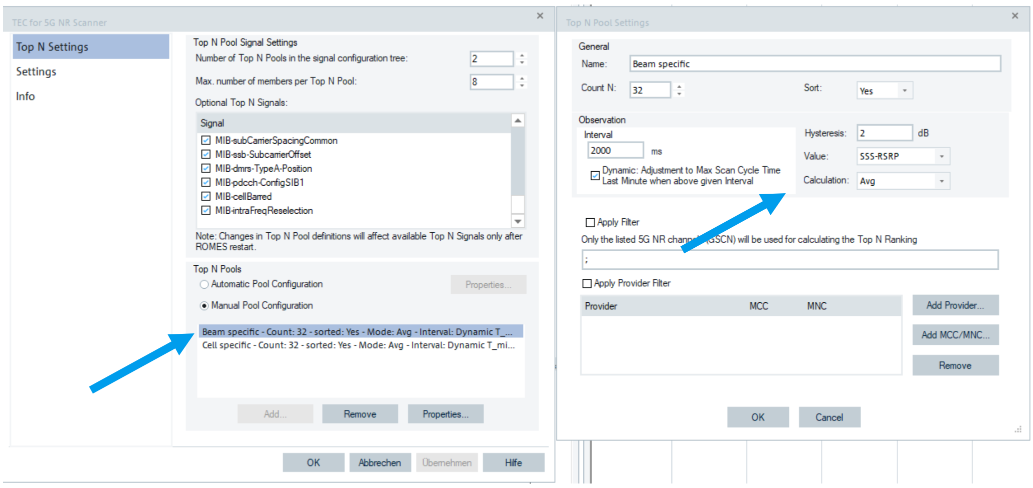


Figure 14: Top N Settings in ROMES4 for a Beam / SSB specific Top N Pool

It is also possible to change the hysteresis and the observation interval for the Top N Pool calculation algorithm. Increasing the Top N observation interval leads to smoother RF measurement results as it observes and calculates the signal for the Top N ranking decision over a longer time interval. Increasing the Top N hysteresis will reduce the frequency of rank changes.

Cell measurement analysis

Additional Top N Pools can be created and configured to deliver cell specific signals that are computed as linear averages of the contributions of each SSB index of the same PCI.

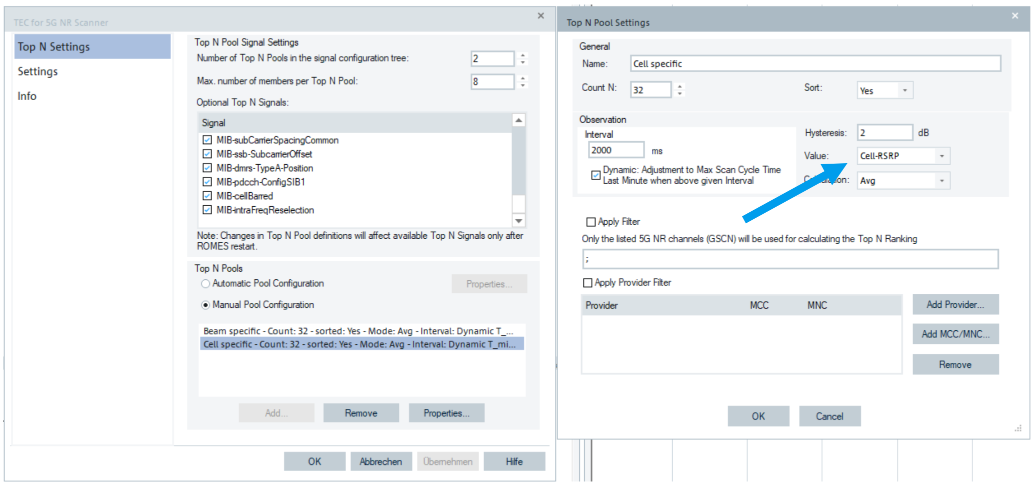


Figure 15: Top N Settings in ROMES4 for a Cell / PCI specific Top N Pool

In Figure 15, the value used for averaging and ranking the Top N Pool is now Cell-RSRP. It can also be configured to use Cell-SINR and Cell-RSRQ.

After configuring a cell specific Top N Pool, the Top N View delivers results for each PCI and averages signals from all received SSB Indices, which are above a certain threshold. Other SSB indices below those thresholds are ignored in Cell specific Top N Pools.

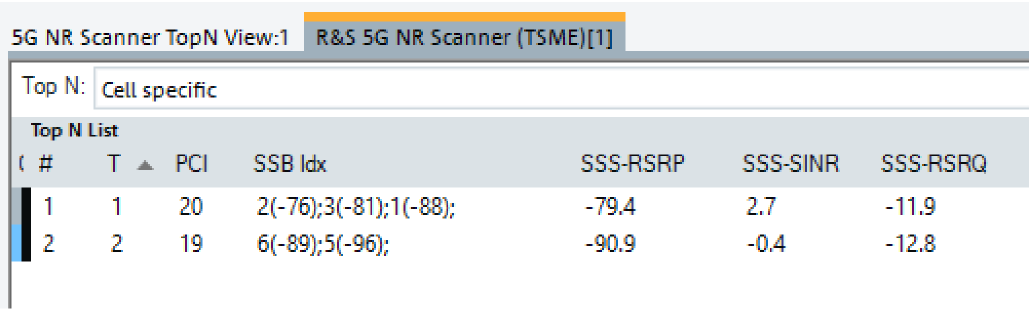


Figure 16: Cell / PCI specific Top N Pool with RF results for each received PCI.

These thresholds correspond to the 3GPP model of Layer3 filtering for cell quality reporting and can be changed in the ROMES4 Technology / TEC settings of the 5G NR scanner in the menu Settings -> Thresholds for Cell Ranking.

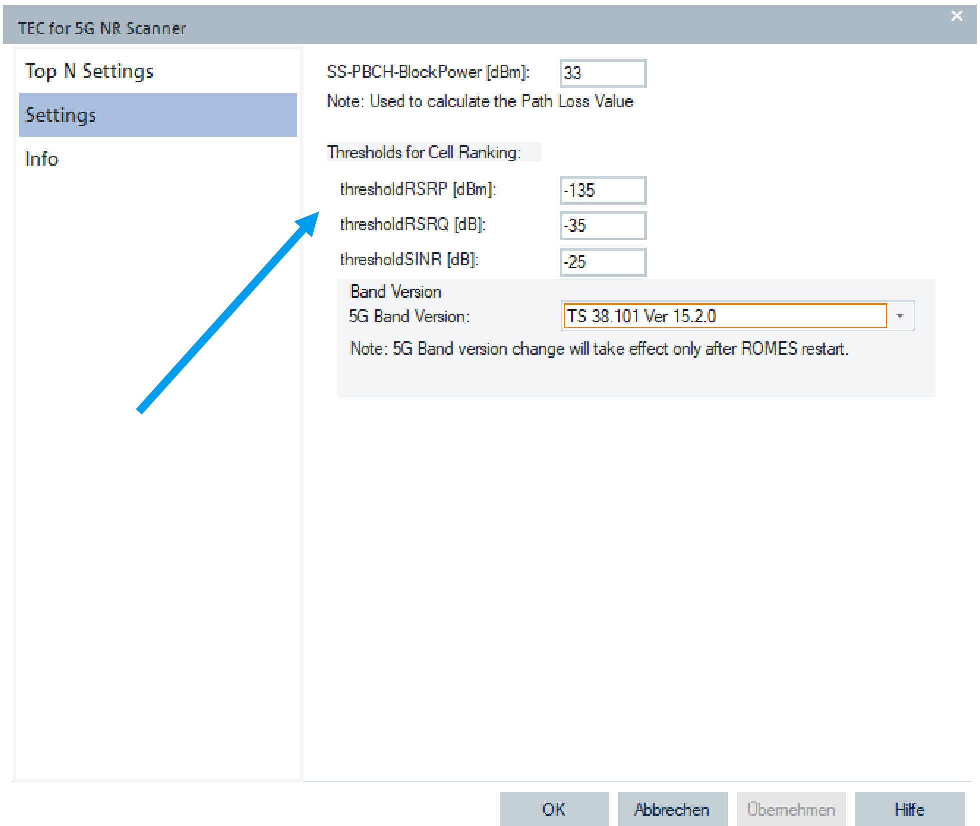


Figure 17: Setting thresholds for PCI / cell based Top N Pools.

The measurements, used for the example above were made within the coverage area of a gNB, which had SSB beamforming (Figure 19) enabled. Depending on the network configuration, it is also possible to transmit several SSBs without beamforming in the same cell sector (Figure 18). In this case, the scanner would deliver measurement results for just one SSB index.

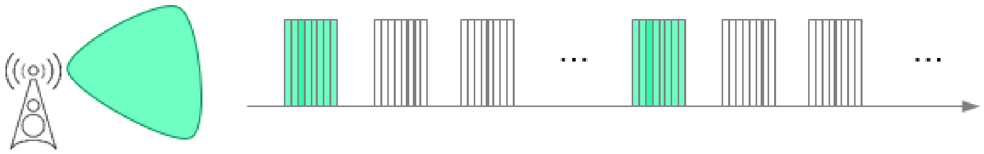


Figure 18: Multiple SSBs (green) transmit the same beam.

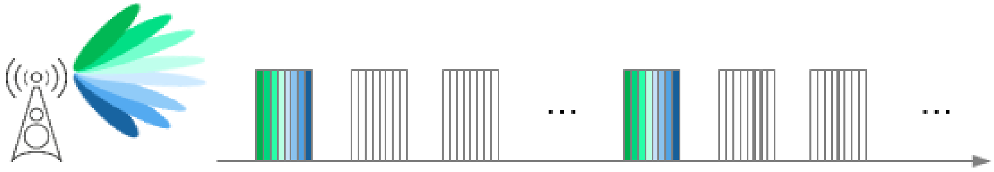


Figure 19: Individual SSBs (blue, grey, green) transmitted on multiple physical beams

Figure 20 and Figure 21 summarize the topic of SSB / beam specific vs. cell specific Top N Pools:

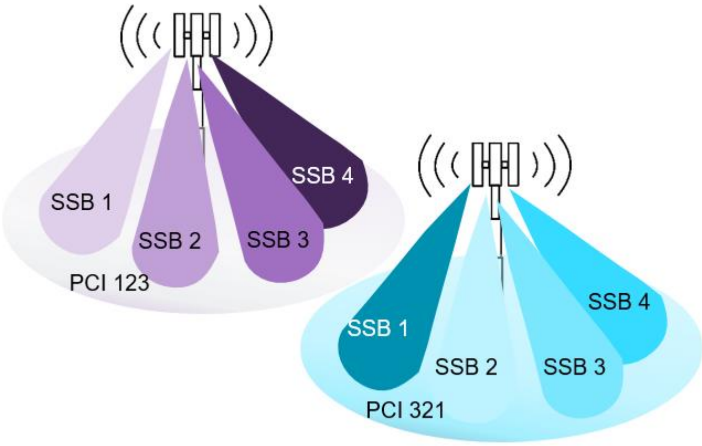


Figure 20: Two 5G NR cells with different PCIs (123, 321) and four SSB beams each

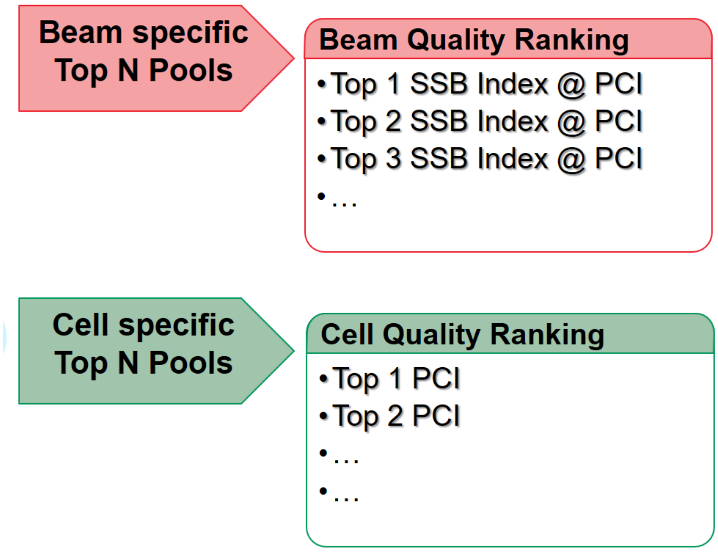


Figure 21: Ranking dimensions for SSB / beam and Cell specific Top N Pools

2.3 SSB Coverage, SINR and quality measurements

As mentioned in chapter 1, 5G NR will be deployed at new cm-/mm-wave frequencies and apply beamforming techniques to overcome the increased path loss. Field-testing is thus important to verify that the intended coverage at a certain frequency is achieved in an operating network. In cellular networks, the coverage area is the geographic area where the base station and the user device can communicate. Coverage depends on multiple factors such as the environment (mountains, buildings, etc.), technology, radio frequency and most importantly for two-way telecommunications, the sensitivity and transmit efficiency including the maximum output power of the base station and the end-user device.

Coverage measurements usually comprise the availability e.g. the signal strength above a defined minimum threshold of the downlink signal components (e.g. broadcast channels, synchronization signals..) in a geographical area that are required to allow the end-user device to synchronize with the base station and to obtain basic network information essential to access the network.

To achieve precise coverage measurements, the network scanner delivers RF measurement results for several SSB signal components. The Reference Signal Received Power that is measured on the Secondary Synchronization Signal is for example called SSS-RSRP. This is the same measurement value as the SS-RSRP, 3GPP specifies for carrying out SSB power measurements

SSBs from one PCI normally do not interfere with each other, because they are transmitted consecutively over time, but SSBs from different PCIs are likely to interfere, depending on the network configuration. Therefore, SINR measurements are an essential part of coverage measurements. Receiving several SSBs, but each one with a bad SINR, leads to the same result as not having any coverage at all. The same applies to RSRQ (SSS-RSRQ) measurements, which indicate the quality of the received signal components where the SINR also plays an important role. The network scanner can deliver RSRP, SINR and Pathloss metrics for several SSB signal components. RSRQ is only available for secondary sync measurements.

Table 1 5G NR Scanner measurement values

Measurement value	Definition
PSS-RSRP	Primary synchronization signal reference signal received power (PSS-RSRP) is defined as the linear average over the power contributions (in [W]) of the resource elements that carry primary synchronization signals (PSS).
PSS-SINR	Primary synchronization Signal-to-noise and interference ratio (PSS-SINR), is defined as the linear average over the power contribution (in [W]) of the resource elements carrying primary synchronization signals divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying primary synchronization signals within the same frequency bandwidth.
PSS-Pathloss	Calculated primary synchronization signal path loss, when the SS-PBCH resource element power is known.
SSS-RSRP	Secondary synchronization signal reference signal received power (SSS-RSRP) is defined as the linear average over the power contributions (in [W]) of the resource elements that carry secondary synchronization signals (SSS).

SSS-SINR	Secondary synchronization signal-to-noise and interference ratio (SSS-SINR), is defined as the linear average over the power contribution (in [W]) of the resource elements carrying secondary synchronization signals divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying secondary synchronization signals within the same frequency bandwidth.
SSS-RSRQ	Secondary synchronization signal reference signal received quality (SSS-RSRQ) is defined as the ratio of N×SS-RSRP / NR carrier RSSI, where N is the number of resource blocks in the NR carrier RSSI measurement bandwidth. The measurements in the numerator and denominator shall be made over the same set of resource blocks.
SSS-Pathloss	Calculated secondary synchronization signal path loss, when the SS-PBCH resource element power is known.
SSB-RSSI	Average power of all resource elements carrying OFDM signals, interference and noise within all SSBs used for carrying out the measurement.
DM-RS- RSRP	Demodulation reference signal received power (PBCH-DMRS-RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements that carry demodulation reference signals within the PBCH configured for RSRP measurements within the considered PBCH bandwidth (max. 20 MHz).
DM-RS SINR	Demodulation reference signal-to-noise and interference ratio, is defined as the linear average over the power contribution (in [W]) of the resource elements carrying demodulation reference signals (configured for RSRP measurements within the considered PBCH bandwidth, max. 20 MHz) divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying demodulation reference signals.
DMRS-Pathloss	Calculated DM-RS pathloss, when the SS-PBCH resource element power is known.
PBCH-RSRP	PBCH reference signal received power (PBCH-RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements that carry PBCH signals configured for RSRP measurements within the considered PBCH bandwidth (max. 20 MHz); DM-RS excluded.
PBCH-SINR	PBCH SINR signal-to-noise and interference ratio, is defined as the linear average over the power contribution (in [W]) of the resource elements carrying PBCH signals (configured for RSRP measurements within the considered PBCH bandwidth) divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying PBCH reference signals; DM-RS excluded.
PBCH-Pathloss	Calculated PBCH path loss, when the SS-PBCH resource element power is known.
SSS-PBCH-RSRP	Secondary synchronization signal and PBCH reference signal received power (SSS-PBCH-RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements that secondary sync signals, PBCH and demodulation reference signals configured for RSRP measurements within the considered PBCH bandwidth (max. 20 MHz). Primary sync signals are excluded.
SSS-PBCH-SINR	Secondary synchronization signal and PBCH signal-to-noise and interference ratio (SSS-PBCH SINR), is defined as the linear average over the power contribution (in [W]) of the resource elements carrying secondary synchronization signals, PBCH and demodulation reference signals (configured for RSRP measurements within the considered PBCH bandwidth, max. 20 MHz) divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying secondary synchronization, PBCH and demodulation reference signals. Primary synchronization signals are excluded.

SSS-PBCH-Pathloss	Calculated SSS-PBCH (excl. primary synchronization signals) pathloss, when the SS-PBCH resource element power is known.
xSS-PBCH RSRP	Primary and secondary synchronization signal, PBCH and DM-RS reference signal received power (xSS-PBCH-RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements that primary. secondary sync signals, PBCH and demodulation reference signals configured for RSRP measurements within the considered PBCH bandwidth (max. 20 MHz).
xSS-PBCH-SINR	Primary, secondary synchronization signal, PBCH and DM-RS signal-to-noise and interference ratio (xSS-PBCH SINR), is defined as the linear average over the power contribution (in [W]) of the resource elements carrying primary, secondary synchronization signals, PBCH and demodulation reference signals (configured for RSRP measurements within the considered PBCH bandwidth, max. 20 MHz) divided by the linear average of the noise and interference power contribution (in [W]) over the resource elements carrying primary, secondary synchronization, PBCH and demodulation reference signals.
xSS-PBCH-Pathloss	Calculated PSS-SSS-PBCH pathloss, when the SS-PBCH resource element power is known.

All values in Table 1 are available as dedicated signals in the ROMES4 Signal Tree and can be displayed in a fully customizable manner.

However, for the tailored 5G NR Scanner presentation views, History View, Performance View and Scanner Chart View, only the SSS signals RSRP, RSRQ, and SINR values are available.

Coverage map visualization

During a drive test or afterwards in file replay, any signal in the ROMES4 Signal Tree (e.g. SSS-RSRP) can be dragged and dropped onto the ROMES Map View. With the 5G NR scanner measuring on each SSB index individually, a beam specific TopN Pool has dedicated signals for each combination of PCI and SSB index.

To combine a measured RF signal with PCI and SSB index in the same map plot the ROMES4 Map View supports route underlays, which helps to visualize the best server PCI and SSB index along with the desired RF signal.

To present the cell and beam coverage as color shaded signal tracks, the wanted RF signal (e.g. SSS-RSRP) is dragged from the Signal Tree and dropped on the map or alternatively directly added using the Map View Configuration menu.

For a beam specific Top N Pool map plot of SSS-RSRP, there will be two additional route underlay colors, see Figure 22 and Figure 23:

- Inner line color by best (Top1) PCI
- Outer line color by best SSB Index

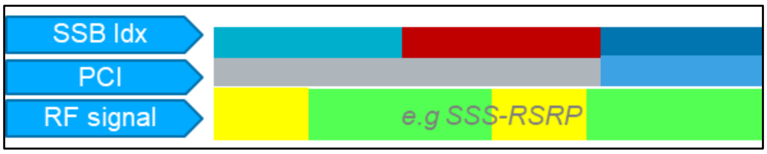


Figure 22 ROMES4 5G NR Scanner map plot coloring for Beam specific Top N signals

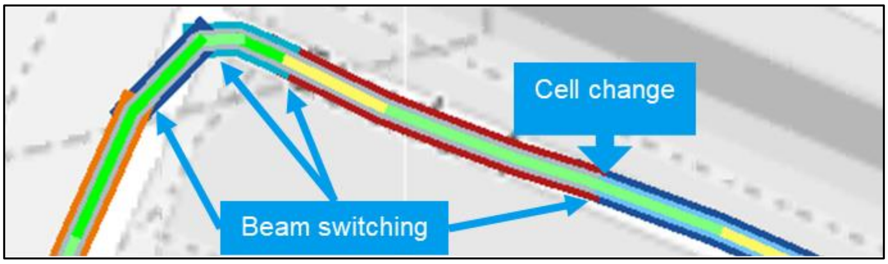


Figure 23 ROMES4 Map example of Beam specific Top N plot

The underlay colors make it very easy to spot the positions of the best cells and where the best beams are changing.

To enhance the focus on the RF signal plot, you may like to hide the underlay colors and this is very easy to do from the Map View menu or with keyboard shortcut 'Ctrl+Alt+M'.

For a cell specific Top N Pool there will be one underlay color displaying the best (Top1) PCI.

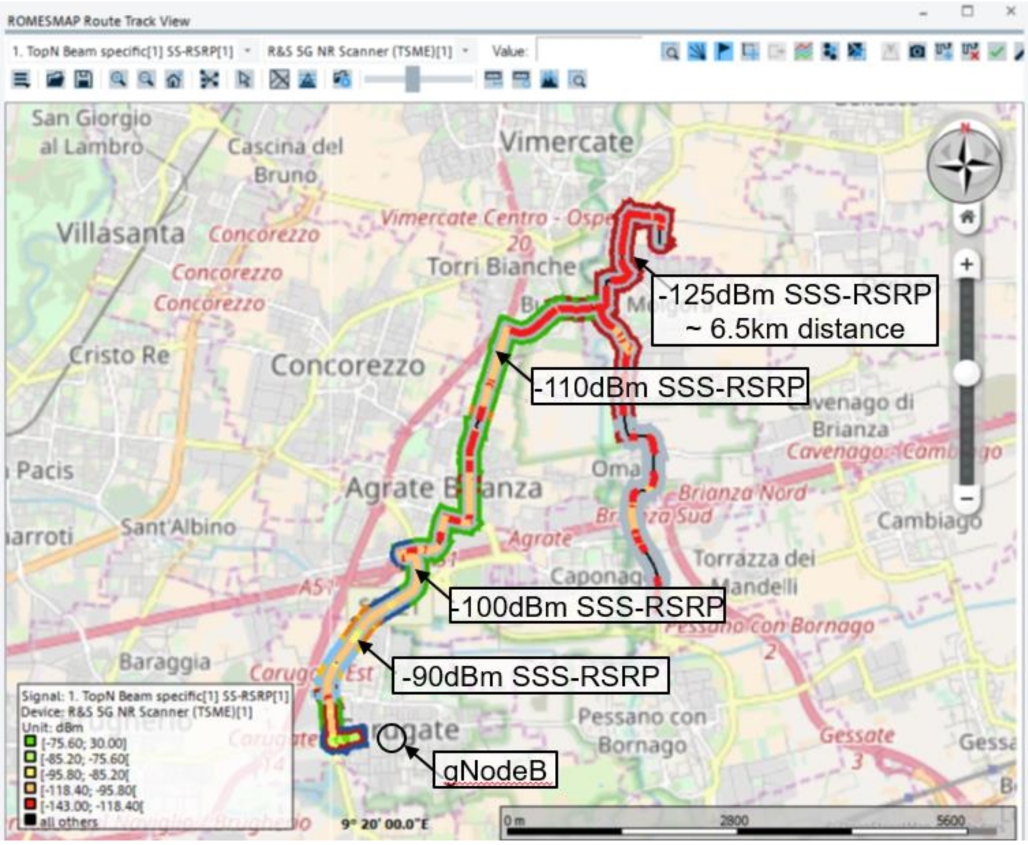


Figure 24: Drive test at 3.7 GHz in a suburban environment.

One of the world's first drive tests in a 3.7 GHz 5G NR network in a sub-urban environment showed a surprisingly good coverage due the beamforming of the SSBs. At a distance of 6.5 km, a SSS-RSRP of still -125 dBm was received (Figure 24).

The fact that the SSBs are beam formed in this case becomes obvious when taking a closer look at the SSB index (outermost layer) during the drive test. In the early test network, the transmission case B was used, which means a group of eight SSBs was transmitted periodically. Taking a closer look at drive test results in Figure 24, the SSB index changes several times represented by different colors, while the PCI (second innermost layer) remains unchanged. By displaying the strongest SSS-RSRP with its corresponding SSB index and PCI on the map, the geographical coverage of the SSB beams can be analyzed.

To highlight the SSB beam coverage, the potential beam directions and coverage areas are drawn on the map.

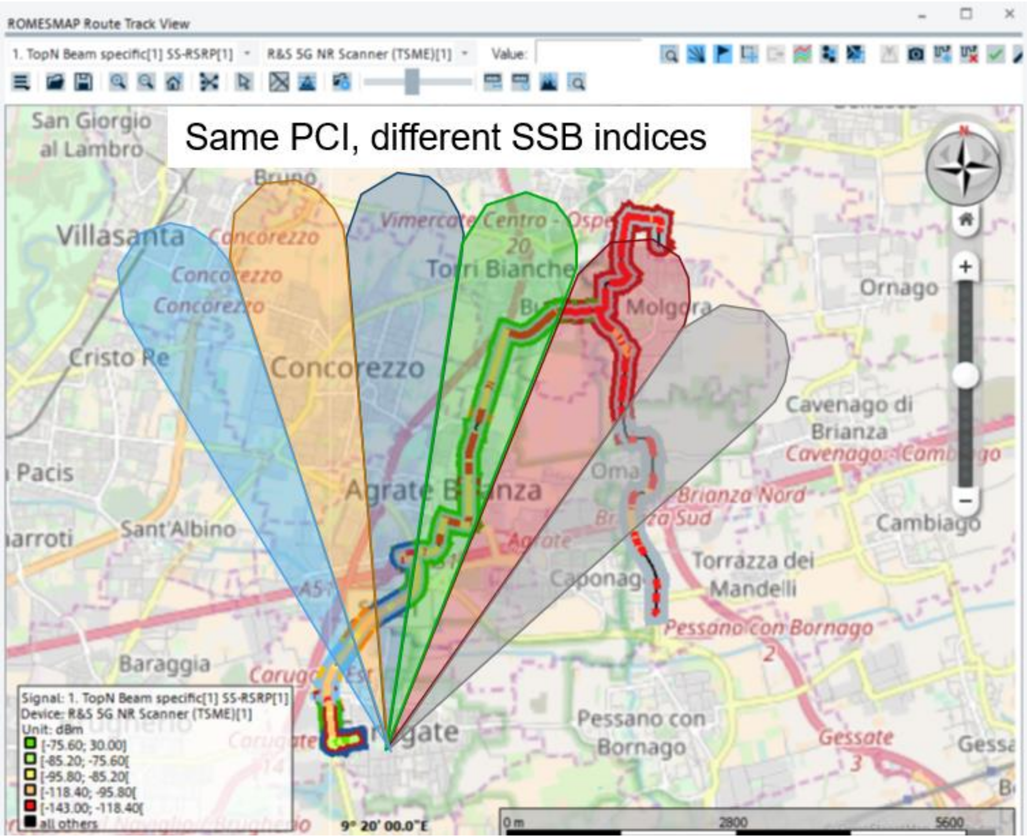


Figure 25: Mapping the potential beam coverage on the SSB index results.

This is also an indication that beamforming with an antenna array (e.g. 64x64 elements) works quite well. With a beam width of around 10° per SSB beam, the radiated power of the SSBs is concentrated horizontally in a narrow area. This explains the extremely good coverage for 5G NR at 3.7 GHz. If the LTE cell uses standard base station antennas with a half power beam width of around 65°, the power is distributed over a wider horizontal area.

SSB index and PCI changes can also be visualized in the 5G NR History View. The view indicates changes to the PCI and the SSB index for the highest ranked cells in a cell specific Top N Pool over time. Color codes for PCI and SSB index are consistent in all 5G NR scanner views including the map. In the example below, the following color codes apply:

PCI 13 - grey, SSB index 7 - grey, and SSB index 0 - red.

Figure 26 shows the 5G NR SSB History View, indicating a change of the SSB index (seven to zero, grey to red) of the best Top N Cell. At a certain point in time, the color and SSB index changes. The 5G NR SSB History View can also visualize PCI and SSB index changes of the second best and third best cell, but in the screenshot the sections are not populated because just one PCI was received at that point of time. At the geographical border between two SSB indices (beams), the signals might change quickly over a short period of time.

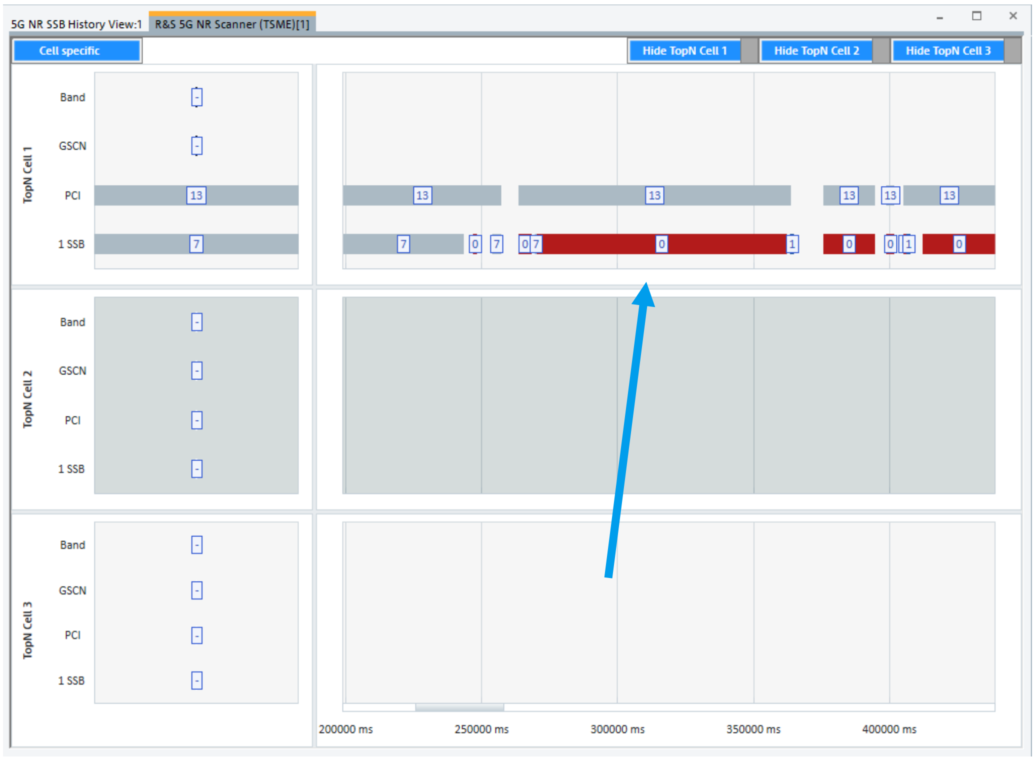


Figure 26: 5G NR scanner SSB History view indicating a change of the SSB index (same PCI)

Important note: The 5G NR Scanner SSB History View requires a cell specific Top N Pool, details are explained in section 2.2. The view is user-configurable, e.g. the visualization of SSB index and PCI changes of the second and third best cell (= PCI) can be hidden for better clarity. A right click in the view -> Properties leads to advanced settings like the update rate. In the advanced settings, the view can also be configured to show two or more SSB indices per PCI (second best, third best…).

Figure 27 highlights the same location of the measurement file on the ROMES4 Map (blue circle). The color of the outermost layer, which visualized the SSB index changes from grey to red, while the second innermost layer (which indicates the PCI) maintains its color (grey).

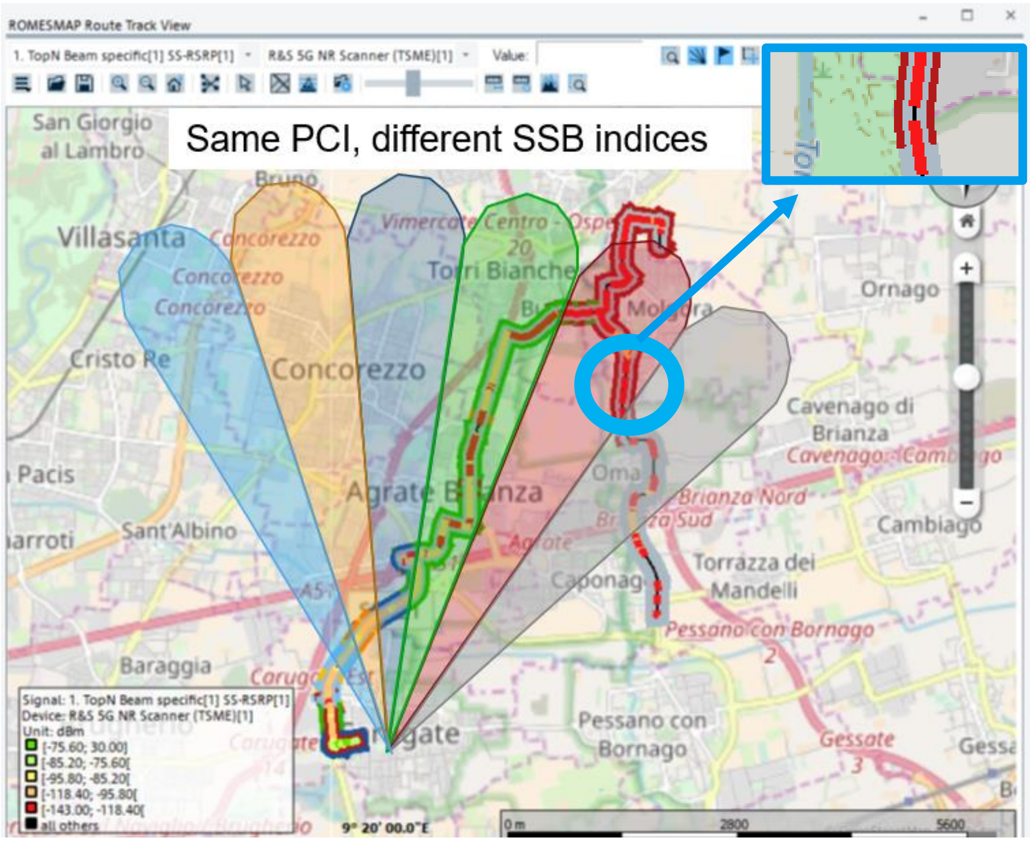


Figure 27: Change of SSB index on the map (highlighted with blue color)

In summary, the 5G NR Scanner History View is a good tool to visualize how the dynamic behavior of Cell specific Top N members (PCIs and SSBs) evolve over time. If scanner based measurements are compared with UE based measurements, the view helps to answer the question of whether the UE uses the strongest beam for the RACH procedure.

While the 5G NR History View shows the PCI and SSB index evolving over time, the 5G NR Scanner SSB Performance View is the right choice if the detailed chronological sequence of the RF signal is of interest. An application could be drive tests to measure the propagation e.g. in street canyons with road junctions and several changeovers from line-of-sight to non-line-of-sight scenarios. The view visualizes major RF signals (SSS-RSRP, -RSRQ, -SINR) evolving over time. It also indicates PCIs and SSB indices with the established color codes (PCI - background color, SSB index - bar color). The view grabs the results from a cell-specific Top N Pool, which is mandatory for the view displaying data. By default, each graph in the right section of the view is filled with data from the first best and second cell. In the left section the PCI and SSB index is displayed. It is very important to consider, that only SSB indices above the thresholds (see section 2.2) for cell specific Top N Pools are shown in the graph. A screenshot of the view can be found in Figure 28. It is user-configurable (right click → 'Properties') for example in terms of the number of displayed PCIs and SSB indices.

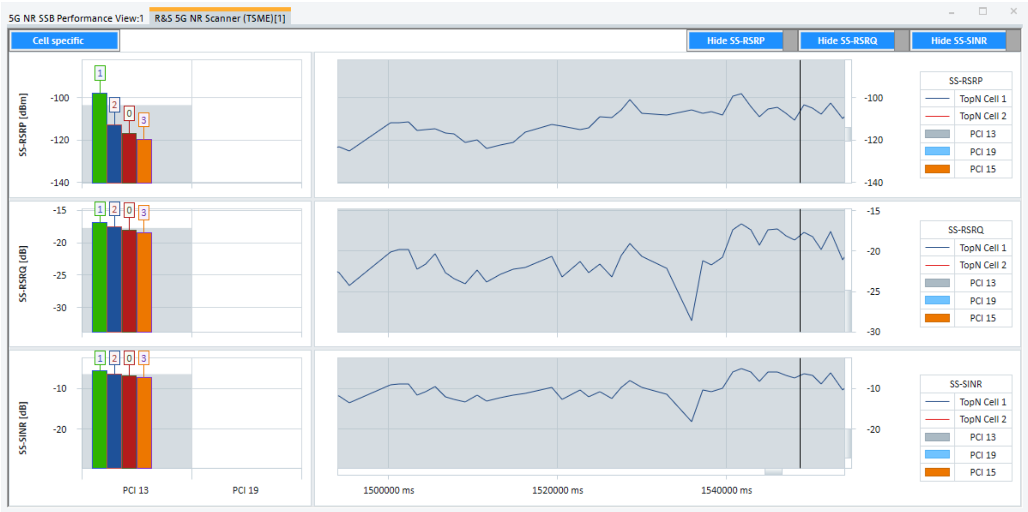


Figure 28: 5G NR Scanner SSB Performance View visualizing values from a Cell specific Top N Pool, with detailed RF results from PCI 13.

All previously discussed 5G NR Scanner Views (including the ROMES4 Map) display Top N Pool signals that are defined in the Signal Tree. The Top N algorithm, which applies a certain user-configurable averaging time interval and ranking hysteresis threshold, which is very similar to the 5G UE measurement filtering algorithm defined by 3GPP, helps to smooth out the measurement results and make it easier to study with the human eye.

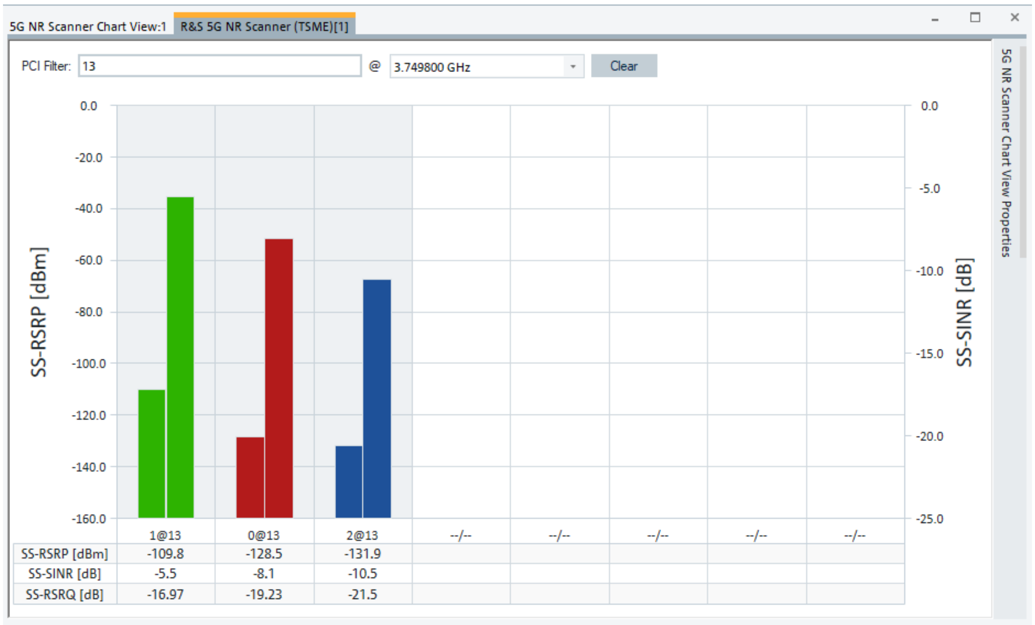
However, some test cases, e.g. lab tests with fast switching SSBs or drive tests exactly on the geographical border of SSBs / beams, might require access to pure scanner data. Therefore, ROMES4 includes the 5G NR Scanner Chart View, which shows SSS-RSRP and SSS-SINR bars for each received PCI - SSB index combination. The number of displayed PCI - SSB index combinations and the ranking criteria (SSS-RSRP, -RSRQ, or -SINR) can be configured in the 'Properties' dialog.

Without running through the Top N algorithm, the data in the view is changing quickly. For identifying the PCI and SSB indices at a glance, the view works with same colors for the PCI and SSB index, derived from the Top N Pool. It uses background colors for PCIs and bar colors for SSB indices. The view also supports filtering on certain PCIs and PCI - SSB index combinations by using the following syntax:

1@13 → SSB index 1 and PCI 13

13 → PCI 13

Figure 29 shows the view filtered by PCI 13. It uses grey background color for PCI 13 and green, red and blue for several SSB indices.



	1@13	0@13	2@13	--/--	--/--	--/--	--/--	--/--
SS-RSRP [dBm]	-109.8	-128.5	-131.9					
SS-SINR [dB]	-5.5	-8.1	-10.5					
SS-RSRQ [dB]	-16.97	-19.23	-21.5					

Figure 29: 5G NR Scanner Chart View filtered by PCI 13.

2.4 PBCH / MIB demodulation

Chapter 1.2.2 explained the PBCH position within the SSB. R&S®ROMES4 with R&S®TSME6 / TSMA6 is able to decode the information carried by the PBCH. 5G NR leaves a high degree of freedom in terms of network configuration, so PBCH demodulation is a valuable feature for example to check the correct network configuration on site.

The PBCH includes the MIB (Master Information Block) and several bits, which are mandatory to identify SSB indices greater than eight. Those SSB indices are primarily used in transmission cases D and E in mm-wave deployments. Without this information the scanner can only decode the three LSBs and it just shows SSB index mod 8, indicated by two stars ** at the first positions of the SSB index.

The MIB includes the following information:

```
systemFrameNumber           BIT STRING (SIZE (6)),
subCarrierSpacingCommon     ENUMERATED {scs15or60, scs30or120},
ssb-SubcarrierOffset        INTEGER (0..15),
dmrs-TypeA-Position         ENUMERATED {pos2, pos3},
pdcch-ConfigSIB1            INTEGER (0..255),
cellBarred                  ENUMERATED {barred, notBarred},
intraFreqReselection        ENUMERATED {allowed, notAllowed},
spare                       BIT STRING (SIZE (1))
```

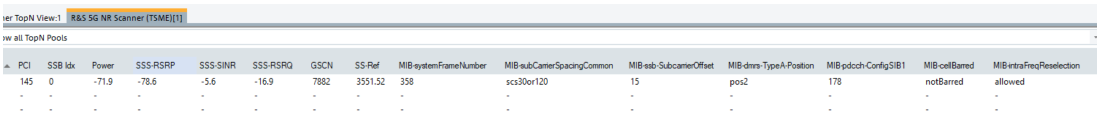
Figure 30: 5G NR MIB content

Decoded MIB information is delivered in dedicated ROMES4 signals for each MIB message.

- [ ] MIB-systemFrameNumber
- [ ] MIB-subCarrierSpacingComm...
- [ ] MIB-ssb-SubcarrierOffset
- [ ] MIB-dmrs-TypeA-Position
- [ ] MIB-pdcch-ConfigSIB1
- [ ] MIB-cellBarred
- [ ] MIB-intraFreqReselection

Figure 31: ROMES4 signals which carry the MIB demodulation results

The Top N View can be used to read the signal / MIB contents by adding the signals to the view. Each measured SSB carries its own set of MIB information; therefore, ROMES4 displays the MIB contents per detected SSB index together with other RF signals explained in section 2.



PCI	SSB Idx	Power	SSS-RSRP	SSS-SINR	SSS-RSRQ	GSCN	SS-Ref	MIB-systemFrameNumber	MIB-subCarrierSpacingCommon	MIB-ssb-SubcarrierOffset	MIB-dmrs-TypeA-Position	MIB-pdcch-ConfigSIB1	MIB-cellBarred	MIB-intraFreqReselection
145	0	-71.9	-78.6	-5.6	-16.9	7882	3551.52	358	scs30or120	15	pos2	178	notBarred	allowed
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 32: MIB contents per SSB index in dedicated signals

PBCH / MIB demodulation is "always-on" and does not have to be enabled separately.

3 Millimeter-wave measurements

The R&S®TSMx6 drive test scanner can be easily upgraded with a downconverter to measure in mm-wave bands. The downconverter R&S®TSME30DC is a hardware component between the receiver antenna and measurement scanner to convert mm-wave frequencies (24 - 30 GHz) to sub 6 GHz frequencies (2.9 – 3.5 GHz, intermediate frequency IF), which are natively supported by R&S®TSMx6. Integrating the downconverter in the measurement setup is very simple. After a unique basic configuration in the TSME DeviceManager, it is fully controlled by the R&S®TSMx6 and ROMES4, which automatically sets all internal down conversion parameters according to the measurement task for the best system performance. Any kind of user input regarding down conversion RF parameters is not required.

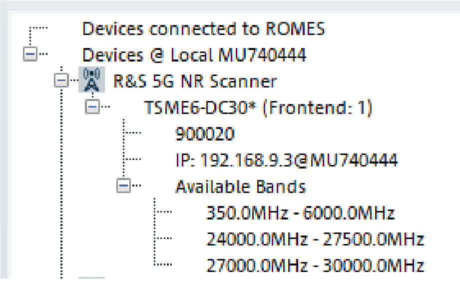


Figure 33: TSME30DC downconverter is automatically recognized as a front-end frequency extension in ROMES4.

One single R&S®TSMx6 with a TSME30DC supports simultaneous mm-wave and sub 6 GHz measurements. In this case, both antennas (sub 6 GHz and mm-wave) are connected to the downconverter, which is able to either bypass sub 6 GHz signals or the down converted (IF) signal. Both operation modes are changed automatically and in real-time during the measurement.

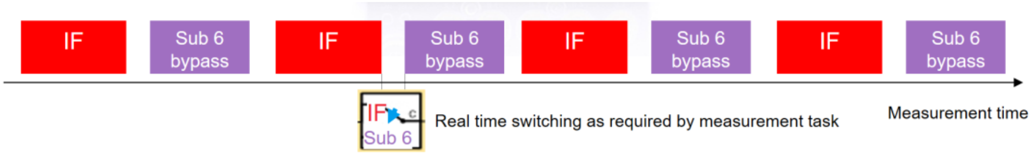


Figure 34: Real time switching between sub 6 GHz bypass and IF

Scanning results for mm-wave measurements are similar to sub 6 GHz results (as explained in section 2) but mm-wave operation uses higher subcarrier spacings (120 kHz, 240 kHz) and different transmission cases (Case D, E) for the SSBs.

PCI	SSB Idx	SSB-RSSI	SSS-RSRP	SSS-SINR	SSS-RSRQ	NR-ARFCN	SS-Ref	DM-RS-RSRP	DM-RS-SINR
278	15	-82.1	-111.0	1.8	-12.5	2082915	28224.96	-110.6	2.1
278	12	-82.1	-107.1	4.4	-11.6	2082915	28224.96	-107.1	5.2
278	3	-82.1	-100.8	9.5	-10.7	2082915	28224.96	-100.8	10.0
278	7	-82.1	-108.6	3.1	-12.0	2082915	28224.96	-108.5	3.2
278	6	-82.1	-94.7	9.9	-10.7	2082915	28224.96	-94.7	15.6
278	5	-82.1	-99.1	9.7	-10.7	2082915	28224.96	-98.8	12.3
278	14	-82.1	-91.8	10.2	-10.6	2082915	28224.96	-91.9	17.3
278	10	-82.1	-99.2	9.4	-10.7	2082915	28224.96	-99.0	11.3
278	2	-82.1	-103.5	6.6	-11.1	2082915	28224.96	-103.4	9.1
278	13	-82.1	-103.1	7.3	-11.0	2082915	28224.96	-103.1	9.0
278	4	-82.1	-110.5	1.1	-12.8	2082915	28224.96	-110.1	1.2

Figure 35: Excerpt of ROMES4 RF measurements of each PCI and each SSB index.

PBCH-RSRP	PBCH-SINR	PSS-RSRP	PSS-SINR	SSS-PBCH-RSRP	SSS-PBCH-SINR	MIB-systemFrameNumber	MIB-subCarrierSpacingCommon
-110.7	1.7	-110.8	2.1	-110.7	1.8	0	scs15or60
-107.1	4.3	-107.2	4.4	-107.1	4.5	0	scs15or60
-100.8	9.1	-100.8	9.9	-100.8	9.4	0	scs15or60
-108.6	2.4	-108.4	3.3	-108.6	2.7	0	scs15or60
-94.7	10.2	-95.0	10.3	-94.7	10.8	0	scs15or60
-98.8	9.8	-99.1	9.8	-98.9	10.2	0	scs15or60
-91.9	10.4	-92.0	10.4	-91.9	11.1	0	scs15or60
-99.0	9.4	-99.3	9.8	-99.0	9.7	0	scs15or60
-103.4	7.1	-103.7	7.1	-103.4	7.3	0	scs15or60
-103.0	7.3	-103.4	7.4	-103.1	7.6	0	scs15or60
-110.1	1.2	-110.5	1.4	-110.2	1.2	0	scs15or60

Figure 36: Excerpt of ROMES4 RF measurements and MIB demodulation result for each PCI and SSB index.

This allows more SSBs (up to 64) / beams in mm-wave deployments to be transmitted. Consequently, the beams have to be narrower to fully exploit the advantages of beamforming and overcome the tremendous path loss at mm-wave frequencies. The path loss is naturally increasing with the distance, which requires narrower beams with an increasing distance from the gNB antenna.

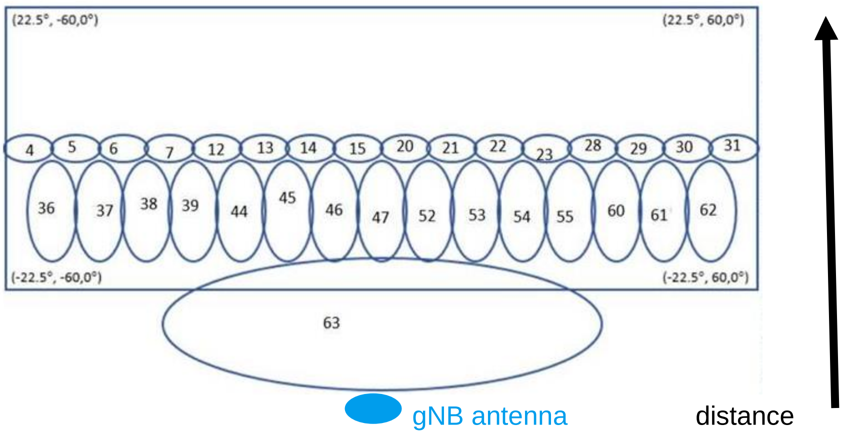


Figure 37: Beam pattern of a configuration with 32 SSBs / beams (projection on geographical area).

4 Multi-technology measurements

4.1 5G NR non-stand-alone operation mode

Most 5G NR trial networks are based on the non-stand-alone operation mode. Each 5G NR cell has an LTE anchor cell (mainly for control signaling), while user data traffic runs on 5G NR. For a successful data transmission on 5G NR, coverage from both 5G NR and LTE is required. From a frequency and propagation perspective, LTE running on 2.6 GHz and 5G NR running on 3.5 GHz is considered to be a robust configuration. 3.5 GHz has moderately more path loss compared to 2.6 GHz, but technical features like beamforming in 5G NR are designed to compensate the higher path loss. In early test networks it was observed, that operators split up a single 20 MHz LTE carrier in two carriers, one for legacy LTE applications and one to provide the 5G NR - LTE anchor.

As coverage for both radio access technologies is required, it is also essential to measure both technologies. R&S® network scanners, like the R&S®TSME6 and TSMA6 are multi-technology scanners therefore two or even more technologies across the frequency bands can be measured simultaneously (leading to a trade-off in measurement speed), with each 20 MHz receiver front-end capture using a very short timeslot. R&S®ROMES4 provides the flexibility to arrange several insightful views providing measurement data from different technologies to be displayed next to each other. Hence, RF results from 5G NR and LTE can be monitored on a user configurable worksheet. It is possible for example to place both Top N Views and the ROMES4 MapView on one worksheet.

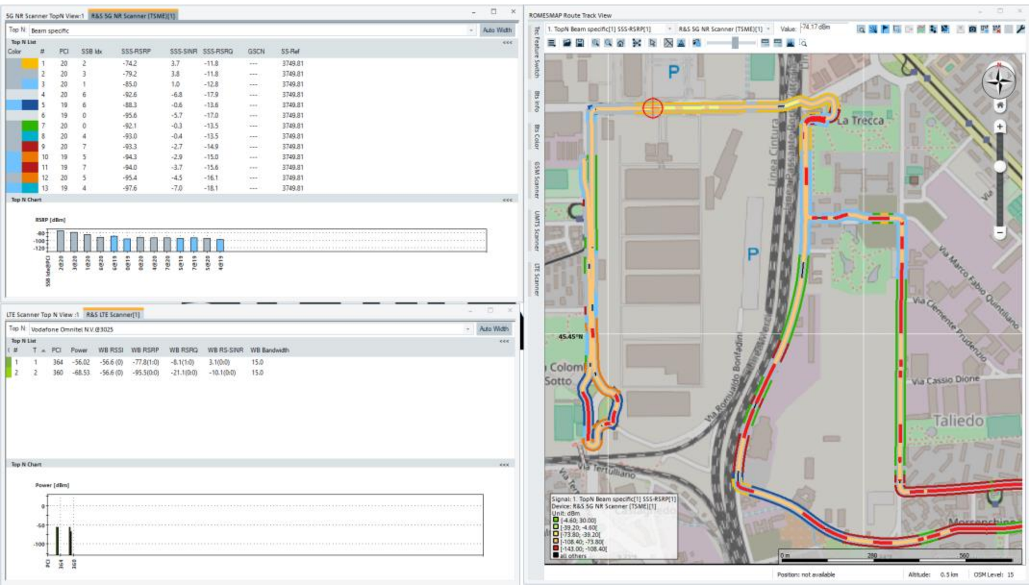


Figure 38: ROMES4 worksheet with the map, 5G NR and LTE scanner Top N View.

Both 5G NR and LTE scanners are delivering RSRP signals. Comparing both RSRP dBm values side-by-side requires deep knowledge about what is exactly measured.

Resource elements of 5G NR SSBs and LTE can be fundamentally different in terms of bandwidth. As explained in chapter 1.2.2, the 5G NR SSB can occur with different subcarrier spacings. In the frequency domain, the 5G NR SSB occupies 240 subcarriers; with a subcarrier spacing of 15 kHz or 30 KHz (for sub 6 GHz) the total SSB bandwidth is 3.6 or 7.2 MHz. In LTE, the subcarrier spacing is 15 kHz (fixed value).

In the case of 30 kHz subcarrier spacing for the 5G NR SSB and 15 kHz subcarrier spacing for LTE, a correction factor of roughly 3 dB has to be applied. The 5G NR SSB subcarrier occupies 30 kHz instead of 15 kHz spectrum.

In addition to power in the frequency domain, the signal duration has to be considered. A 5G NR SSB occupies four symbols. By definition, SSS-RSRP is the linear average over all SSS resource elements. Therefore, SSS-RSRP refers to one symbol in the time domain and one subcarrier in the frequency domain. LTE has a fixed symbol duration of 66.7 µs (without considering the cyclic prefix) while 5G NR has different symbol durations for different subcarrier spacings (15 kHz - 66,7 µs; 30 kHz - 33,3 µs; 120 kHz - 8,3µs; 240 kHz - 4,2µs …). This leads to another correction factor of -3dB for a half symbol duration.

Example (rule of thumb):

LTE - 15 kHz SCS, 66.7 µs symbol duration

5G NR - 30 kHz SCS, 33.3 µs symbol duration

+ 3dB for different / double SCS; - 3dB from different / half symbol duration

---

0 dB → LTE RSRP and SSS-RSRP is comparable for 30 kHz subcarrier spacing for 5G NR SSB.

Note: This calculation does not consider different propagation losses or beamforming gains.

4.2 5G NR Spectrum clearance and spectrum measurements

RF interference is one of the largest contributors to poor network performance. It leads to dropped calls and low data throughput rates.

In existing networks such as LTE, OSS data is able to provide a list of sites with bad performance that may be due to interference and this method defines the areas for interference hunting quite well. In very early phase of network roll out in a new frequency band, where the network is not deployed yet, interference in the desired frequency range could be theoretically everywhere. Spectrum measurements in huge geographical areas have to be performed to characterize the RF environment and identify interfering signals, but collecting drive test data is just a small part of the work. Post-processing and geographically locating interference is the major part of the process.

To simplify this process, RF power scan measurements can be performed with R&S®TSME6 / TSMA6 and ROMES4 and later be post-processed with the R&S®ROMES4 NPA (network problem analyzer). The R&S®TSME6 / TSMA6 connected to R&S®ROMES4, which delivers spectrum measurements (see the screenshot in Figure 39) with a location tag. After collecting the data, the

R&S®ROMES4 NPA creates a map and a list with all locations of where a potential interferer was found within a configured spectrum (see the screenshot in Figure 40).

A dedicated and detailed Application Note and App Card on this topic entitled "Automated Spectrum Clearance" can be found on the Rohde & Schwarz webpage (https://www.rohde-schwarz.com/solutions/test-and-measurement/mobile-network-testing/interference-hunting/interference-hunting_231996.html).

Figure 39: Performing a spectrum scan for spectrum clearance with a R&S®TSMx network scanner and R&S®ROMES4

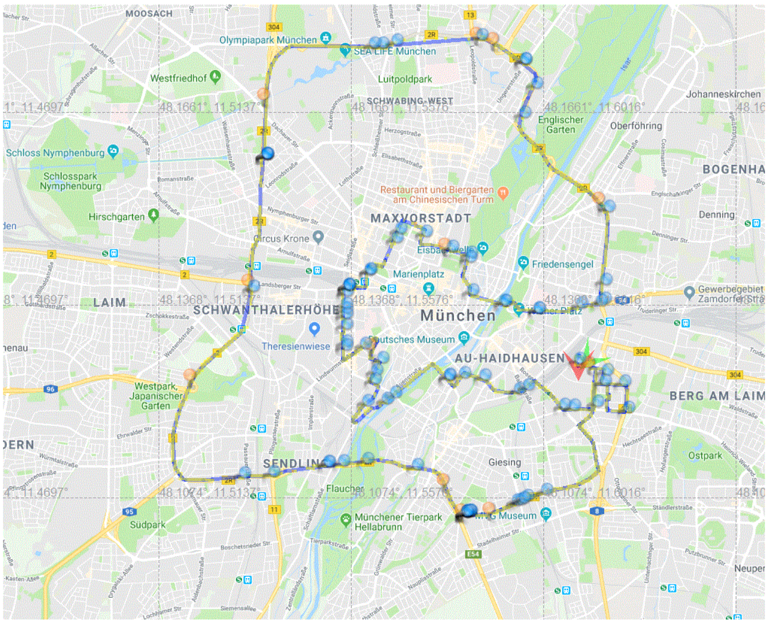


Figure 40: R&S®ROMES4 Network Problem Analyzer with detected interference problem spots

After conducting spectral clearance and deploying the network, spectrum measurements are a valuable tool to observe the 5G NR carrier on air and its position in the spectrum. In chapter 2.1, the Automatic Channel Detection feature is described, which is able to detect SSBs using an internal spectrum scan and an algorithm searching for SSBs. During first field measurements, it was nearly impossible to reliably detect the center frequency of the SSBs with a pure spectrum scan. One reason for that is that one SSB just has a duration of four symbols. Depending on the SSB transmission case, the next (four symbols long) SSB is transmitted a few symbols later. After e.g. eight transmissions (which also depend on the case), there is quite a long break until the sequence of SSBs is repeated (e.g. 20 ms; if 20 ms SSB periodicity is configured in the network). From the visualization chart of SSB transmissions with a certain periodicity in Figure 7, it becomes very clear that the breaks between the SSB sequences are quite long compared to the SSB transmissions themselves. This fact makes is very complicated to see all SSB transmissions in the spectrum and hence identify the transmission as SSBs. The RF power scan functionality in R&S®TSME6 / TSMA6 supports various frequency resolutions of the FFT, which is performed to produce the spectrum scan results. Changing this setting changes the FFT size for the spectrum scan results. This results in either a good frequency resolution or a good time resolution, but adds elements of uncertainty to one of them.

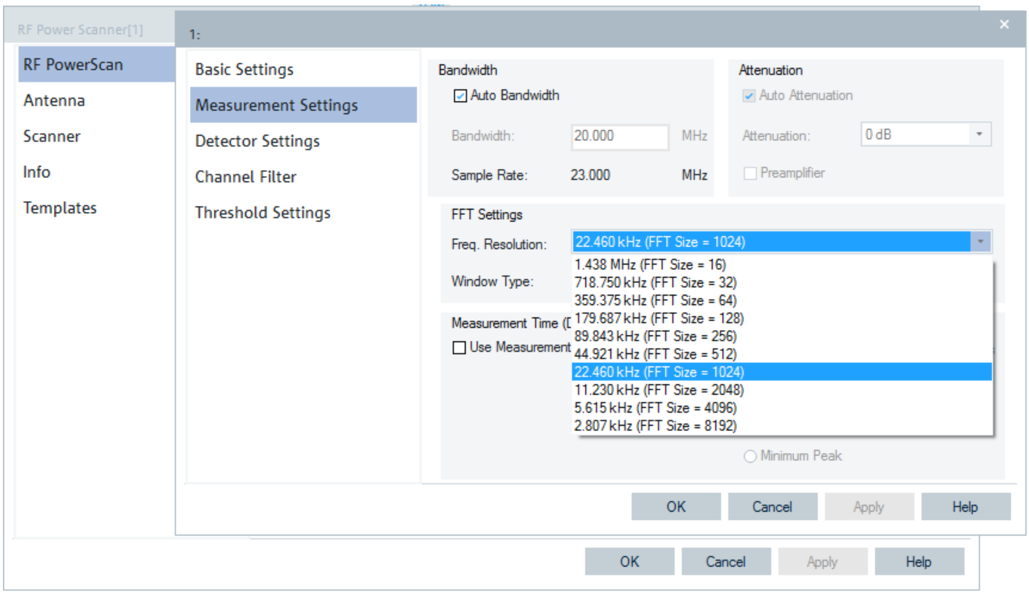


Figure 41: RF power scan FFT size / frequency resolution settings to change the resolution in time and frequency.

Choosing a small FFT size can visualize SSB transmissions over time but with uncertainty on the center frequency.

Figure 42: Spectrum scan of a SSB with small FFT size.

Increasing the FFT size will improve the results in terms of detecting the center frequency but over time a significant number of SSB transmissions is skipped or are cross-faded due to the time resolution (Figure 43).

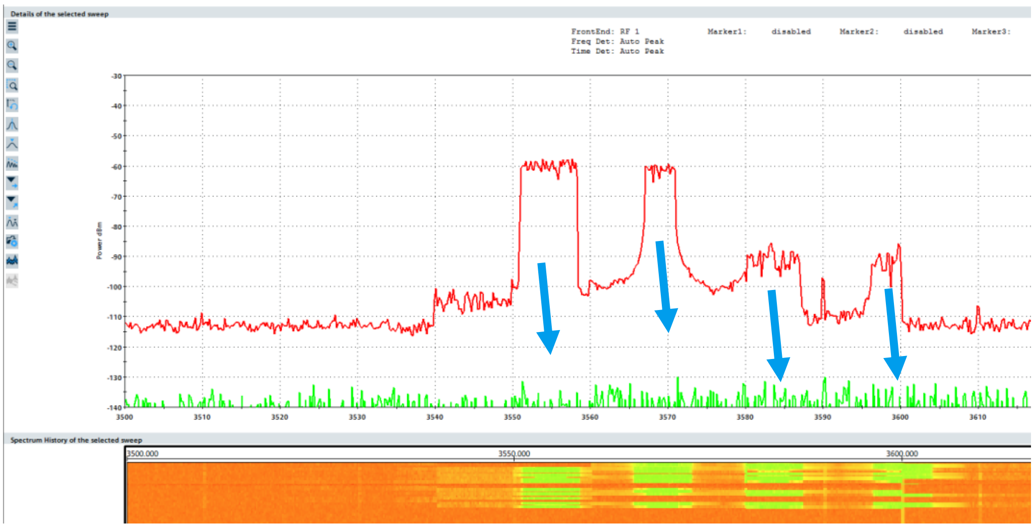


Figure 43: Spectrum scan of four SSBs with a higher FFT size.

Both screenshots (Figure 42 and Figure 43) are captured from a strong 5G NR SSB signal from a signal generator without any other signals (e.g. data traffic) on air. In the case of field measurements, the situation even gets worse. Received SSB transmissions are weaker or there is traffic is on the network. Both situations significantly complicate the SSB detection just from the spectrum shape. 5G NR uses several UE specific signals, which just appear as long data traffic is active. Figure 44 illustrates the spectrum of a 5G NR carrier fully populated with UE specific signals (data traffic) across the 5G NR carrier. In this case, it is impossible to identify any SSBs between UE specific signals any more. The most reliable way to identify SSBs and their center frequency on the spectrum is using the Automatic Channel Detection feature.

Figure 44: Spectrum scan of a 5G NR carrier with four SSBs and UE specific signals (data traffic on air distributed over the whole 100 MHz 5G NR carrier)

5 5G NR Post processing

As presented in chapters 1 and 2, there are several aspects to consider when analyzing the 5G NR measurement results coming from the R&S®TSMx6 mobile network scanners. With the flexibility of the 5G NR standard, it could easily lead to complexity in the data analysis.

Below a few challenges are listed that need to be addressed by efficient processes and the correct tools:

- Aggregating data from multiple test teams that can deliver measurement files from the same cluster to get complete statistics
- Analyze and report the coverage distribution for a region, for a carrier and per cell
- Analyze and visualize the SSB beamforming
- Calculate the coverage differences between 5G NR and LTE
- Remember that exporting the data from each measurement is time consuming when there can be hundreds of measurement files

5.1 5G NR network coverage analysis use case

R&S®SmartAnalytics is use-case driven post processing product family that enables users to get more value out of collected drive test data and deeper insights with less manual intervention. In the next pages, we will show how it can be used for post processing of 5G NR Scanner measurement data.

The example follows the typical workflow, described in Figure 45.

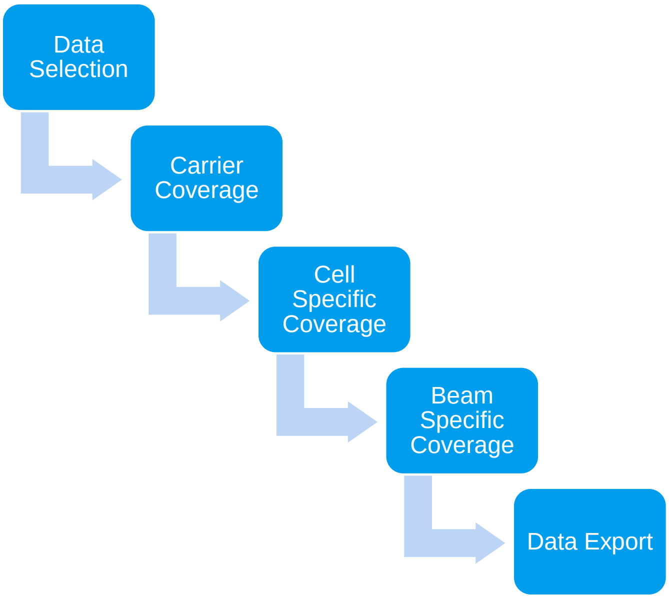


Figure 45 Network coverage analysis workflow

5.2 Data selection

The navigation in SmartAnalytics Scene follows a top-down approach.

Figure 46 shows the first page in our default 5G Scanner workspace visualizes where and when the drive test team collected the measurement data and what data collection groups they are divided into.

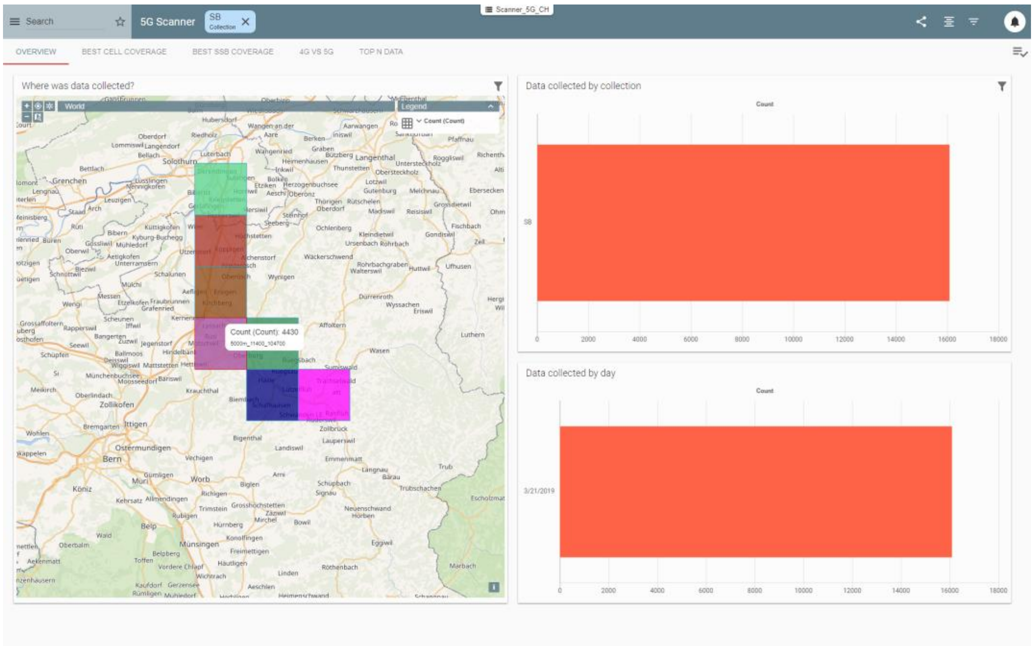


Figure 46 SmartAnalytics Scene 5G Scanner Overview

The geographical raster in the map represents aggregated data bins. By hovering with the mouse cursor over a bin, a label displays the count of samples and raster size.

In SmartAnalytics Scene it is very easy to apply filters of various dimensions to narrow down the data scope. In addition, with the appropriate user account rights, it is possible to modify the workspaces to apply any required custom layout to fit with the target working process and to support different analysis tasks.

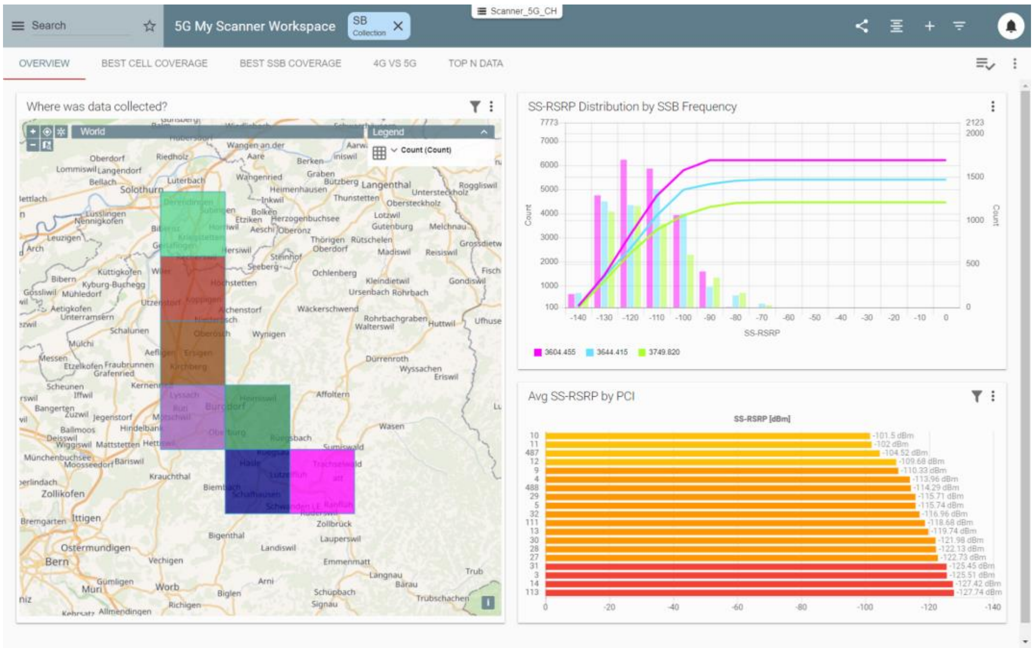


Figure 47 SmartAnalytics custom 5G Scanner workspace with a filter applied

As seen in Figure 47, after a modification the workspace now has new charts showing SS-RSRP Distribution per SSB Frequency and SS-RSRP per PCI. The Application Bar indicates that a filter on the Collection is applied. Now the workspace shows us that there are measured data from three different 5G NR carriers in the 3.6 - 3.7 GHz frequency band and that there are many active cells.

The carrier at 3604.455 MHz has the highest count of samples and the 3749.820 MHz carrier the highest dynamic range in our data set. The four top most cells (PCIs) have average an SS-RSRP above -110 dBm.

As a user should expect from any modern web-based user interface, it is also possible to interact with the presented data. By intuitively clicking with the mouse on any of the graphical data elements, such as a map bin or a bar in a chart, a filter is applied and the map zooms automatically into the active area. The map grid size is automatically adjusted for the used zoom level, from 5000 meters down to 50 meters.

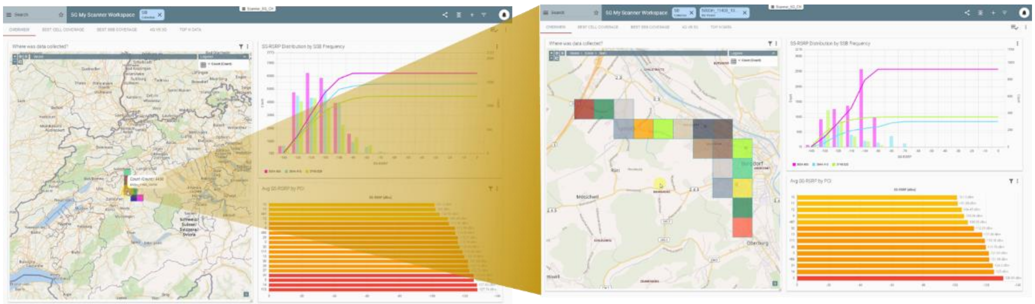


Figure 48 SmartAnalytics map interaction to enable a geographical filter

5.3 Carrier coverage analysis

We will continue the analysis with one of the carriers and apply a filter for the SSRef frequency 3749.820 MHz.

The next step in the workflow is to get a coverage map and the statistics of the best cell coverage for the carrier. We find that in the Best Cell Coverage page, Figure 49.

The cells are ranked by average SSB received power (SS-RSRP) as default. However, it is easy to change to another ranking parameter like signal-to-interference ratio (SS-SINR).

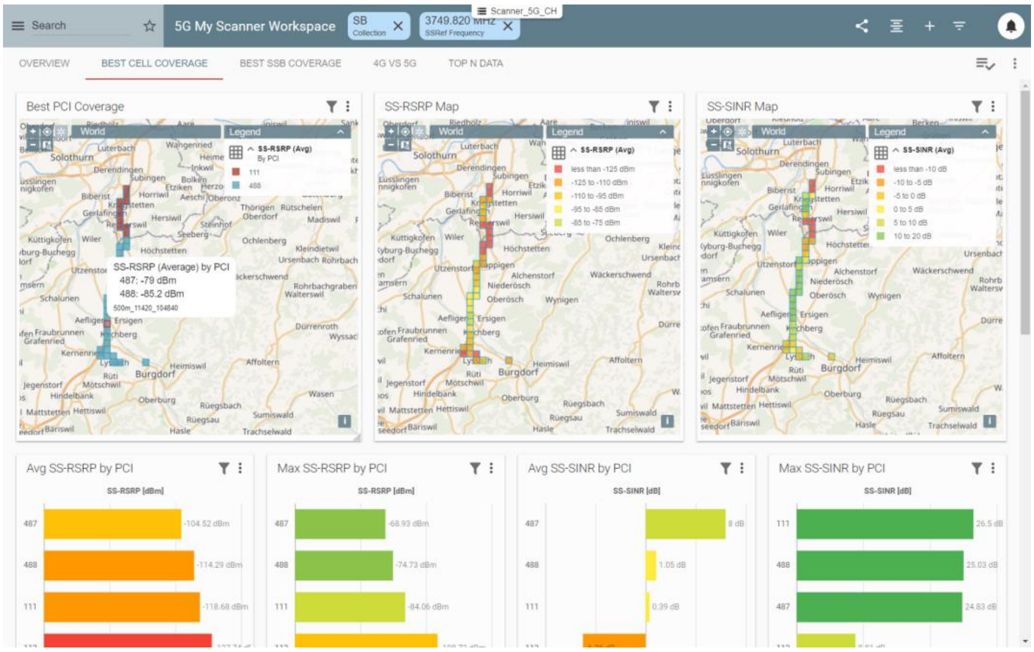


Figure 49 5G Scanner Best cell coverage analysis

The Best PCI Coverage map shows the best cell with the map raster colored by PCI. With the mouse hovering over the raster, we can analyze cell overlap. The pop-up window will show the detected cells with their PCI and average SS-RSRP in each raster bin.

In the presented example we are looking at a rather small drive test campaign, that covers just a few main roads, and therefore it is no surprise to find cells with low power and bad interference. This would of course not be enough data for a "real" cluster acceptance where the drive test routes need higher density to cover each cell's central areas as well as the close and far cell edge areas.

5.4 Cell specific coverage

We continue the analysis by narrowing-down the data scope to analyze a specific cell.

By clicking on a bar labeled PCI 487 in any of the charts, SmartAnalytics will apply a PCI filter that will restrict the presented coverage map and statistics to only this specific cell.

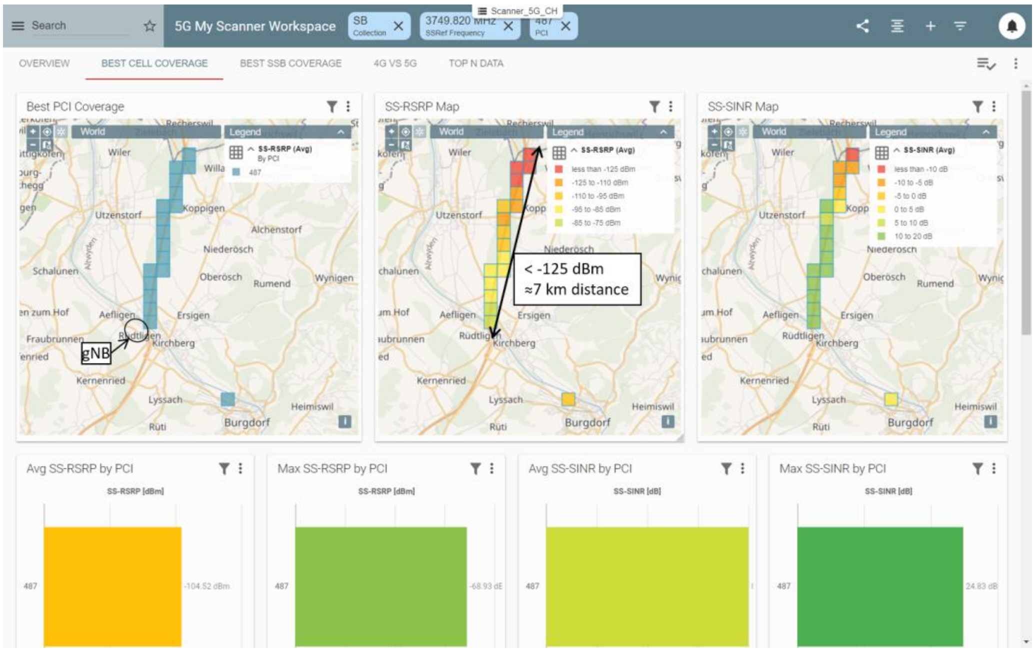


Figure 50 5G Scanner PCI 487 coverage analysis

As seen in

Figure 50, the PCI487 cell has good coverage in the Northern driving direction along the A1 Road.

Similar to the previously presented measurement on 3.7 GHz in Figure 24, the distance to the cell edge is around 7 km with the difference that here we have a rural environment.

The SS-SINR Map shows that the coverage signal-to-interference ratio is good with average values > 10 dB up to as far as 5 km where corresponding SS-RSRP is > -110 dBm.

5.5 Beam specific coverage

The next step in the analysis is to study the SSB beamforming using the Best SSB Coverage page. The Best SSB Coverage map shows the best-ranked SSB index and the bar charts show the Avg and Max SS-RSRP and SS-SINR by SSB index. Further below on the page includes a Statistics table and CDF-PDF charts.

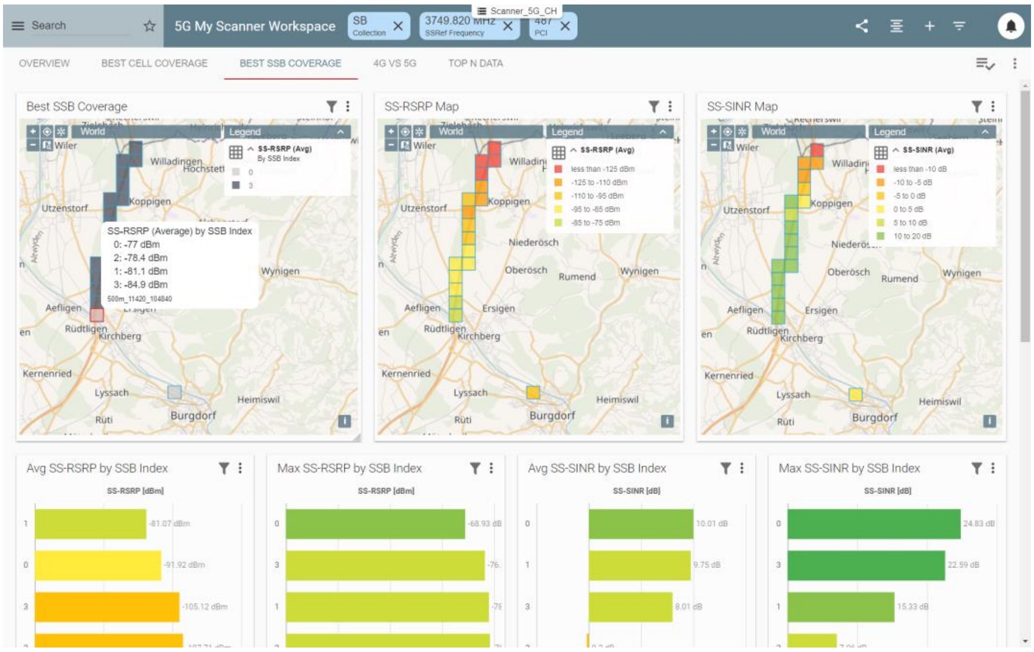


Figure 51 5G Scanner Best SSB Coverage for PCI 487

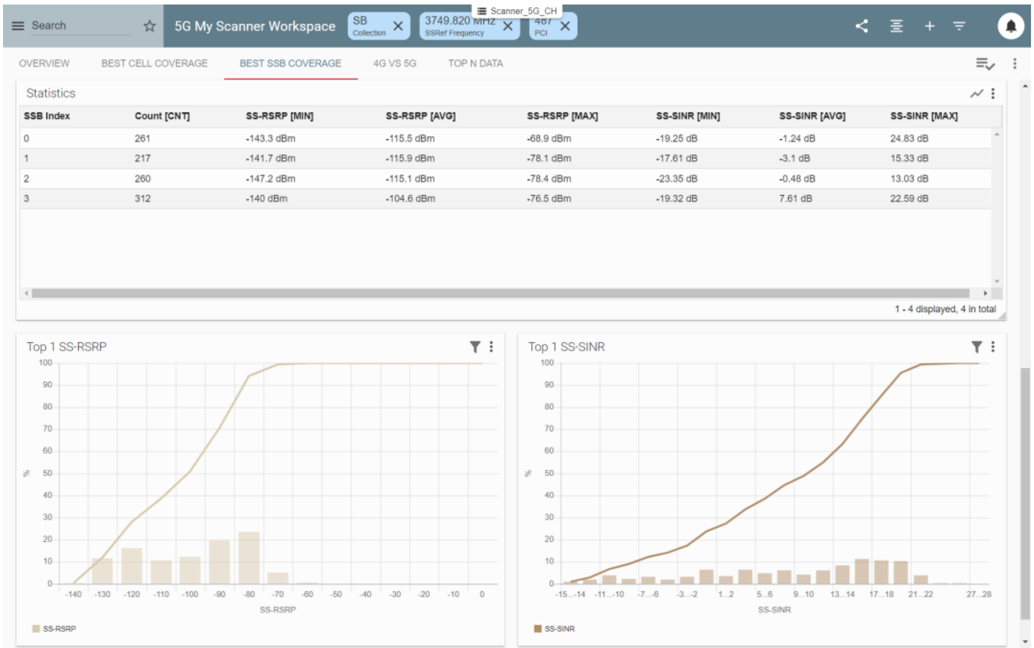


Figure 52 5G Scanner Best SSB Coverage for PCI 487, part 2

The SSB Coverage map in Figure 51, indicates that the PCI487 cell has only two top ranked SSB beams along the driven route having SSB index 0 and 3. Nevertheless, the bar charts and the table tell us that also SSB index 1 and 2 were measured but with lower SS-RSRP.

The pop-up window in the map indicates that these two weaker SSB beams were measured only in the 500-meter bin area closest to the village of Kirchberg. The obvious explanation behind this small coverage area is that the drive route has not included their respective beam coverage areas.

Adding a filter on SSB index 3 will present the coverage and statistics of this specific beam, see Figure 53.

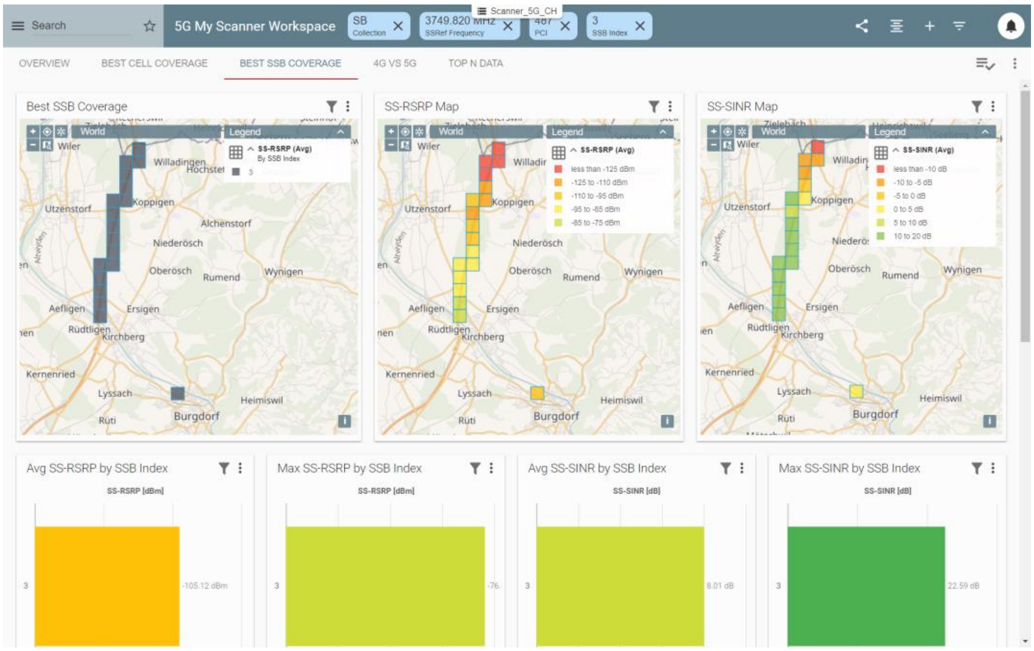


Figure 53 5G Scanner Best SSB Coverage for PCI 487 and SSB index 3

It is clear to see that for the PCI487 cell, it is the beam with SSB index 3 that provides the extensive 7km coverage to the North.

We will now look at another data collection that is a more interesting example of SSB beam forming analysis in SmartAnalytics, see Figure 54.

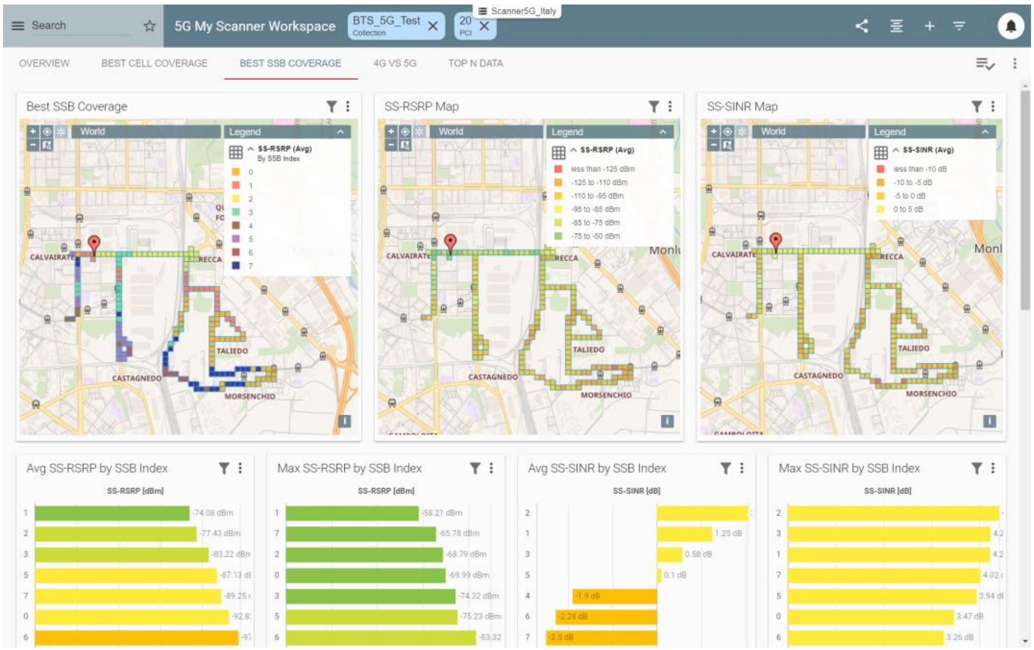


Figure 54 5G Scanner Best SSB Coverage for PCI 20 having 8 different SSB indices

The PCI20 cell is using all 8 out of 8 maximum possible SSB indeces on a Sub-6 GHz carrier in 5G NR, to provide coverage in the East to Southeast direction.

The Best SSB Coverage map shows where each SSB index was providing the most dominant signal power, indicating their configured azimuth on the gNB antenna array.

In the next pages, we do a detailed analysis of the individual beams.

Besides the aggregated data layer, SmartAnalytics can also access the detailed time domain data as it was captured by the scanner. In the 5G Scanner workspace, the detailed data is available in Top N Data page, see Figure 55, that is our final level of data drill down.

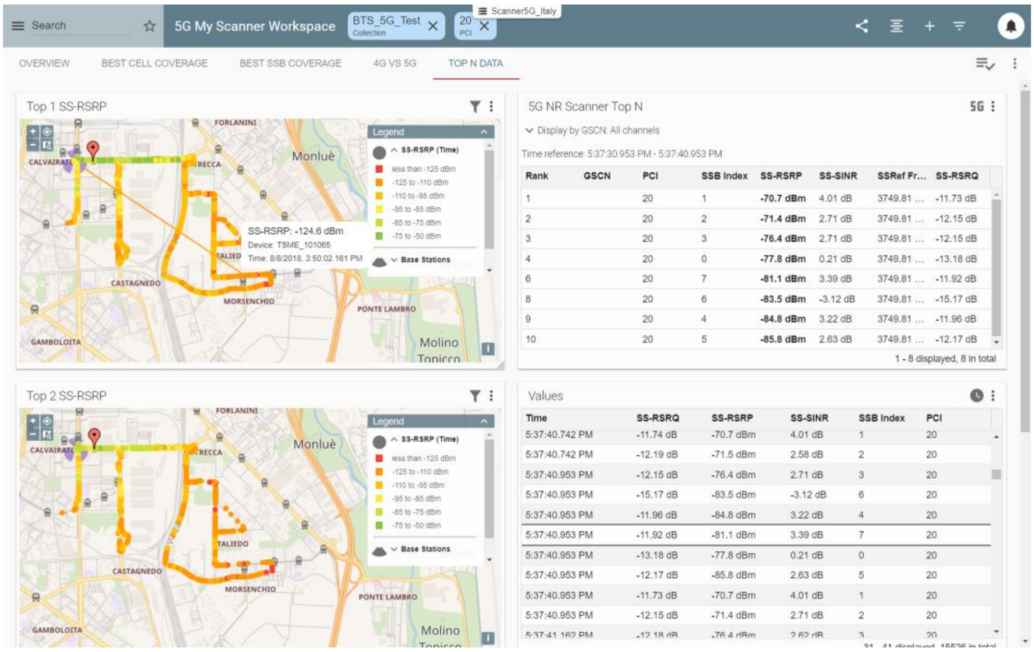


Figure 55 5G Scanner Top N Data page

The 5G Scanner Top N pool data has a dedicated panel that is time synchronized with the maps and the other detailed displays.

The Top N map shows the data points and in our example we have also included a small list of BTS data and we see three cell sectors in Figure 55 (only one sector - PCI20 - is chosen here). With the BTS data loaded, the map can display coverage lines from the data points to the serving cell sector; a feature that we will use to facilitate the beam coverage analysis.

Firstly we apply an SSB filter on index 1 and the Best SSB Coverage page shows the aggregated picture of the beam coverage map and statistics, as shown in Figure 56.

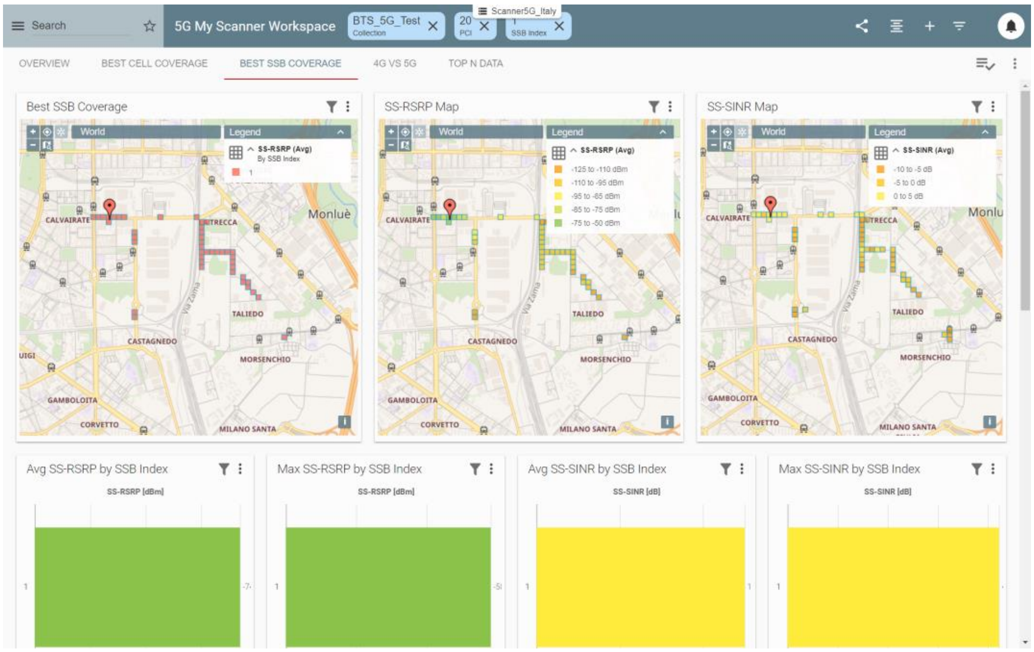


Figure 56 5G Scanner Best SSB Coverage for PCI 20 and SSB index 1

The Top N Data page shows the detailed map point plot and by selecting the cell sector with the mouse, SmartAnalytics will draw color shaded serving cell lines (colored by the SS-RSRP level) from the sector to each data point, see Figure 57.

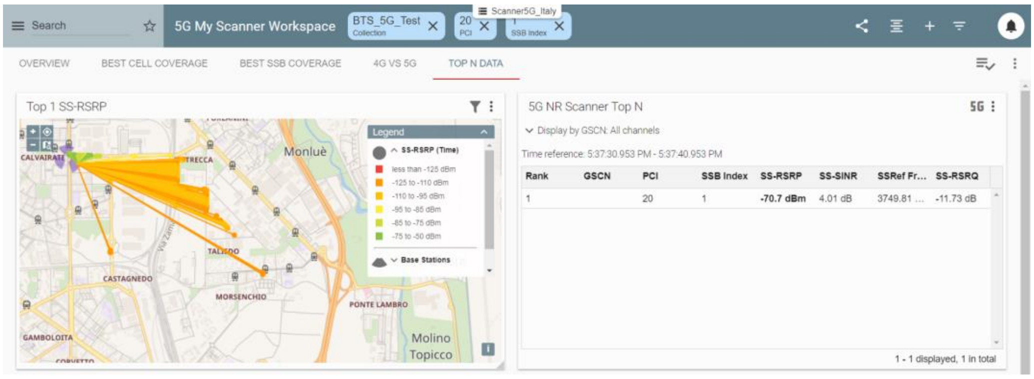


Figure 57 5G Scanner Top N Data with PCI 20 and SSB index 1 cell sector coverage lines

Figure 58 shows the results of a beam coverage analysis as a collage of plots that compare the Best SS coverage map for PCI 20 with Top 1 SS-RSRP point plot for 6 of the 8 SSB indices used in this cell.

The detected beam's main direction and far edge coverage are estimated and drawn with the SSB index color on top of the screen pictures.

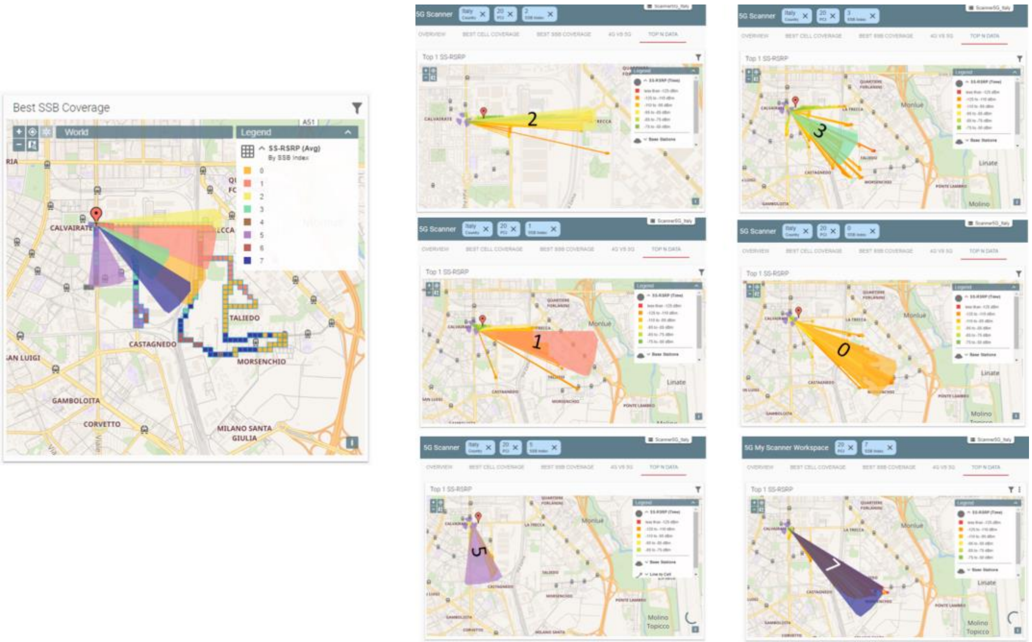


Figure 58 5G Scanner Beam coverage analysis

The plots in Figure 58 show how an active antenna array can control the SSB transmission in both the horizontal and elevation plane.

The beams with SSB index 2, 1, 0, 7 and 5 have distinctly different horizontal directions of the main lobe.

However, the beams with SSB index 0 and 3 seem to have the same horizontal direction but different coverage dominance zones. SSB index 3 is providing coverage close to the cell site and SSB index 0 is further away. The most probable explanation is that the beams have different elevation angles (a.k.a. tilt angles), as exemplified in Figure 59.

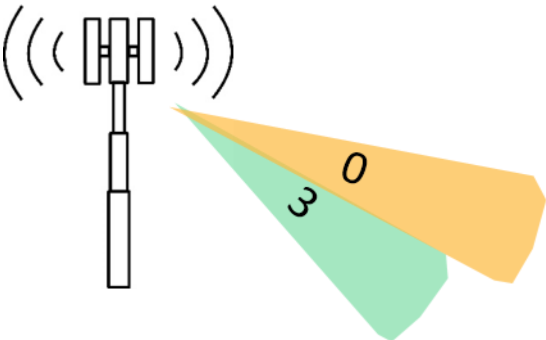


Figure 59 SSB index 0 and 3 elevation

5.6 Data export

SmartAnalytics supports export of the data into CSV format and offers full flexibility in defining the export parameters.

As seen in Figure 60, it is possible to create tables in both Aggregated and Time based dimensions, and then export the content to a CSV file.

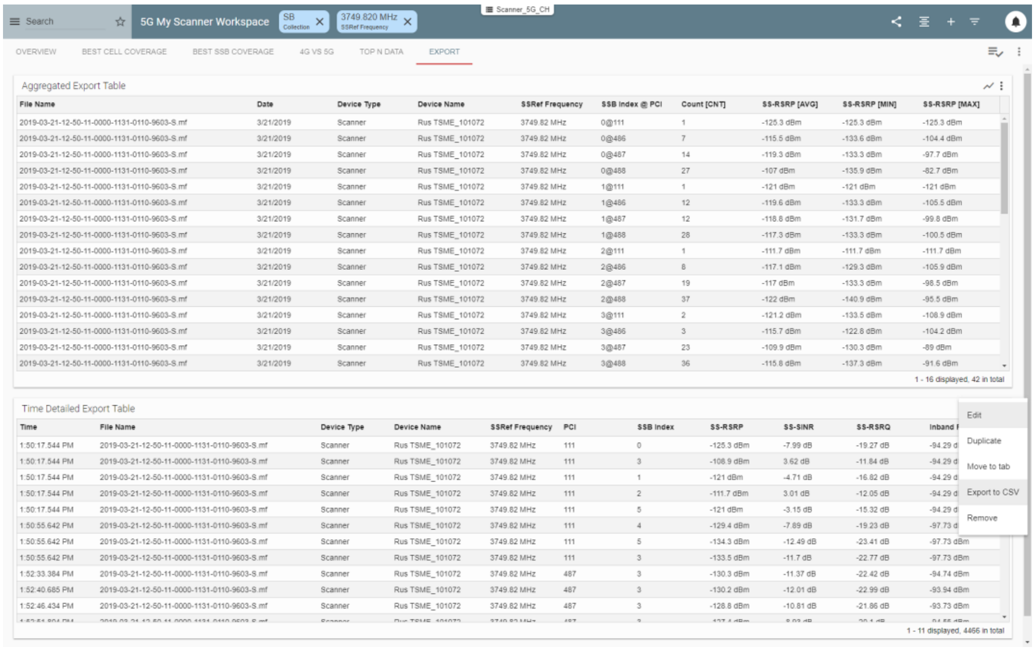


Figure 60 SmartAnalytics Scene Data export tables

6 Ordering Information

Designation	Type	Order No.
Ultracompact drive test scanner	R&S® TSME6	4900.0004.02
Autonomous mobile network scanner	R&S®TSMA6	4900.8005.02
5G NR scanning	R&S®TSME6-K50	4900.2436.02
5G NR scanning	R&S®TSMA6-K50	4901.0966.02
Simultaneous measurement in all bands	R&S®TSME6-KAB	4900.2107.02
Simultaneous measurement in all bands	R&S®TSMA6-KAB	4901.0708.02
Drive test software	R&S®ROMES4	1117.6885.04
R&S®TSME6 driver for R&S®ROMES4 drive test software	R&S®ROMES4T1E	1117.6885.82
R&S®TSME30DC driver for R&S®ROMES4 drive test software	R&S®ROMES4T30D	4900.5293.02
R&S®TSME30DC ultra compact downconverter	R&S®TSME30DC	4901.1004.02
R&S®ROMES4 driver, automatic channel detection	R&S®ROMES4ACD	1506.9869.02
Network Problem Analyzer - basic package	R&S®ROMES4NPA	1510.9276.02
NPA Spectrum Analysis	R&S®ROMES4N18	1117.6885.74
RF power scan	R&S®TSME6-K27	4900.2120.02
RF power scan	R&S®TSMA6-K27	4901.0720.02

Appendix

A SSB transmission patterns - an overview

SSB Mapping

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	n = 0,1,2,3	
		s = 2,8,16,22 L = 4	s = 2,8,16,22,30,36,44,50 L = 8	
Case B : 30 kHz	{4,8,16,20}+28n	n = 0	n = 0,1	
		s = 4,8,16,20 L = 4	s = 4,8,16,20,32,36,44,48 L = 8	
Case C : 30 kHz	{2,8} + 14n	n = 0,1	n = 0,1,2,3	
		s = 2,8,16,22 L = 4	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

The transmission pattern (Case A to E) determines the subcarrier spacing of the SSBs, the number of SSBs (L) and the start-OFDM symbol of each transmitted SSB.

Glossary

A

ACD: Automatic Channel Detection (automatically searches for carriers of several technologies on air, e.g. LTE, 5G NR SSBs, WCDMA, GSM… and delivers a channel template for ultra-fast scanner configuration)

B

BWP: Bandwidth Part (one part of the total 5G NR carrier bandwidth)

D

DM-RS: Demodulation Reference Signals (signal component of a SSB in 5G NR)

E

eMBB: Enhanced Mobile Broadband (use case of 5G NR)

G

GSM: Global System for Mobile Communication (also known as 2G, radio access technology for basic voice and data services)

L

LTE: Long Term Evolution (also known as 4G, radio access technology for voice and data rates >> 50 Mbit / s)

LTE-M: LTE machine type: Standard based on LTE for connecting things (sensors, actors) to the internet

M

MIB: Master Information Block (broadcasts fundamental network information for accessing the network)

mMTC: massive Machine Type Communication (5G NR use case for connecting a massive number of devices and sensors to the internet)

N

5G NR NSA: 5G NR (5G new radio) uses an LTE anchor carrier for signalization (5G NR non-stand-alone)

NB-IoT: Narrowband-IoT (radio access technology for connecting things to the internet)

O

OFDM: modulation type (Orthogonal Frequency Division Multiplex)

P

PBCH (broadcast channel in the 5G NR synchronization block)

PCI: Cell identifier in LTE and 5G NR (primary cell identifier)

PSS: Component of the 5G NR synchronization block (primary synchronization signals)

R

RSRP: Measurement value for measuring the power of several signals in LTE and 5G NR (reference signal received power)

RSRQ: Measurement value for measuring the quality of several signals in LTE and 5G NR (reference signal received quality)

S

SCS: distance of two adjacent subcarriers in LTE and 5G NR (subcarrier spacing)

SIB: data block carrying system information in LTE and 5G NR (system information block)

SSB, SSBlock, SS/PBCH block, synchronization block: a block of four symbols carrying all necessary synchronization signals in 5G NR (synchronization block)

SINR: Measurement parameter for measuring noise and interference in LTE and 5G NR (signal to noise and interference ratio)

SSRef: Center frequency of the SSB in 5G NR

SSS: Component of the 5G NR synchronization block (secondary synchronization signals)

Sub 6 GHz: frequency range below 6 GHz

U

UE: smartphone, end-user device or customer premises equipment (CPE) (user equipment)

URLLC: 5G NR use case for the field of ultra-reliable communication in 5G NR

W

WCDMA: also known as 3G, radio access technology for delivering basic voice and data service (data rate >>1 Mbit/s); (wideband code division multiple access)

Wi-Fi: Wireless LAN

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Version 2.0 | 5G NR network measurements using network scanners and advanced data analytics

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