Narrowband Internet of Things Measurements

Application Note

Products:

- R&S®VSE
  - R&S®VSE-K106
- R&S®FSW
- R&S®FSV3000
- R&S®FSVA3000
- R&S®FPS
- R&S®SMW200A
  - R&S®SMW-K115
- R&S®SGT
  - R&S®WinIQSIM2
  - R&S®SGT-K415

The Internet of Things (IoT) is considered the driving force of current and future wireless communications. In release 13, 3GPP has specified Narrowband-IoT (NB-IoT) as a new physical layer. This application note gives a short introduction to NB-IoT and shows the easy measurements with Rohde & Schwarz instruments.

Note:

Visit our homepage for the most recent version of this application note (www.rohde-schwarz.com/appnote/1MA296).

Application Note

1MA296_2e

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Contents

1 Introduction

The Internet of Things (IoT) is considered the driving force of current and future wireless communications. The term refers to communications among machines without any human interaction. Examples include ATMs that request account balances from banks when customer withdraw money as well as sensor data transmissions, e.g. temperature information from industrial facilities. As early as 2008, more objects (machines) than people were connected to the Internet and the number continues to grow.

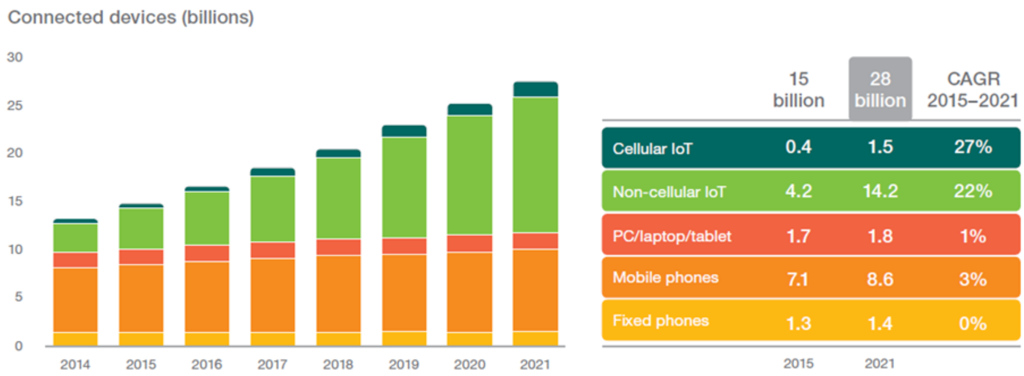


Figure 1-1: Number of devices connected to the Internet: IoT is expected to be the greatest driver of growth [1]

And an increasing number of devices have direct wireless connections to the Internet. Such applications include:

- Wearables (smartwatch, sensors,...)
- Smart homes
- Smart cities
- Healthcare
- Automotive
- Asset tracking
- Retail
- Drones
- ...

IoT communications requirements can vary. Simple sensors, for example, need only very low data rates and do not have high latency requirements. There are, however, very large numbers of them. On the other hand, critical communications such as automotive applications require higher data rates and very low latency.

The primary requirements that devices have in common include:

- Low cost ("simple" wireless technology)
- Low power requirement (battery life)

At the network part additional requirements appear:

- Low latency

- Accessibility
- Coverage/range
- Overload control

These various requirements are reflected in different wireless solutions:

- Wireless WAN (2G/3G/4G)
  – GSM, CDMA, UMTS, LTE
- Wireless PAN/LAN
  – Bluetooth, ZigBee, Thread, Wi-Fi
- Low power WAN
  – Sigfox, Weightless, LoRa, NB-IoT
- Other
  – Satellite, DSL, Fiber

Starting with Release 10, 3GPP began developing improvements for what is known as machine type communications (MTC). This became the basis for various solution approaches in Release 12 that led to three different solutions in Release 13:

- NB-IoT
- eMTC
- EC-GSM-IoT

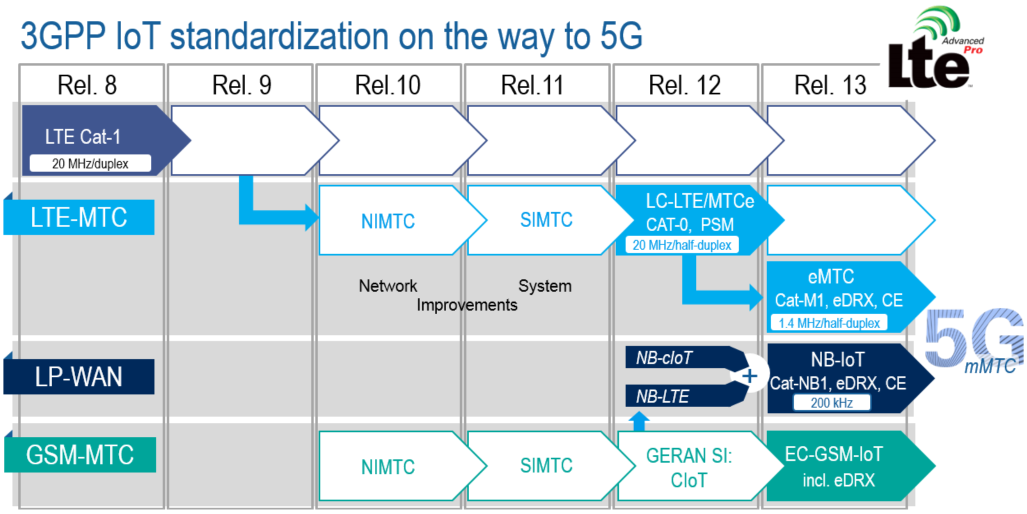


Figure 1-2: IoT in 3GPP

This application note covers NB-IoT. Chapter 2 takes a brief look at the theoretical background. For more detailed information, please refer to the white paper titled Narrowband Internet of Things. Chapter 3 presents the user-friendly T&M solutions from Rohde & Schwarz.

The following abbreviations are used in this application note for Rohde & Schwarz test equipment:

- The R&S®VSE vector signal explorer software is referred to as the VSE.
- The R&S®SMW vector signal generator is referred to as the SMW.

2 Narrowband Internet of Things (NB-IoT)

This section briefly covers the basics of NB-IoT. For a more detailed description, please refer to the white paper titled 1MA266 - Narrowband Internet of Things.

Though specified under 3GPP LTE (Release 13), NB-IoT actually represents a new physical layer. This means that NB-IoT is not backward compatible with LTE. From the beginning, the specification of NB-IoT included considerations for its coexistence with both LTE and GSM. Parts of the physical layers of LTE were reused in NB-IoT. As the name suggests, a narrowband signal is used. NB-IoT is therefore primarily for low data rates applications that are quasi-stationary and battery-powered. There is no need to specify handover scenarios, however the number of devices is expected to be quite large. Sensors are a good example. In addition, LTE specifies eMTC for higher data rates.

Release 13 introduced a new UE category for NB-IoT: Cat. NB1.

2.1 Modes of Operation

NB-IoT has a channel bandwidth of 200 kHz but occupies only 180 kHz. This is equal to one resource block in LTE (1 RB). This bandwidth enables two modes of operation:

- **Standalone operation –** NB-IoT operates independently, for example on channels previously used for GSM. The GSM channel bandwidth of 200 kHz provides a 10 kHz guard buffer on both sides to neighboring GSM channels.
- **Guard band operation –** NB-IoT utilizes resource blocks in the guard bands of an LTE channel.
- **In-band operation –** NB-IoT re-uses frequencies which are not used by LTE inside the LTE channel bandwidth.

Figure 2-1 shows the three modes:

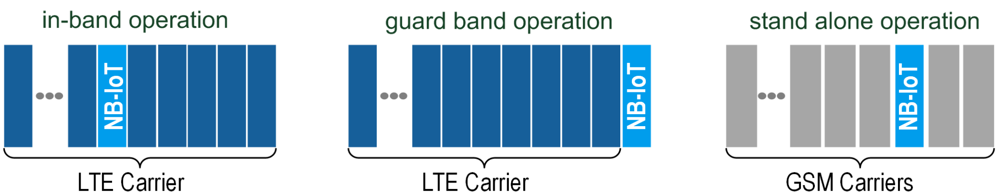


Figure 2-1: The three NB-IoT modes of operation. (NB-IoT operates independently in standalone mode (right). The GSM channels are shown only to illustrate coexistence.)

In-band operation

It is not specified how to allocate the resource blocks (RB) between LTE and NB-IoT. But the cell connection (synchronization, paging) can only be established on certain RB's. The "center" RB's (six for even channel bandwidths, seven for odd channel bandwidths) cannot be used since that is where LTE transmits synchronization signals. Due to capacity limitations, NB-IoT is not designed for 1.4 MHz channel bandwidth.

The RB's allocated for a cell connection are referred to as anchor carriers (see Table 2-1). For the actual exchange of data (in the connected state), other RB's (non-anchor carriers) can be assigned.

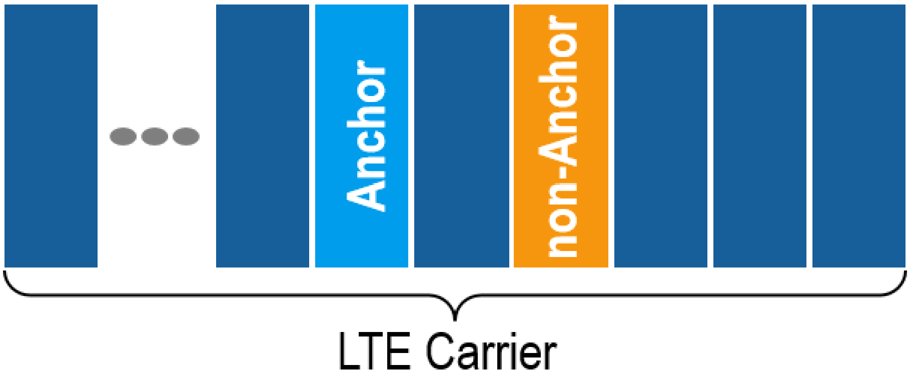


Figure 2-2: Non-anchor carrier.

Table 2-1: Allowed LTE PRB indices for cell connection in NB-IoT in-band mode

LTE system bandwidth	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
LTE PRB indices for NB-IoT synchronization	2, 12	2, 7, 17, 22	4, 9, 14, 19, 30, 35, 40, 45	2, 7, 12, 17, 22, 27, 32, 42, 47, 52, 57, 62, 67, 72	4, 9, 14, 19, 24, 29, 34, 39, 44, 55, 60, 65, 70, 75, 80, 85, 90, 95

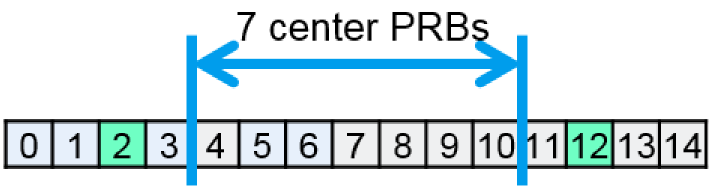


Figure 2-3: Anchor carriers (example for 3 MHz channel bandwidth). The inner RB's are always forbidden since this is where LTE transmits synchronization signals.

Guard band operation

In guard band mode, NB-IoT uses RB's in the guard band of an LTE channel. The synchronization signal must lie entirely within the guard band.

Half-duplex mode

For Release 13, *type B half-duplex FDD* is the chosen duplex mode. This means that UL and DL are separated in frequency and the UE either receives or transmits, though not simultaneously. In addition, between every switch from UL to DL or vice versa there is at least one guard subframe (SF) in between, where the UE has time to switch its transmitter and receiver chain.

2.2 Frequency Bands

Release 13 provides the following bands: NB-IoT uses the same numbers as LTE but only a subset is defined.

Table 2-2: NB-IoT frequency bands

Band number	Uplink frequency range / MHz	Downlink frequency range / MHz
1	1920 - 1980	2110 - 2170
2	1850 - 1910	1930 - 1990
3	1710 - 1785	1805 - 1880
5	824 - 849	869 - 894
8	880 - 915	925 - 960
12	699 - 716	729 - 746
13	777 - 787	746 - 756
17	704 - 716	734 - 746
18	815 - 830	860 - 875
19	830 - 845	875 - 890
20	832 - 862	791 - 821
26	814 - 849	859 - 894
28	703 - 748	758 - 803
66	1710 - 1780	2110 - 2200

2.3 Downlink

The downlink (DL) is the same as in LTE but has limiting simplifications. Spatial multiplexing is not defined. Only one data stream is transmitted, but TX diversity with two antennas is defined. The downlink uses OFDMA with a carrier spacing of 15 kHz. NB-IoT uses only 12 carriers, which leads to an occupied bandwidth of 180 kHz. One slot consists of seven OFDMA symbols. This produces the following grid, which is exactly equal to one resource block (1 RB) in LTE. A **resource element (RE)** is one subcarrier in one OFDMA symbol and is shown as one square in the figure. NB-IoT defines only QPSK modulation in the downlink.

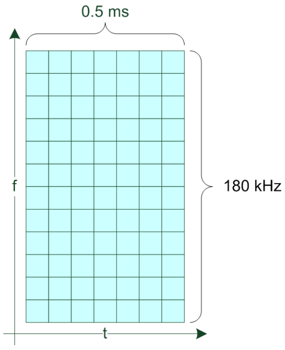


Figure 2-4: Downlink grid: 12 carriers with 15 kHz spacing yields a channel bandwidth of 180 kHz. One slot consists of seven OFDMA symbols.

There are two slots in a subframe (SF) and ten subframes in a radio frame (RF).

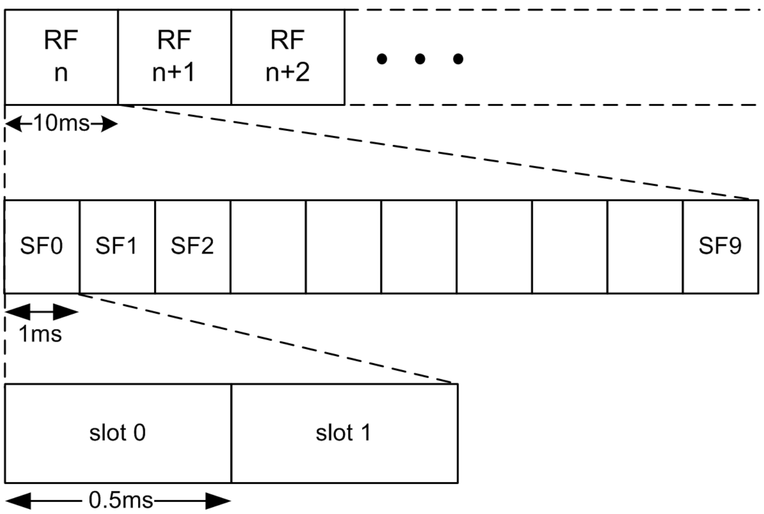


Figure 2-5: Relationship between slots, subframes (SF) and radio frames (RF) in the downlink.

Reference and synchronization signals

As in LTE, NB-IoT provides the UE with signals in the downlink:

- Synchronization signals help the UE evaluate the timing and frequency.
  - Narrowband primary synchronization signal (NPSS)
  - Narrowband secondary synchronization signal (NSSS)
- The narrowband reference signal (NRS) helps the UE to estimate the channels and supports up to two antennas (for TX diversity)

Physical channels

NB-IoT defines three physical channels with the same designation as in LTE but with a leading "N" (for narrowband):

- **NPBCH** – the narrowband physical broadcast channel carries the narrowband master information block (MIB-NB)

- **NPDCCH** – the narrowband physical downlink control channel provides the UE with two important pieces of information:
  – Which data are directed towards the UE in the downlink (NPDSCH)
  – What resource the UE can use in the uplink
- **NPDSCH** – the narrowband physical downlink shared channel transports user data in the downlink.

NPBCH

The NBPCH consists of eight independent 80 ms blocks. A block is always transmitted in subframe 0 of a radio frame and then repeated eight times (once per radio frame). The NBPCH is not transmitted in the first three symbols to avoid conflicts with the LTE control channels.

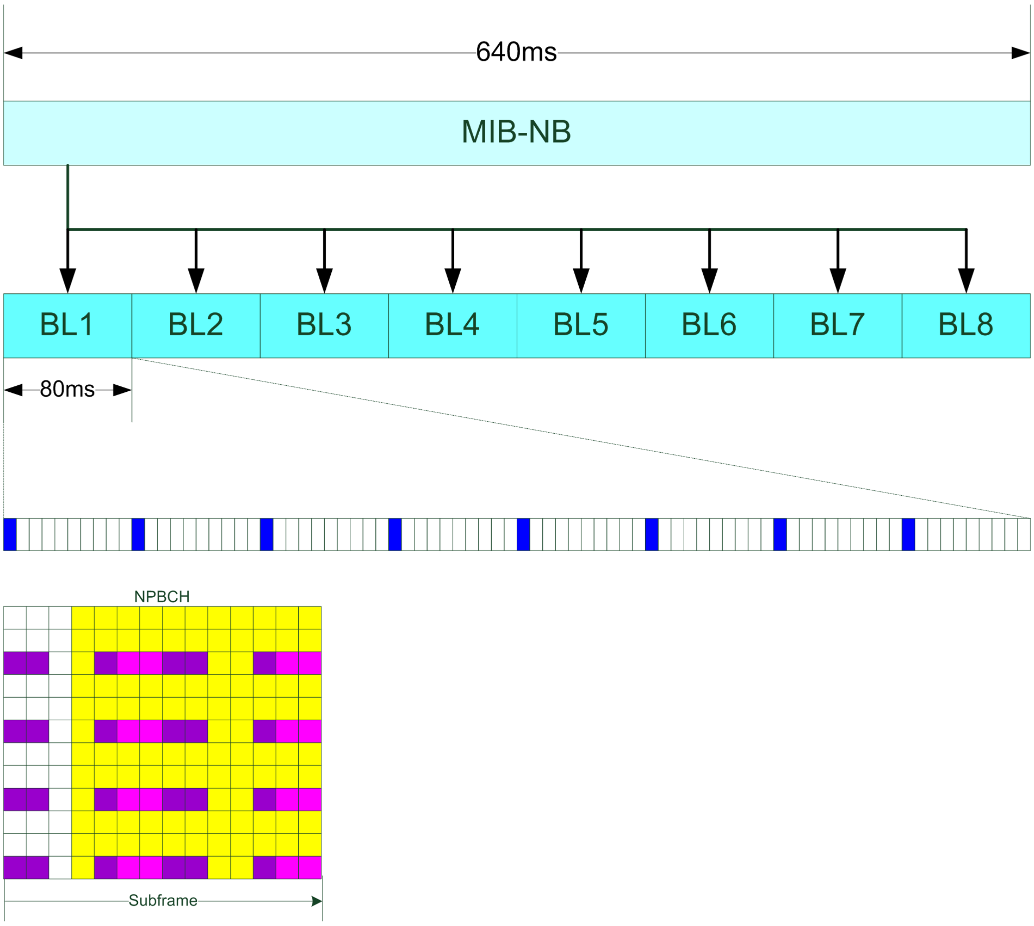


Figure 2-6: The REs occupied by NPBCH are shown in yellow. Reference signals occupy the REs in other colors [pink: NRS (NB-IoT), purple: CRS (LTE)].

NPDCCH

The NPDCCH has three new DCI formats:

- **N0**: allocates resources to the UE, which it can use to send data via the NPUSCH
- **N1**: informs the UE when to expect data on the NPDSCH

- **N2**: for paging and direct indication

The NPDCCH occupies either the six lower subcarriers or all 12 subcarriers in a subframe. The l^{N}_{start} parameter defines the start symbol in the subframe.

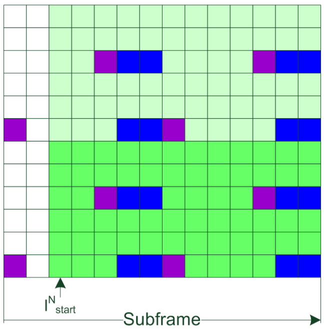


Figure 2-7: The NPDCCH is shown in green (dark green: NCCE 1, light green: NCCE2). Reference signals occupy the REs in other colors (purple: CRS, blue: NRS). The example shows an in-band operation with one antenna in LTE and two in NB-IoT.

There is a certain delay between the signaling to the UE by the NPDCCH and when execution actually occurs. This delay is at least five (5) subframes between NPDCCH and NPDSCH, and eight (8) subframes between NPDCCH and NPUSCH.

NPDSCH

The NPDSCH has the same format as the NPDCCH (see Figure 2-7).The data can span several subframes. The NPDSCH can repeat the data (repetition) to increase the range. The number of repetitions (up to 2048) is communicated to the UE via the NPDCCH.

The base station can request an acknowledgement (ACK) from the UE. This ACK is in NPUSCH DCI format 2 (see Chapter 2.4, "Uplink", on page 10).

The NPDSCH also supports multicarrier operation. In the idle state, the UE synchronizes with the anchor carrier. In the connected state, another RB (non-anchor carrier) can be requested for data transmission.

2.4 Uplink

In the uplink (UL), two different possibilities are defined. It can use either a single carrier or multiple carriers.

- Single-tone: 15 kHz or 3.75 kHz carrier spacing (single-tone is mandatory)
- Multitone: SC-FDMA with 15 kHz carrier spacing (optional)

Here, the carrier spacing in the multitone process is the same as in the downlink and in LTE.

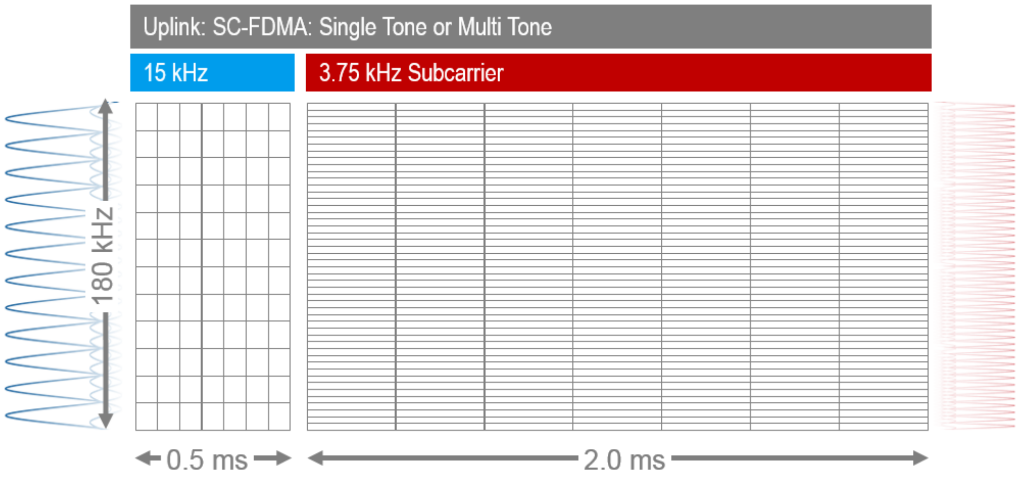


Figure 2-8: Resource element grid in the uplink.

With a carrier spacing of 15 kHz, 12 carriers are available; 3.75 kHz spacing yields 48 carriers.

NB-IoT defines two physical channels and a demodulation reference signal (DMRS). The channel designations are the same as in LTE but preceded by an "N" (for narrowband):

- NPUSCH – narrowband physical uplink channel
- NPRACH – narrowband physical random access channel

NPUSCH

The NPUSCH transports two types of information:

- The actual data in the uplink (NPUSCH format 1)
- Uplink control information (UCI) (NPUSCH format 2)

Format 2 (control) always uses one carrier and is always BPSK-modulated. It carries the ACK function for the downlink data channel (NPDSCH). Format 1 (data) can use one or more carriers. For single-tone, the modulation is π/2-BPSK or π/4-QPSK; for multitone it is always QPSK. The NPUSCH can repeat data (up to 128 times) to increase the range.

Table 2-3: NPUSCH formats

Physical channel	Transport channel	Number of carriers	Modulation scheme	Channel coding
NPUSCH format 1	UL-SCH	1 (single-tone)	π/2-BPSK π/4-QPSK	Turbo 1/3
		> 1 (multitone)	QPSK	
NPUSCH format 2	UCI	1 (single-tone)	π/2-BPSK	Block 1/16

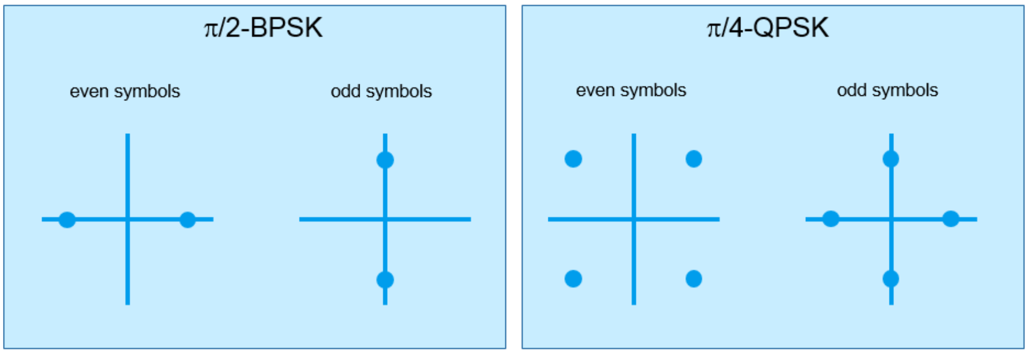


Figure 2-9: Uplink modulation schemes

NB-IoT defines a new resource unit (RU), which describes how an NPUSCH is allocated to the carriers and slots. A slot consists of seven (7) SC-FDMA symbols.

Table 2-4 provides an overview. Figure 2-10 shows a graphical view.

Table 2-4: RU overview.

NPUSCH format	Transport channel	Δf in kHz	Number of carriers	Number of slots	Number of symbols	T^{slot} in ms	T^{RU} in ms
1	UL-SCH	3.75	1	16	7	2	32
		15	1	16		0.5	8
			3	8		0.5	4
			6	4		0.5	2
			12	2		0.5	1
2	UCI	3.75	1	4		2	8
		15	1	4		0.5	2

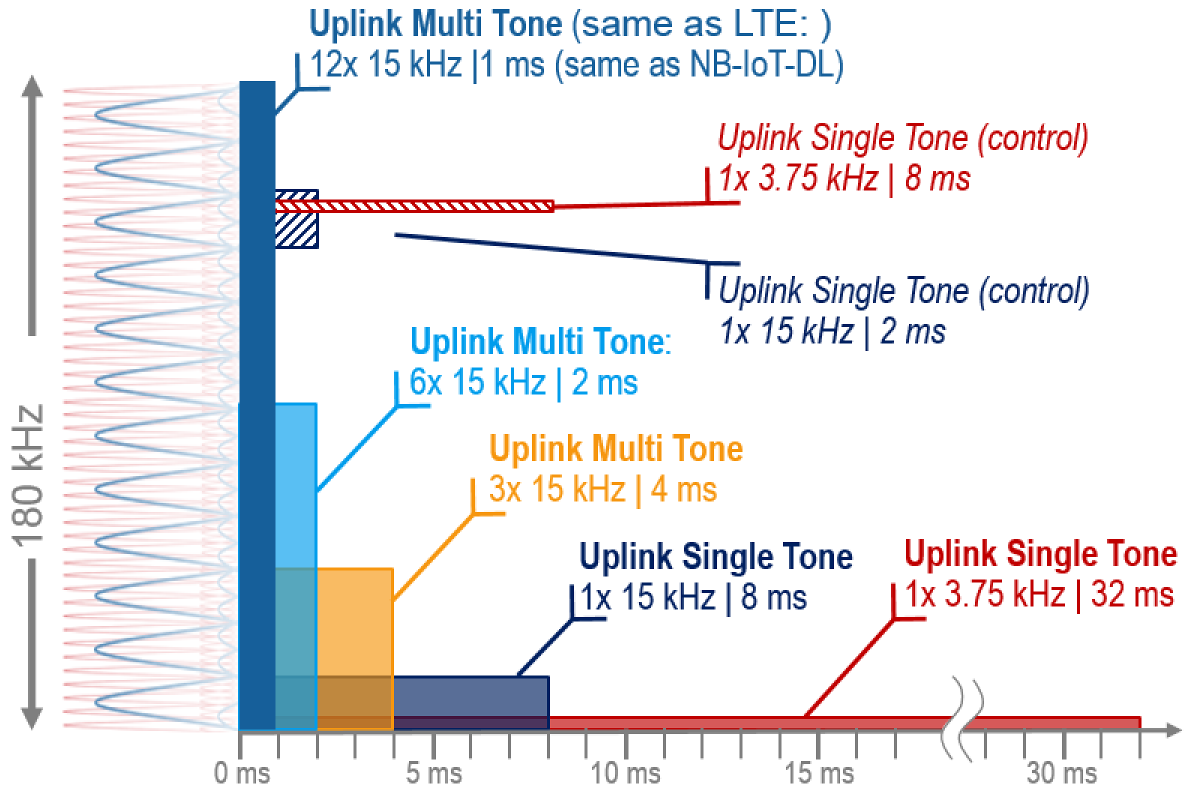


Figure 2-10: Graphical view of possible RUs.

NPRACH

The random access channel (NPRACH) uses a single tone with frequency hopping and 3.75 kHz spacing. The preamble consists of four symbol groups, which are repeated 1, 2, 4, 8, 16, 32, 64 or 128 times. Each of the four groups is made up of a cyclic prefix (CP) and four identical symbols.

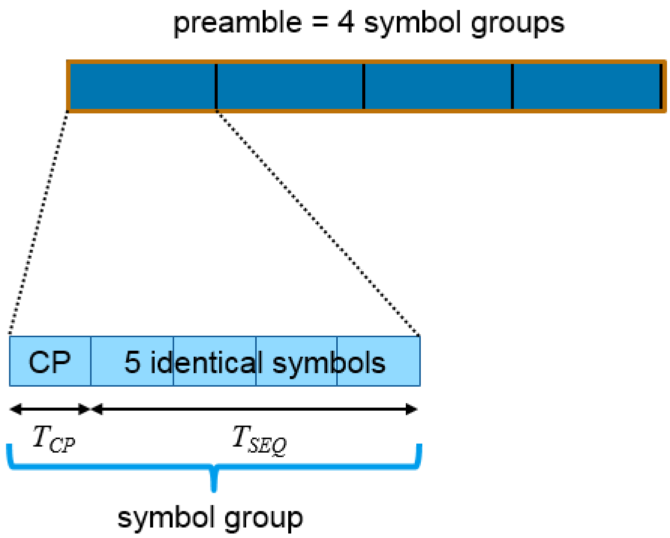


Figure 2-11: The NPRACH consists of four (4) symbol groups, each containing a cyclic prefix (CP) and five identical symbols.

The NPRACH hops among 12 neighboring carriers. The base station specifies a range for the allowed carriers, and communicates both the delay and the allowed range via the SIB. The UE can choose 12 subcarriers. If the UE uses a specific range within the designated carriers, this lets the base station know that it supports multitone.

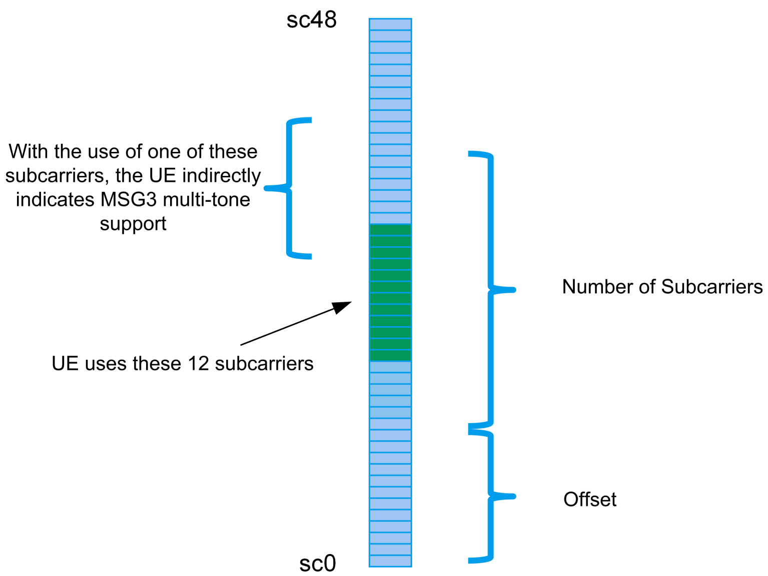


Figure 2-12: Example of NPRACH range specification. The UE has chosen the green range (12 sub-carriers) from the range provided by the base station and is using it for random access.

Frequency hopping is defined by a special algorithm.

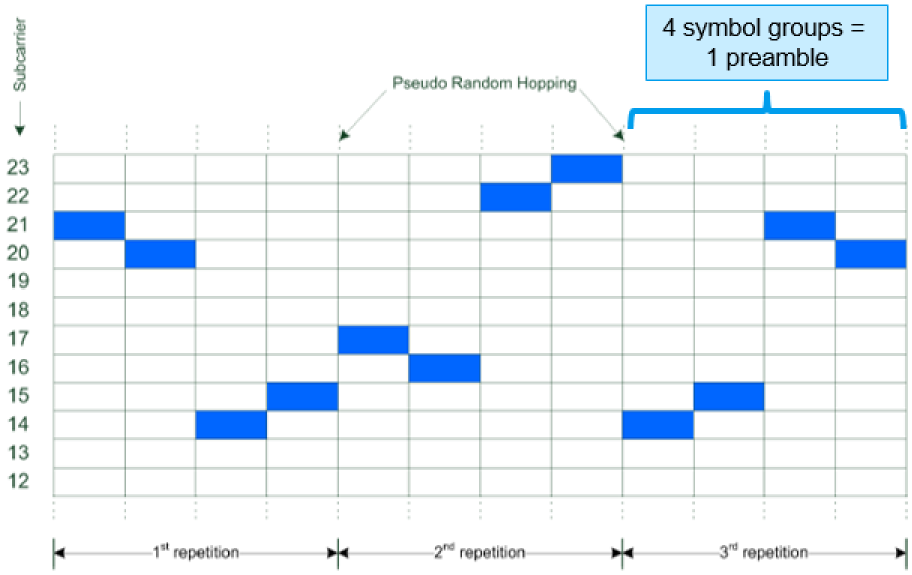


Figure 2-13: Example of NPRACH hopping

3 NB-IoT Measurements at the Basestation (eNodeB)

Measurements on the base station include eNodeB transmitter and receiver tests.

3.1 Transmitter Measurements (Downlink)

The VSE vector signal explorer software provides the analysis capabilities of a signal and spectrum analyzer on a PC. It remotely controls a data collection instrument (e.g. FSW, FSV(A), FPS or RTO) and then analyzes the data. The VSE also supports numerous digital communications standards. The VSE-K106 enables NB-IoT analysis. For further information on VSE operation, please refer to the manual [4] and [5].

The VSE supports two different NB-IoT types of measurement:

- Demodulation measurements
  – EVM and frequency error.
  – Time alignment error (for Tx Diversity)
- Spectrum measurement
  – Adjacent channel power (ACLR)
  – Spectrum Emission Mask (SEM)

To switch between the measurements, open the **Meas Setup|Select Measurement** menu.

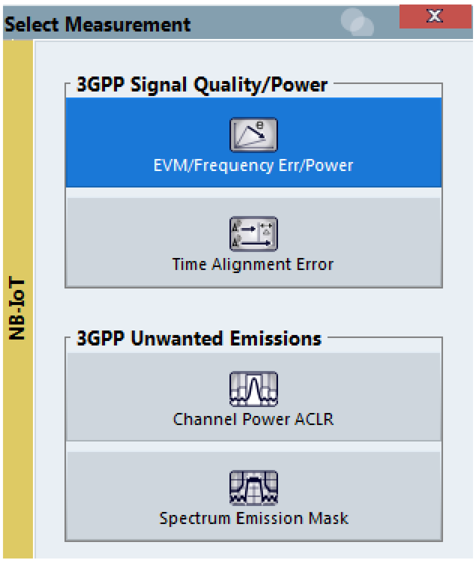


Figure 3-1: Switching between demodulation (e.g. EVM) and spectrum measurements (ACLR, SEM) for NB-IoT.

Test setup

The eNodeB transmitter signal is recorded with a spectrum analyzer connected via a base station attenuator. The VSE software runs on a separate PC. It controls the spectrum analyzer, performs the measurements and clearly displays the results. Figure 3-2 shows the test setup.

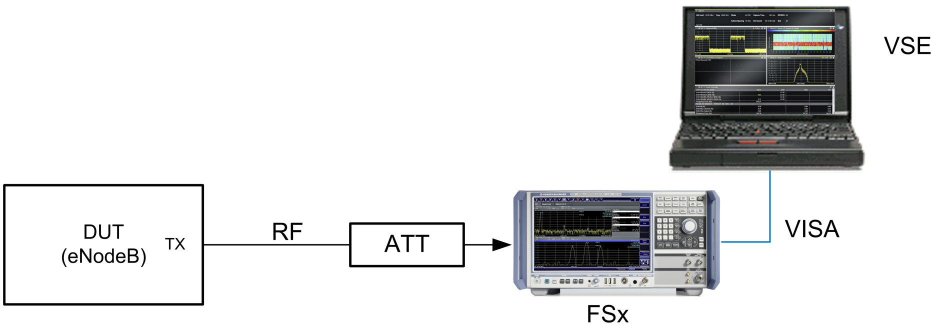


Figure 3-2: Setup for the TX test on the eNodeB

3.1.1 Stand-alone

The VSE software is used to measure the NB-IoT downlink signal from the eNodeB transmitter. On the **Signal Description** tab, set the **Mode** to *FDD Downlink* and select the correct *Deployment*, here *Stand-alone*. On the **MIMO Setup** tab, configure the number of antennas used (for TX diversity with two transmit antennas) and specify which antennas are to be measured.

The VSE automatically finds and displays the NPDSCH configuration. You can also manually configure the settings. No additional settings are required in *Stand-alone* operation.

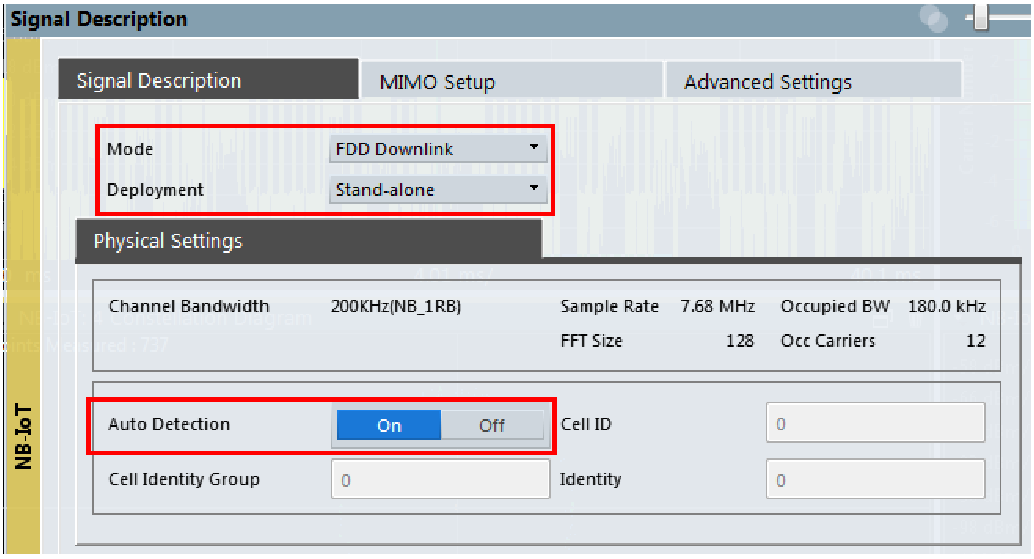


Figure 3-3: Parameters of the NB-IoT signal in the VSE in standalone operation.

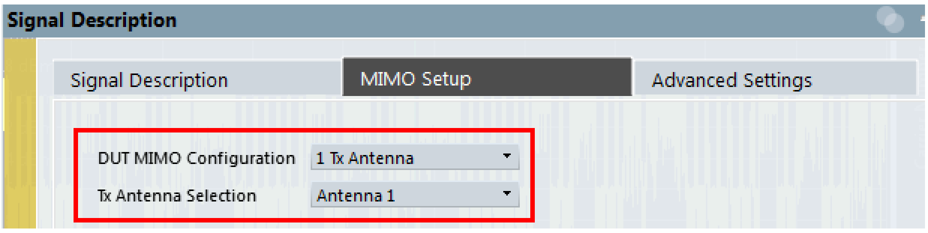


Figure 3-4: Number of antennas: TX diversity uses two antennas.

The VSE provides an overview of the measurements:

- Top left: spectrum over time
- Top right: time and frequency plan
- Lower left: constellation diagram (always QPSK and reference signals in the down-link)
- Lower right: power spectrum
- Bottom: a table with an overview of the scalar measurement values.

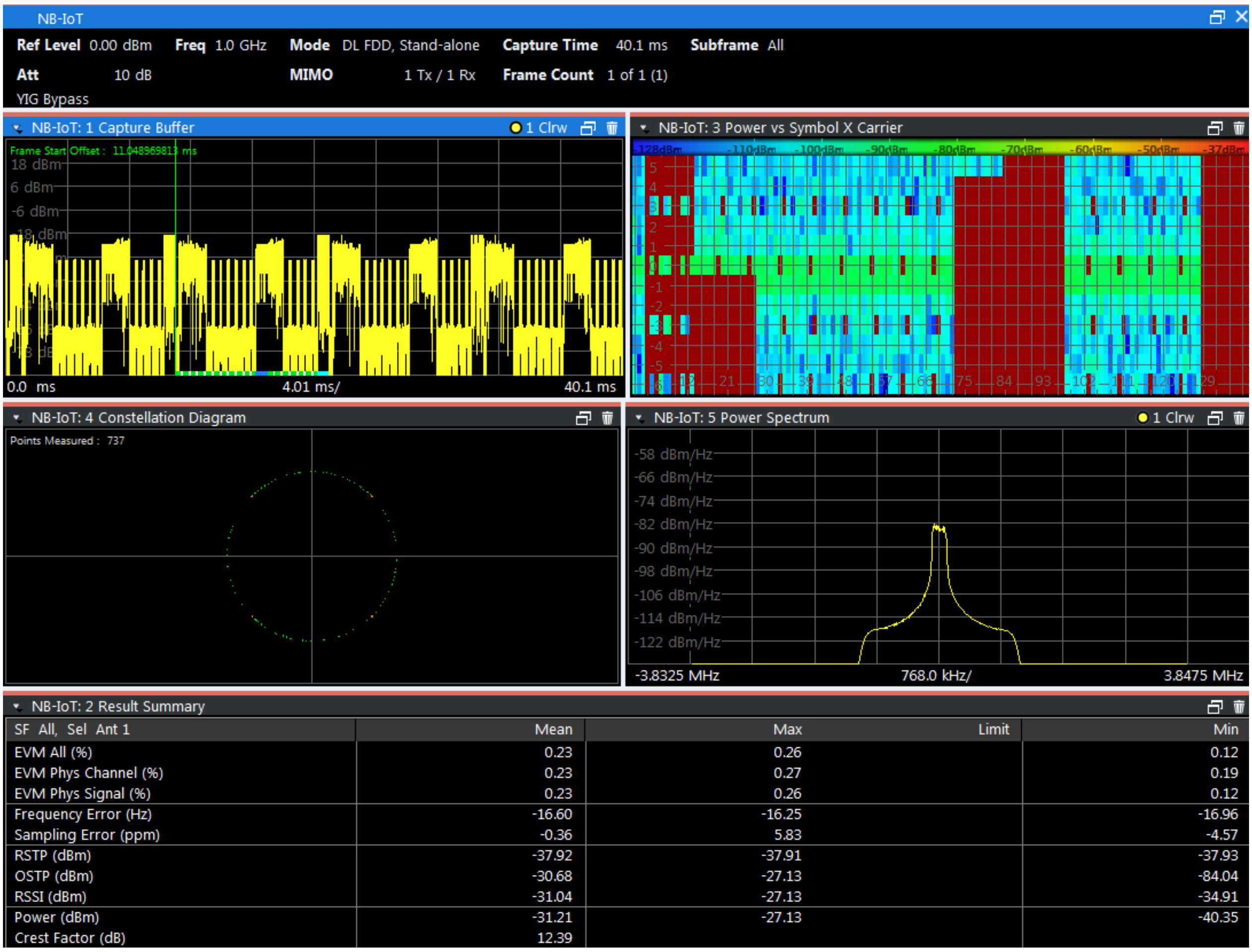


Figure 3-5: Overview of the downlink TX measurement in the VSE. It clearly displays all relevant measurement values.

3.1.2 In-band

In in-band mode NB-IoT uses RB's inside the LTE channel bandwidth.

Set the *Deployment* to *In-band*. In *Inband* mode, all settings refer to the LTE channel. Set the following parameters:

- **E-UTRA Center Frequency**
- **E-UTRA Channel Bandwidth**
- **E-UTRA CRS Sequence Info**: The UE needs this information to be able to use the CRS for channel estimation (see PRB index).
- **E-UTRA PRB Index**: Automatically calculated from the CRS sequence and shows the RB used for NB-IoT. This is the **anchor** carrier.
  The VSE also uses the PRB index to calculate and display the NB-IoT center frequency automatically.

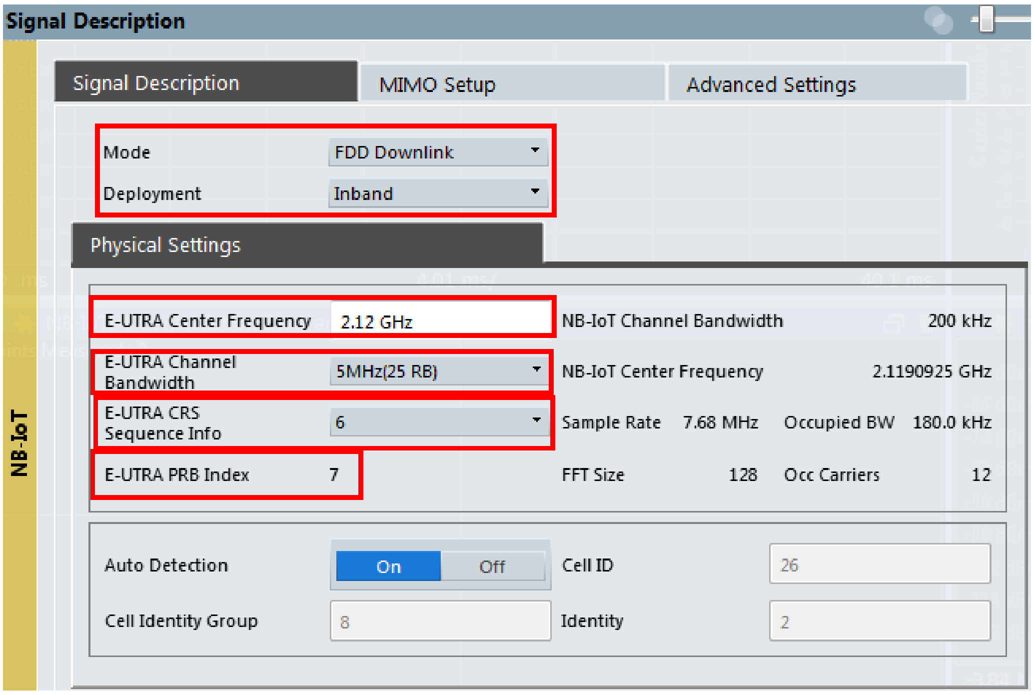


Figure 3-6: Parameters of the NB-IoT signal in the VSE in in-band mode, the VSE displays the RB (including the frequency) used for NB-IoT.

Measurement of NB-IoT and LTE in the downlink

In in-band mode, the basestation typically transmits LTE signals in parallel to the NB-IoT signal.

The VSE offers the possibility of operating multiple measurement channels nearly simultaneously. For the in-band NB-IoT operation, you can alternate between the LTE channel and NB-IoT and measure them practically in parallel.

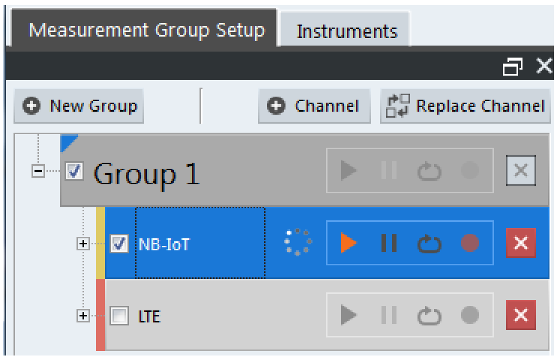


Figure 3-7: Two measurement channels in the VSE: NB-IoT and LTE in this example.

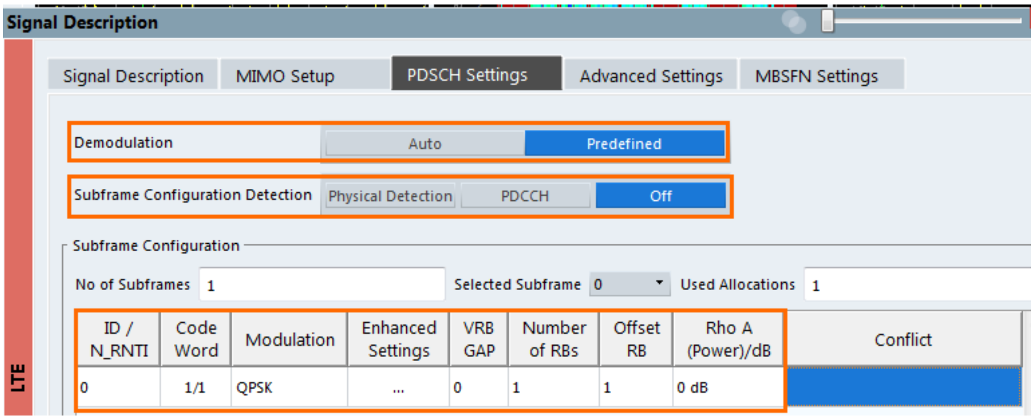


Figure 3-8: Manual LTE PDSCH setting in order not to measure the NB-IoT signal part. In this example: one RB with QPSK.

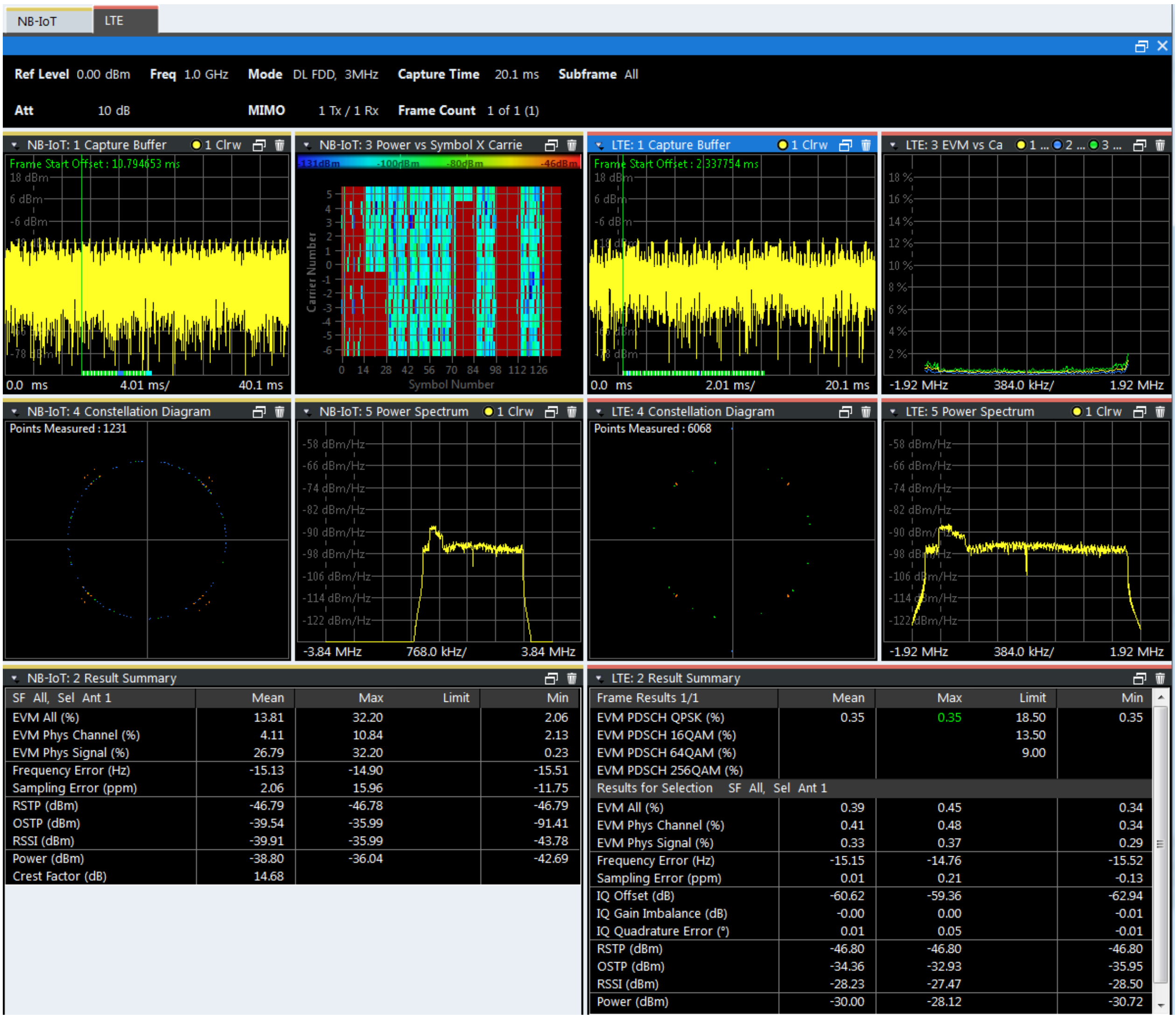


Figure 3-9: Overview of NB-IoT and LTE measurements in the downlink quasi-parallel.

3.1.3 Guardband

In guardband mode, NB-IoT uses RB's in the guard band of the LTE channel bandwidth.

The settings for NB-IoT measurements are the same like in Standalone mode (see Chapter 3.1.1, "Stand-alone", on page 17). Set the frequency of NB-IoT to the center frequency of the occupied RB in the guard band. For calculation of the frequency with a given RB index see Chapter 5.2, "NB-IoT Allocation Frequencies for In-Band and Guard Band", on page 58.

Here you can measure again in parallel the LTE channel. The settings are in principle the same like in "Measurement of NB-IoT and LTE in the downlink" on page 20, subchapter **Measurement of NB-IoT and LTE in the downlink**.

3.1.4 Time Alignment Error

The eNodeB might use transmit diversity (Tx Diversity) with two antennas. If so, both antennas have to transmit their signal in a certain time alignment to each other.

The VSE is able to measure the time alignment error with the following setup:

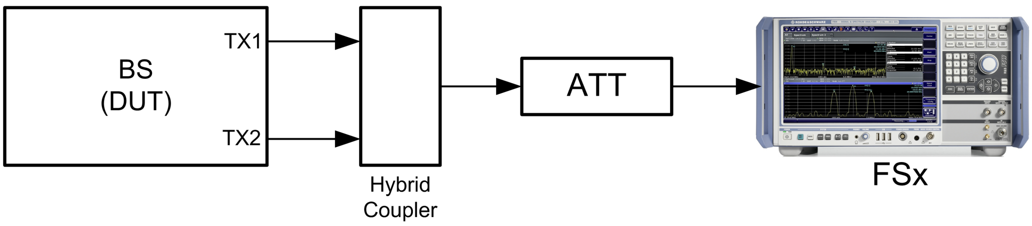


Figure 3-10: Test setup: time alignment error.

The antennas to be measured are connected via a hybrid coupler. The FSx is connected via an attenuator. To achieve precise measurements, the RF cables being used should be equal in electrical length.

Select the **Time Alignment Error** measurement.

The VSE sets the MIMO configuration to 2 Tx antennas automatically, if not done before.

The measurement is taken on the reference signals (NRS) of the individual antennas, and NPDSCHs are ignored. The measurement is always relative to one reference antenna. The antenna can be changed under "Reference Antenna".

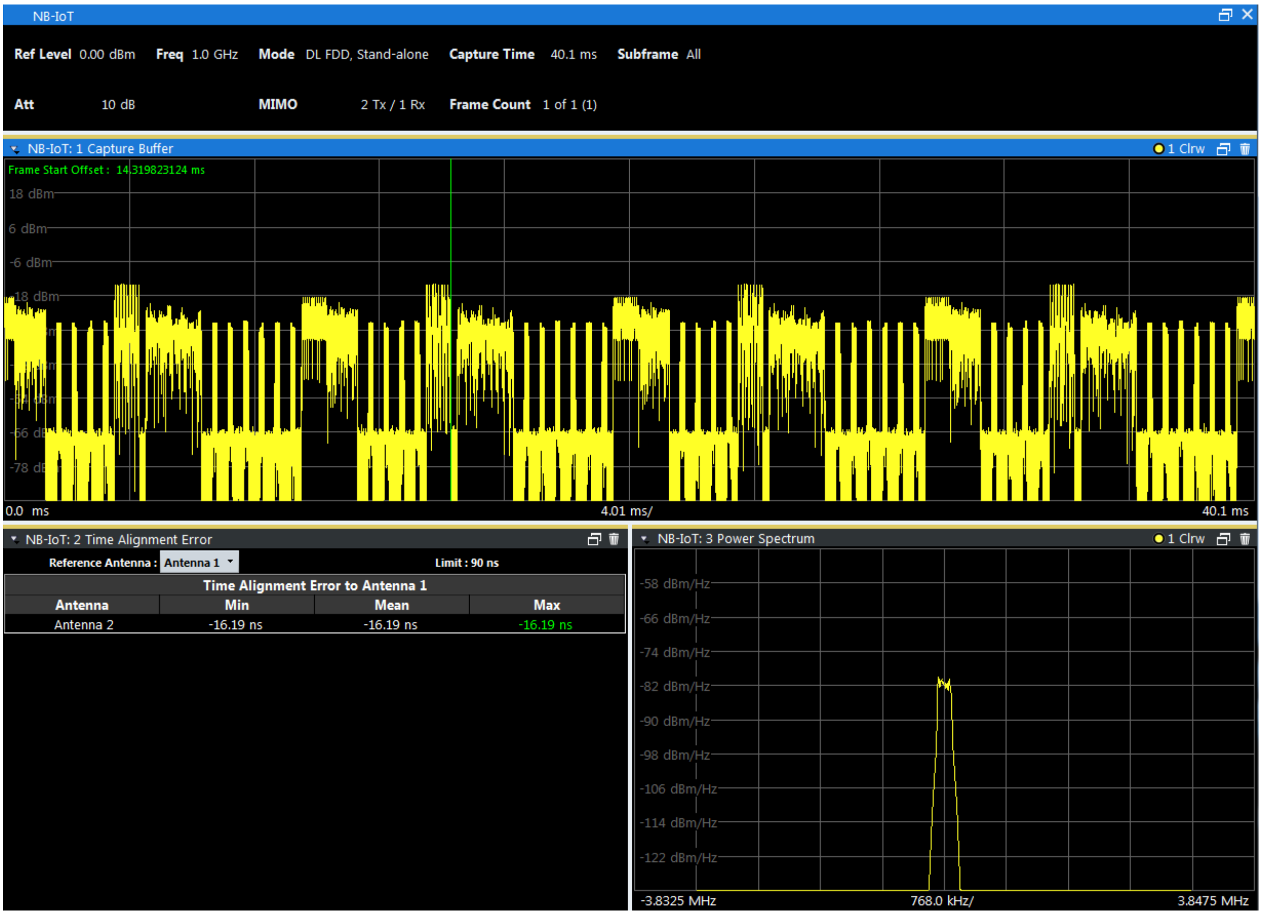


Figure 3-11: Time alignment: the measurement is displayed relative to a selectable reference antenna.

3.1.5 Spectrum Measurement: ACLR

Select the **Channel Power ACLR** measurement.

The VSE automatically sets the relevant parameters for ACLR measurements.

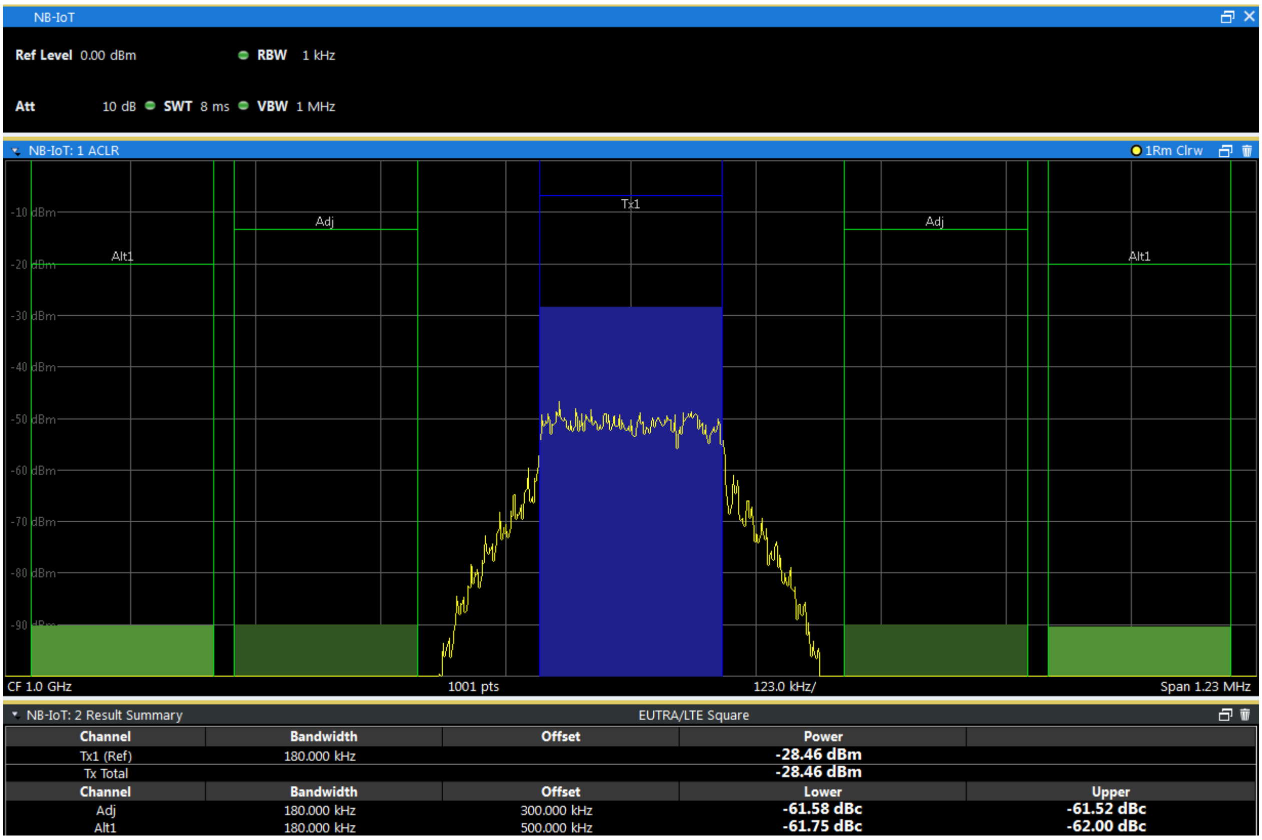


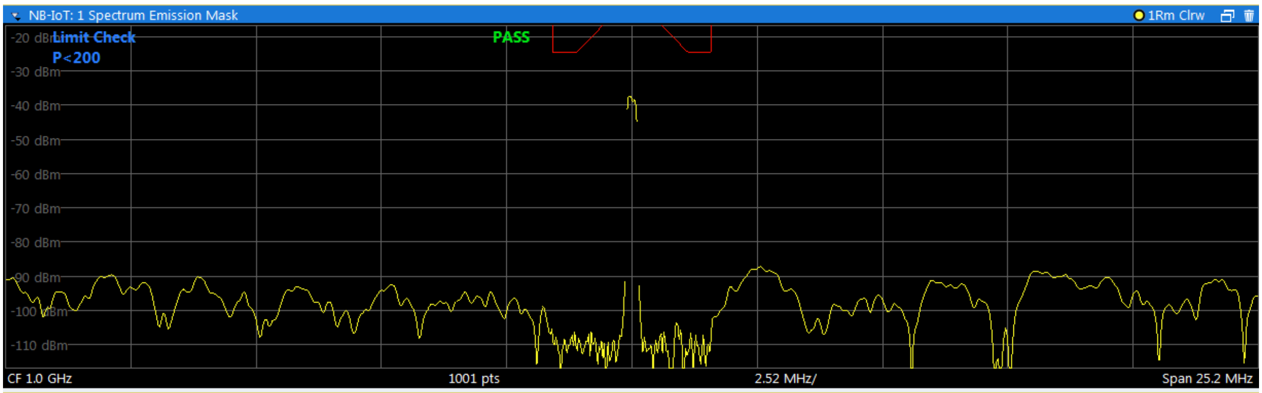
Figure 3-12: ACLR measurement in the downlink.

3.1.6 Spectrum Measurement: SEM

Select the **Spectrum Emission Mask** measurement.

The VSE automatically sets the relevant parameters for SEM measurements.

Figure 3-13 shows a SEM test. The **Result Summary** displays the results of the individual ranges. The global limit check is displayed along the top.



NB-IoT: 2 Result Summary

Sub Block A — Center 1.00 GHz — Tx Power -30.69 dBm — Tx Bandwidth 200.000 kHz — RBW 30.000 kHz — LTE DL

Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-12.600 MHz	-10.600 MHz	1.000 MHz	989.31139 MHz	-90.09 dBm	-59.40 dB	-75.09 dB
-10.600 MHz	-1.600 MHz	1.000 MHz	989.53866 MHz	-89.60 dBm	-58.91 dB	-78.10 dB
-1.600 MHz	-1.115 MHz	30.000 kHz	998.84671 MHz	-106.21 dBm	-75.52 dB	-81.71 dB
-1.115 MHz	-315.000 kHz	30.000 kHz	998.92371 MHz	-108.10 dBm	-77.41 dB	-84.18 dB
-315.000 kHz	-265.000 kHz	30.000 kHz	999.71000 MHz	-112.39 dBm	-81.69 dB	-99.89 dB
-265.000 kHz	-165.000 kHz	30.000 kHz	999.81833 MHz	-103.07 dBm	-72.37 dB	-90.57 dB
-165.000 kHz	-115.000 kHz	30.000 kHz	999.86000 MHz	-91.55 dBm	-60.86 dB	-79.05 dB
115.000 kHz	165.000 kHz	30.000 kHz	1.00014 GHz	-92.68 dBm	-61.99 dB	-80.18 dB
165.000 kHz	265.000 kHz	30.000 kHz	1.00018 GHz	-105.19 dBm	-74.50 dB	-92.69 dB
265.000 kHz	315.000 kHz	30.000 kHz	1.00029 GHz	-112.02 dBm	-81.33 dB	-99.52 dB
315.000 kHz	1.115 MHz	30.000 kHz	1.00090 GHz	-103.44 dBm	-72.75 dB	-82.23 dB
1.115 MHz	1.600 MHz	30.000 kHz	1.00118 GHz	-106.51 dBm	-75.82 dB	-82.01 dB
1.600 MHz	10.600 MHz	1.000 MHz	1.00257 GHz	-87.08 dBm	-56.38 dB	-75.58 dB
10.600 MHz	12.600 MHz	1.000 MHz	1.01188 GHz	-90.89 dBm	-60.20 dB	-75.89 dB

Figure 3-13: The VSE cares about the correct settings automatically. Please note that there is a gap in the measurement range defined by the specification.

3.2 Receiver Testing (Uplink)

Rohde & Schwarz vector signal generators offer many options for generating signals for various communications standards. In addition to the NB-IoT signals as part of Release 13 of the 3GPP LTE-A standard, Rohde & Schwarz generators support all major standards such as 5G air interface candidates, LTE MIMO, 3GPP FDD/HSPA/HSPA+, GSM/EDGE/EDGE evolution, CDMA2000® /1xEV-DO, WLAN IEEE 802.11a/b/g/n/j/p/ac/ad and Bluetooth.

- The SMW supports a multipath concept with excellent RF characteristics, real-time baseband signals plus fading/AWGN.
- As a cost-effective alternative, the SGT offers an ARB generator to play predefined I/Q files (e.g. files generated by WinIQSIM2).

The SMW-K115 option enables generation of NB-IoT signals in line with 3GPP Release 13 and supports uplink and downlink signals. The SMW-K112 and SMW-K113 options unlock LTE-Advanced in line with Releases 11 and 12. LTE also requires the SMW-K55 basic LTE option. For further information on SMW operation, please refer to the manual [3].

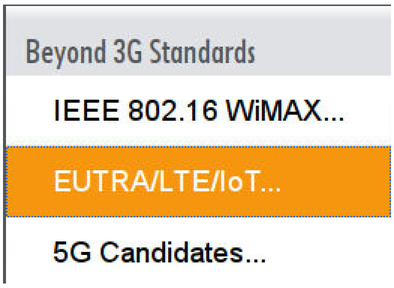


Figure 3-14: In the SMW, the NB-IoT signals are in the EUTRA/LTE/IoT part.

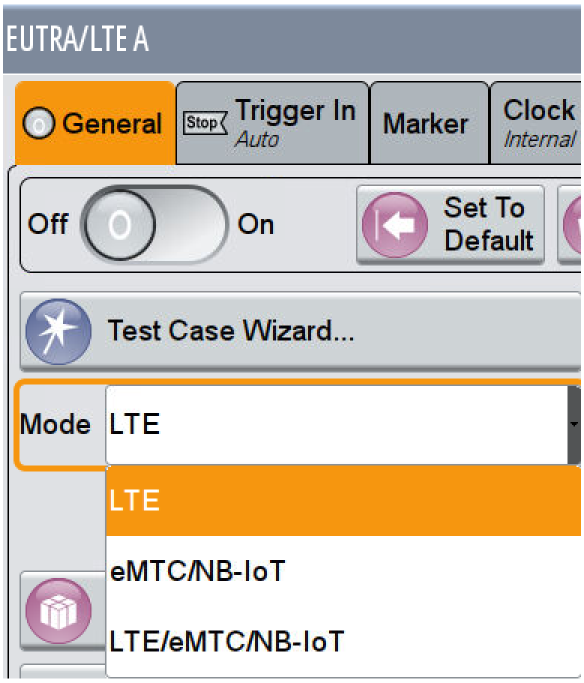


Figure 3-15: Switch to choose LTE/eMTC/NB-IoT (only available when all necessary options are installed).

Test setup

The signal generator provides an uplink signal for the eNodeB receiver test. The SMW can also simulate the channel (fading and AWGN, see Chapter 3.2.4, "Channel Simulation: Fading and AWGN", on page 40). Figure 3-16 shows the test setup.

Figure 3-16: Setup for the eNodeB RX test.

3.2.1 Settings for NB-IoT in the Uplink.

The SMW can simultaneously generate up to four (4) UEs in a single LTE/NB-IoT baseband. This makes it possible to test a receiver with an NB-IoT signal and an LTE signal in parallel.

For the base station receiver test, set the **Link Direction** to *Uplink (SC-FDMA).*

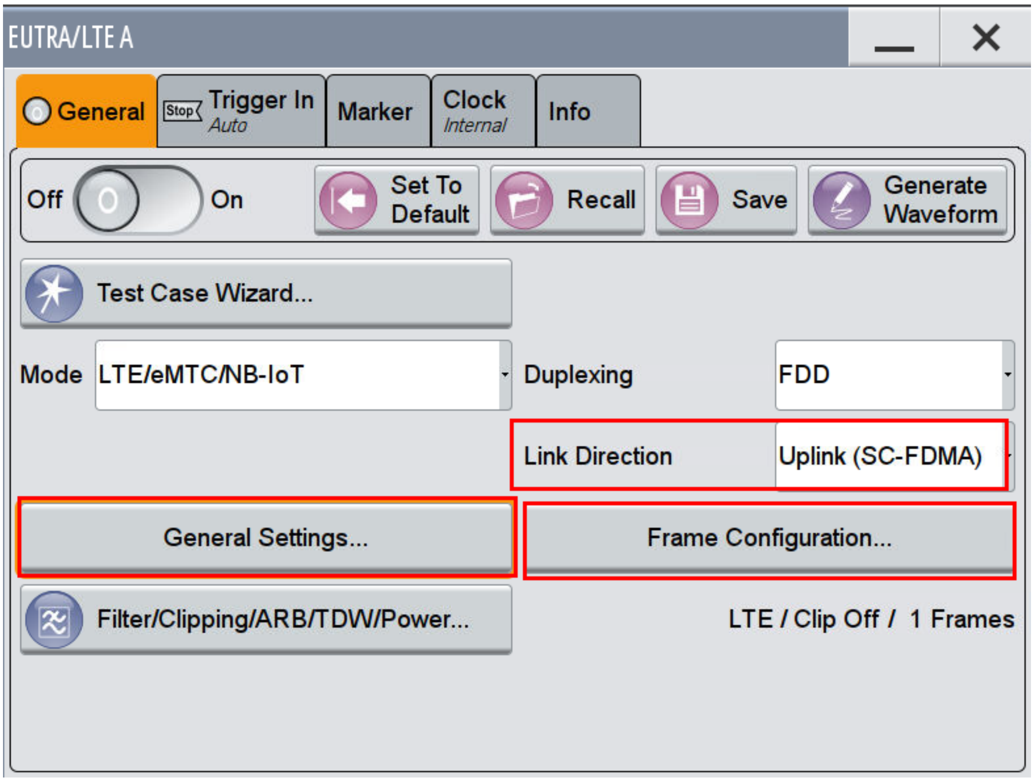


Figure 3-17: Default NB-IoT setting. An uplink signal is generated for eNodeB receiver tests.

Click **General Settings**, open the **Physical** tab and select the correct **Channel Bandwidth**:

- **200 kHz**: standalone mode
- **LTE bandwidths:** in-band or guard band mode

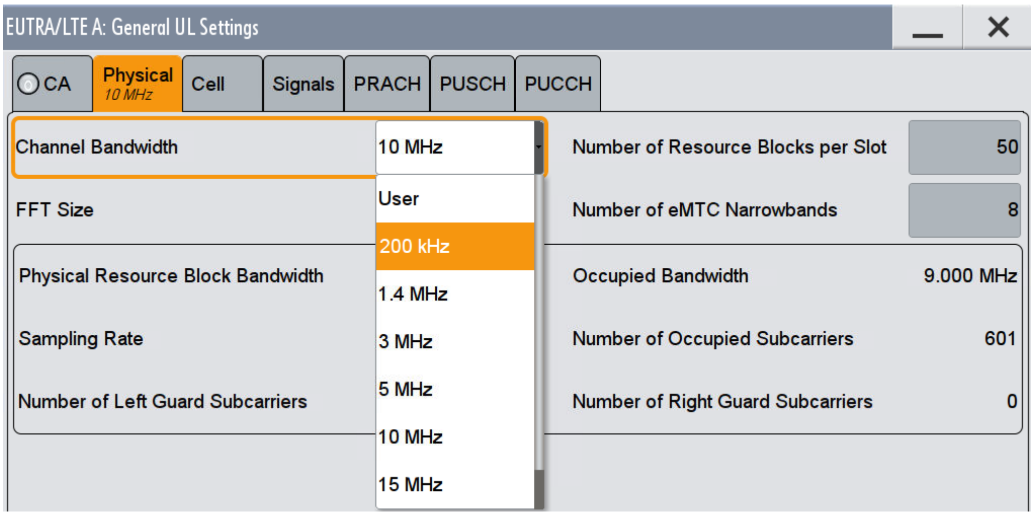


Figure 3-18: Choosing the channel bandwidth : 200 kHz is the standalone mode; all other LTE bandwidths lead to in-band or guard band operation. (The 1.4 MHz bandwidth is not defined for NB-IoT operation.)

In the main view, click **Frame Configuration** and for 3GPP Release, select NB-IoT. Click the (already) activated UE1.

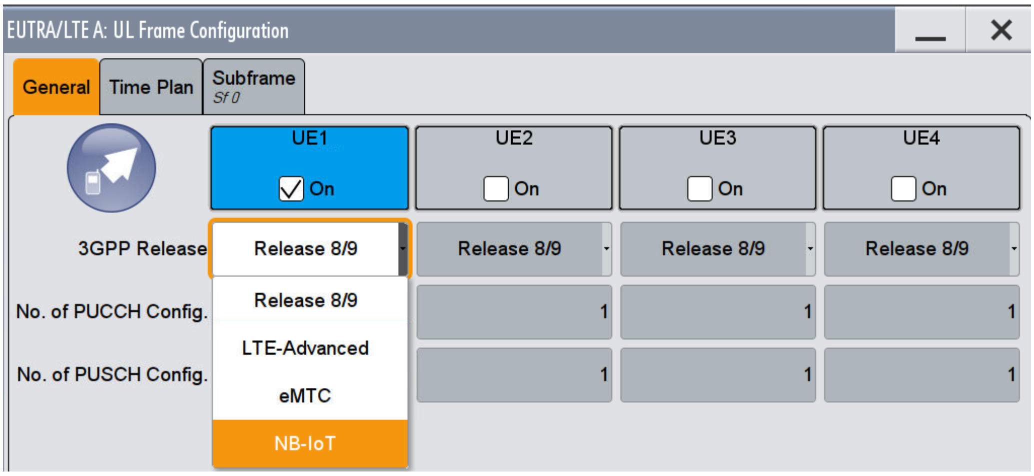


Figure 3-19: UE1 generates an NB-IoT signal.

On the **NB-IoT Allocation** tab, set the relevant uplink signal parameters. The key parameter in the uplink is **Subcarrier Spacing**: 3.75 kHz or 15 kHz. Under **Mode**, *select In-Band* or *Guard Band*. The SMW automatically uses standalone mode if 200 kHz is selected as the channel bandwidth (see previous step Figure 3-18).

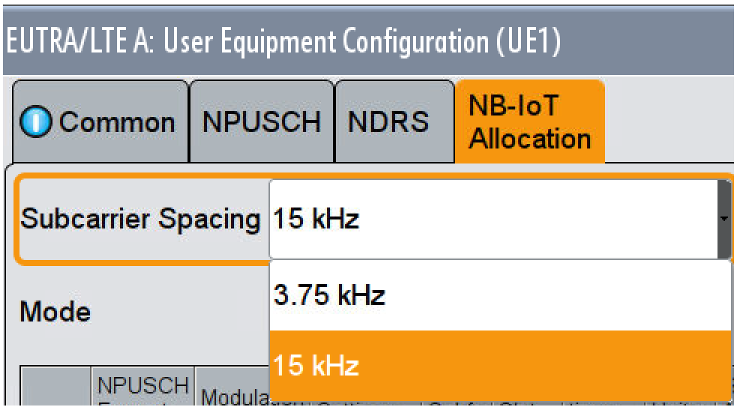


Figure 3-20: Subcarrier spacing in the uplink.

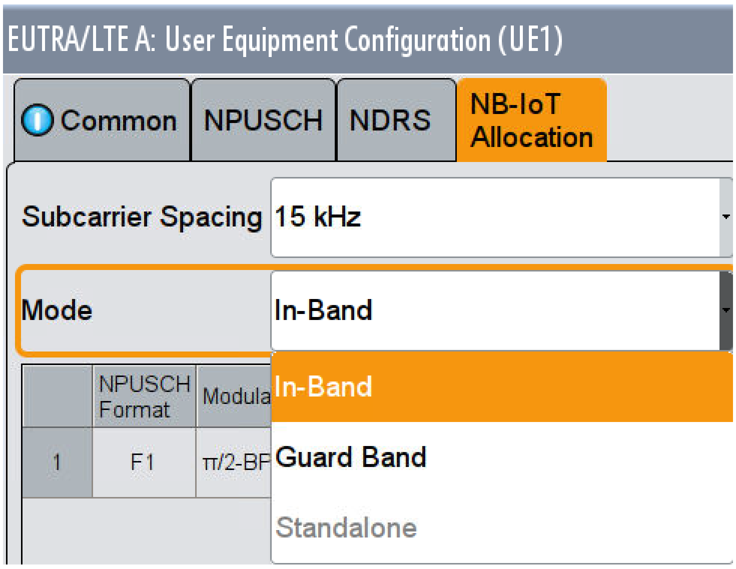


Figure 3-21: Operation mode: standalone is grayed out in this example because an LTE channel bandwidth was selected.

In in-band or guard band mode, use the **Resource Block Index** to set the position of the RB used for NB-IoT transmissions. This also sets the frequency. Please note that the frequency set on the main SMW screen only applies directly to NB-IoT in stand-alone mode. In in-band and guard band mode, the main frequency is the center frequency of the LTE channel. The frequency of the NB-IoT part is set indirectly via the resource block index.

Number of Transmissions indicates the number NB-IoT channels (within the reserved RB). **Repetitions** indicates the number of NPUSCH repetitions (up to 128).

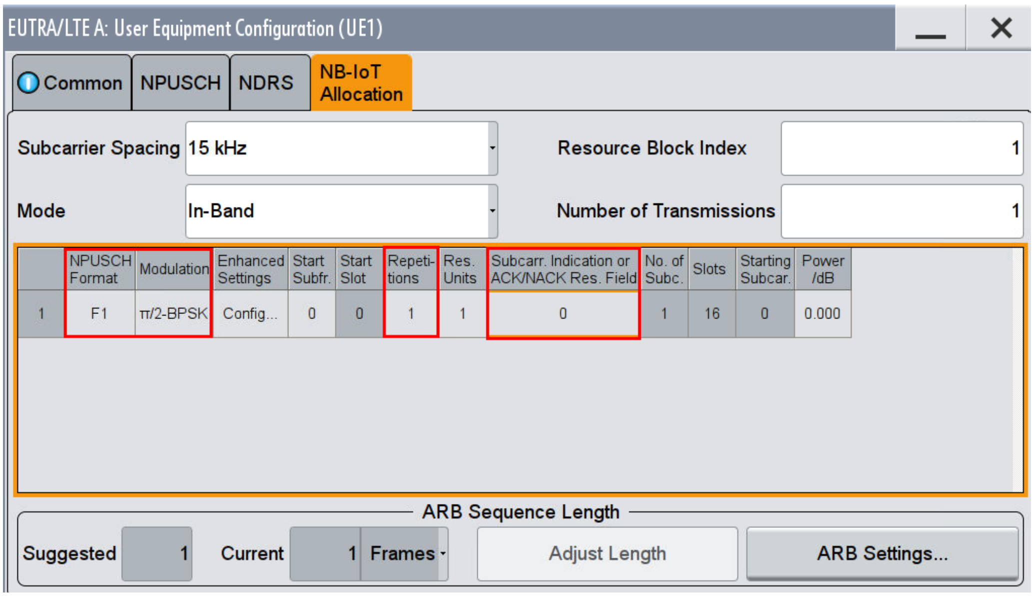


Figure 3-22: Configuration of an NB-IoT uplink signal.

Generating individual physical channels is described below. Note that the SMW displays how many frames are to be generated. If necessary, confirm this number by clicking **Adjust Length**.

The **Time Plan** in the SMW provides a graphical view of the configuration. There are two view modes. **Channel BW** shows the entire LTE channel where the NB-IoT range is displayed as a single RB (Figure 3-23). **Single RB** shows the NB-IoT allocation within the RB (Figure 3-24).

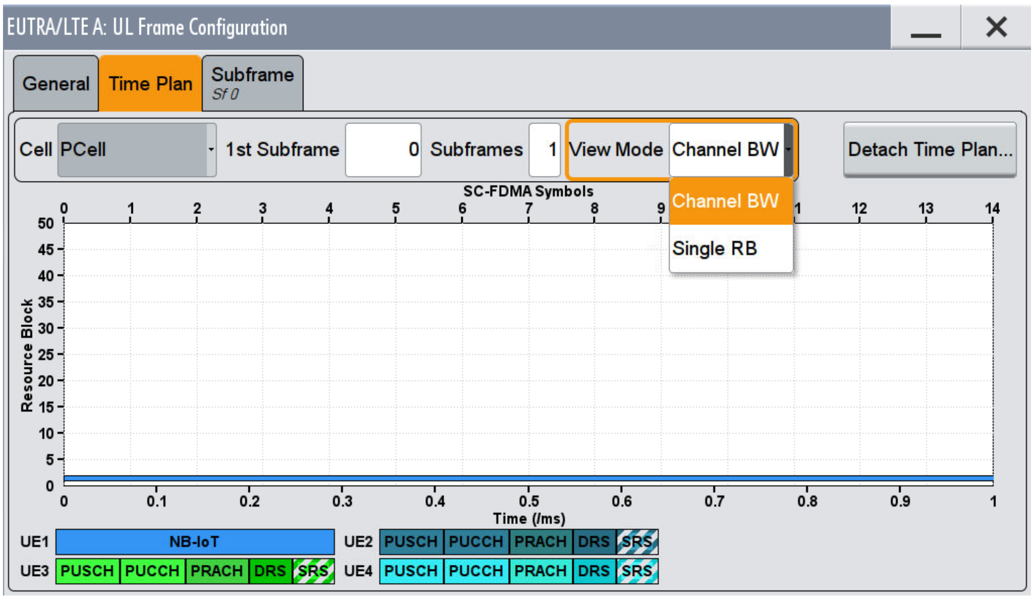


Figure 3-23: Graphical view of the entire LTE channel bandwidth. The NB-IoT range is only one RB (blue).

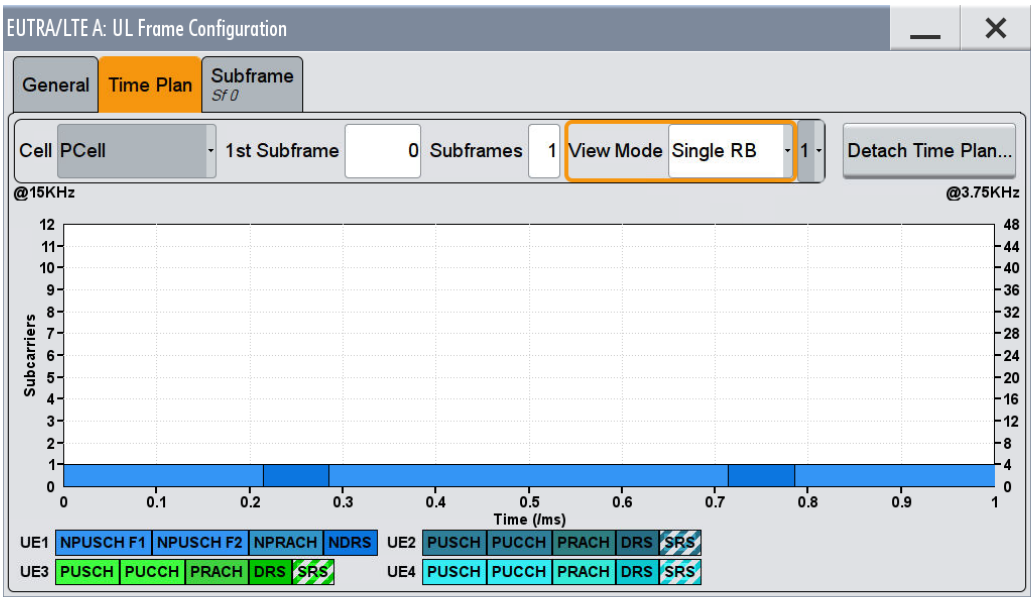


Figure 3-24: Graphical view of the NB-IoT range: this example shows an individual single-tone transmission.

NPUSCH format 1 – data

The NPUSCH in F1 format is used to transmit data to the base station. Format 1 uses π/2-BPSK, π/4-QPSK (in single-tone) and QPSK (in multitone) modulation. Set the **Start Subframe**, number of **Repetitions** and the quantity of **RU**s. Use the **Subcarrier Indication** field to control RU allocation in subcarriers and timeslots (see Table 3-1).

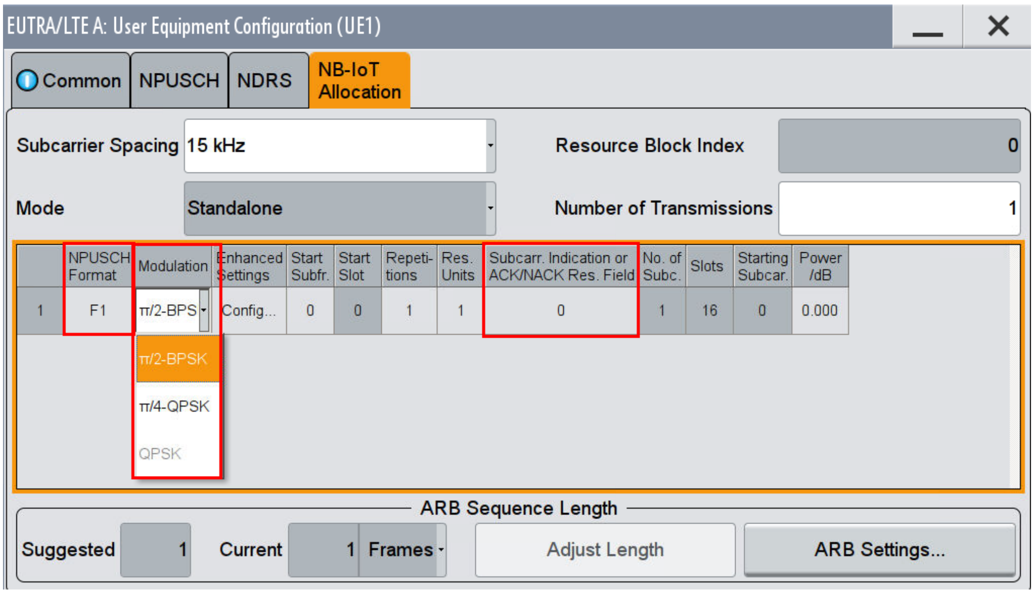


Figure 3-25: NPUSCH format 1.

Table 3-1: Subcarrier indication for 15 kHz spacing.

Subcarrier indication	Number of subcarriers	Number of slots	Subcarrier start
0	1	16	0
1			1
2			2
3			3
4			4
5			5
6			6
7			7
8			8
9			9
10			10
11			11
12	3	8	0
13			3
14			6
15			9
16	6	4	0
17			6
18	12	2	0

Only single-tone is defined for 3.75 kHz subcarrier spacing, i.e. the **Subcarrier Indication** has a range of 0 to 47 and displays the appropriate **Start Subcarrier**. There are always 16 slots in this case.

NPUSCH format 2 – ACK

The NPUSCH in F2 format is used to transmit acknowledgments (ACK/NACK) for the NPDSCH to the base station. Only single-tone π/2-BPSK modulation is allowed. Set the **Start Subframe** and the number of **Repetitions**. You can use the **Subcarrier Indication** field to control the subcarriers. Four (4) timeslots are always occupied.

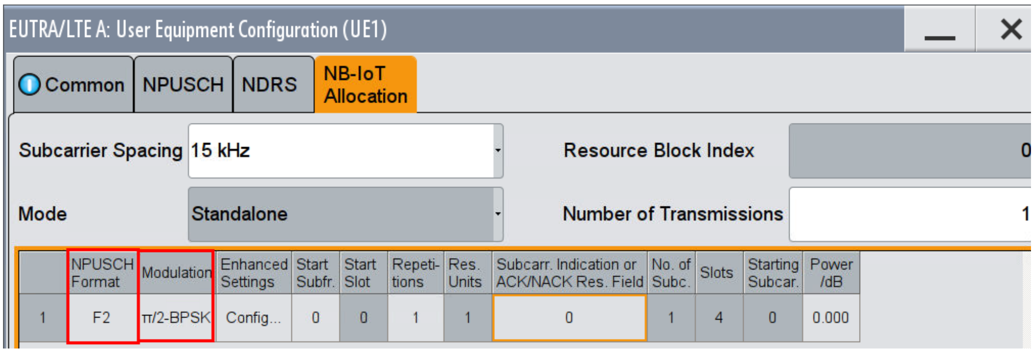


Figure 3-26: NPUSCH format 2.

F2 format always transmits one bit as ACK/NACK information (for the NPDSCH), which is expanded to 16 coded bits. "1" means ACK and "0" means NACK.

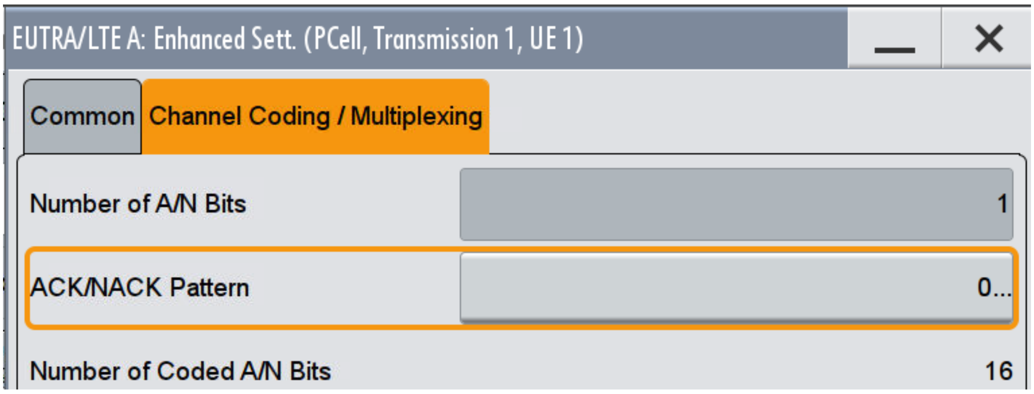


Figure 3-27: ACK/NACK settings for NPUSCH F2.

NPRACH

The SMW is able to generate an NPRACH in NB-IoT. The general settings are in **General UL settings**, tab **PRACH** small tab **NB-IoT**:

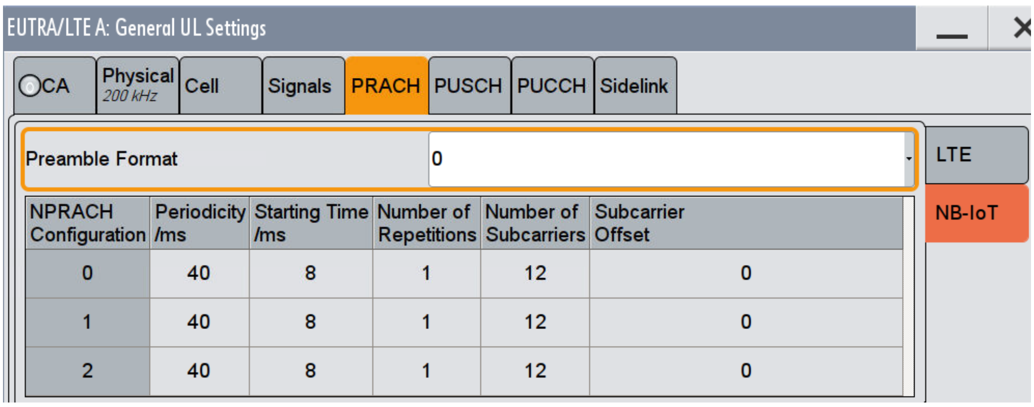


Figure 3-28: General NPRACH configuration

To generate an NPRACH, open the **Common** tab and set the **Mode** to *PRACH*. Then configure the details on the **NPRACH** tab. The graphical view in **Time Plan** shows the NPRACH. You can change the **1st Subframe** to view the entire NPRACH step by step.

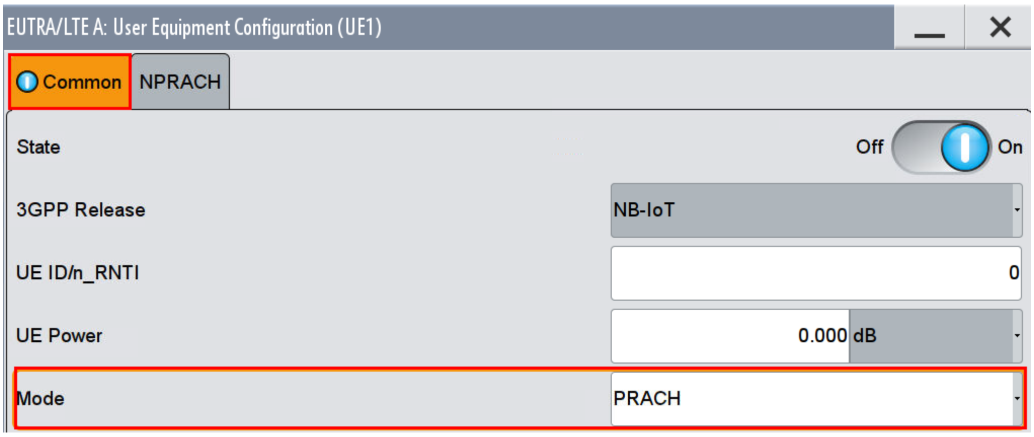


Figure 3-29: NPRACH mode.

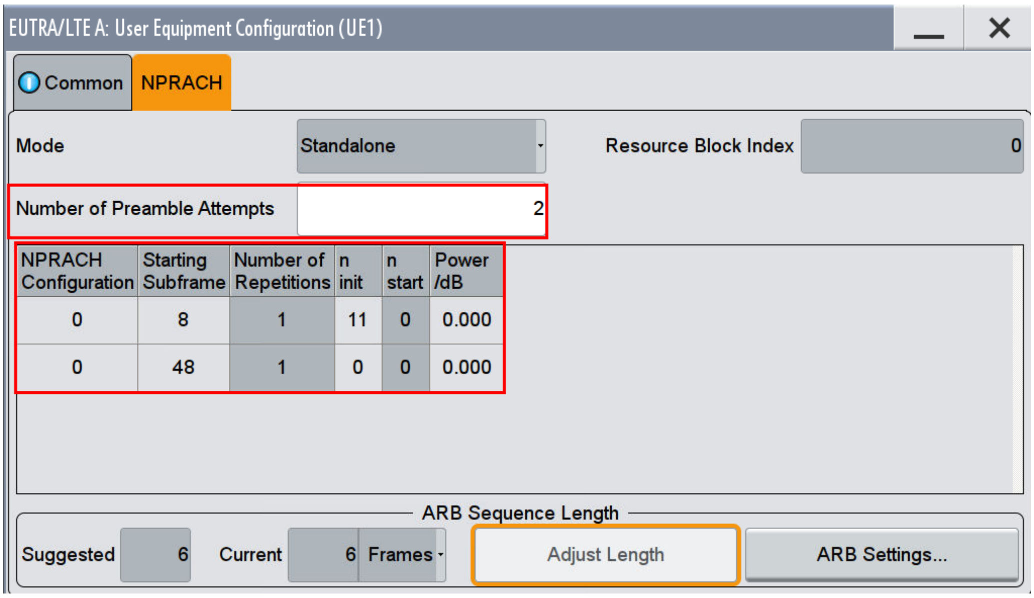


Figure 3-30: NPRACH configuration.

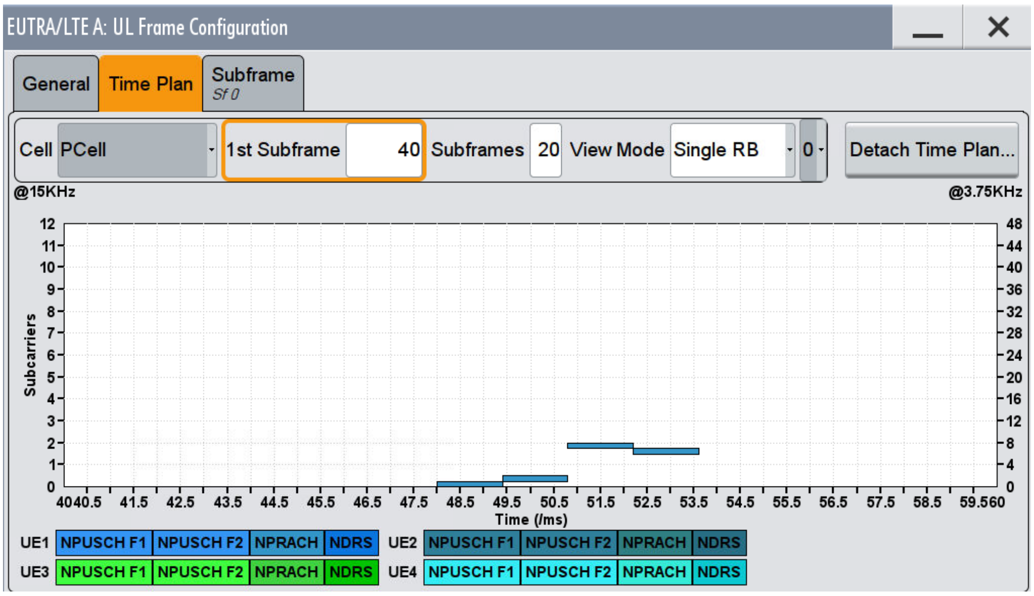


Figure 3-31: Graphical view of an NPRACH. The second attempt starting with subframe 48 is shown here.

3.2.2 Fixed Reference Channels (FRC)

The base station conformance testing [6] specification defines FRC's for the receiver test to achieve a uniform, predefined set of test scenarios. FRC's A14, A15 and A16 are used for NB-IoT tests.

The following parameters must be set manually on the SMW – all others are automatically set (fully automatic setting will be available in a later firmware version):

TS36.141	SMW
IMCS / TBS (A14)	Transport Block Size Index I_{TBS}
Allocated resource unit	Res. Units
ITBS / IRU (A16)	Transport Block Size Index I_{TBS}

An example of the settings for A14-2:

Reference channel	A14-1	A14-2	A14-3	A14-4
Sub-carrier spacing (kHz)	15	3.75	15	3.75
Number of tone	1	1	1	1
Diversity	No	No	No	No
Modulation	π/2 BPSK	π/2 BPSK	π/2 BPSK	π/2 BPSK
Frequency offset	0	0	0	0
Channel estimation length (ms)[Note1]	4	16	4	16
Number of NPUSCH repetition	1	1	TBD	TBD
IMCS / TBS	0 / 0	0 / 0	0 / 0	0 / 0
Payload size (bits)	32	32	32	32
Allocated resource unit	2	2	2	2
Code rate (target)	1/3	1/3	1/3	1/3
Code rate (effective)	0.29	0.29	0.29	0.29
Transport block CRC (bits)	24	24	24	24
Code block CRC size (bits)	0	0	0	0
Number of code blocks - C	1	1	1	1
Total number of bits per resource unit	96	96	96	96
Total symbols per resource unit	96	96	96	96
Tx time (ms)	16	64	TBD	TBD
Note 1: Channel estimation lengths are included in the table for information only.				

Figure 3-32: FRCs A14 [6].

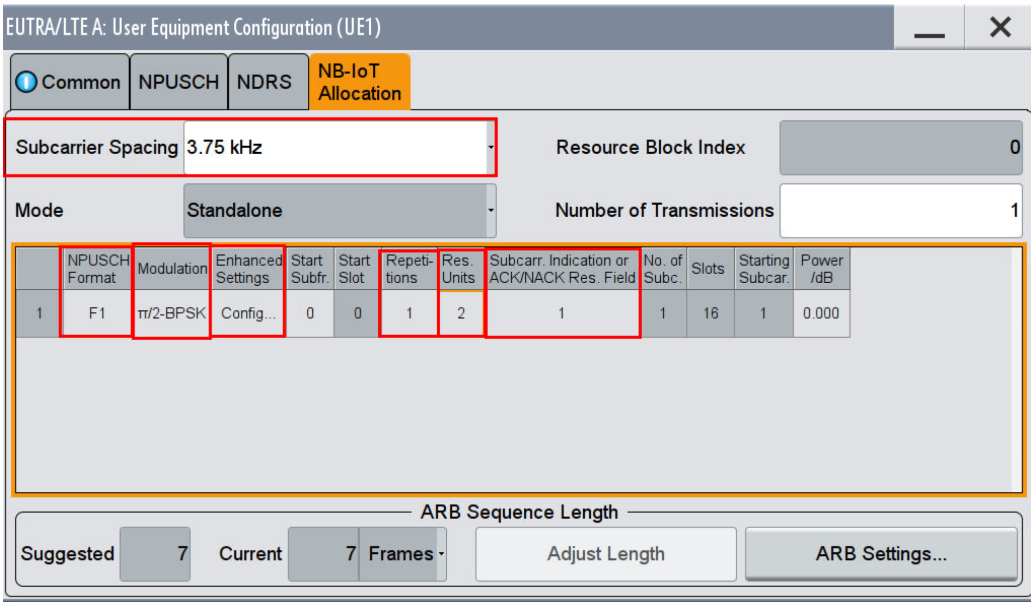


Figure 3-33: Settings for FRC A14-2 example.

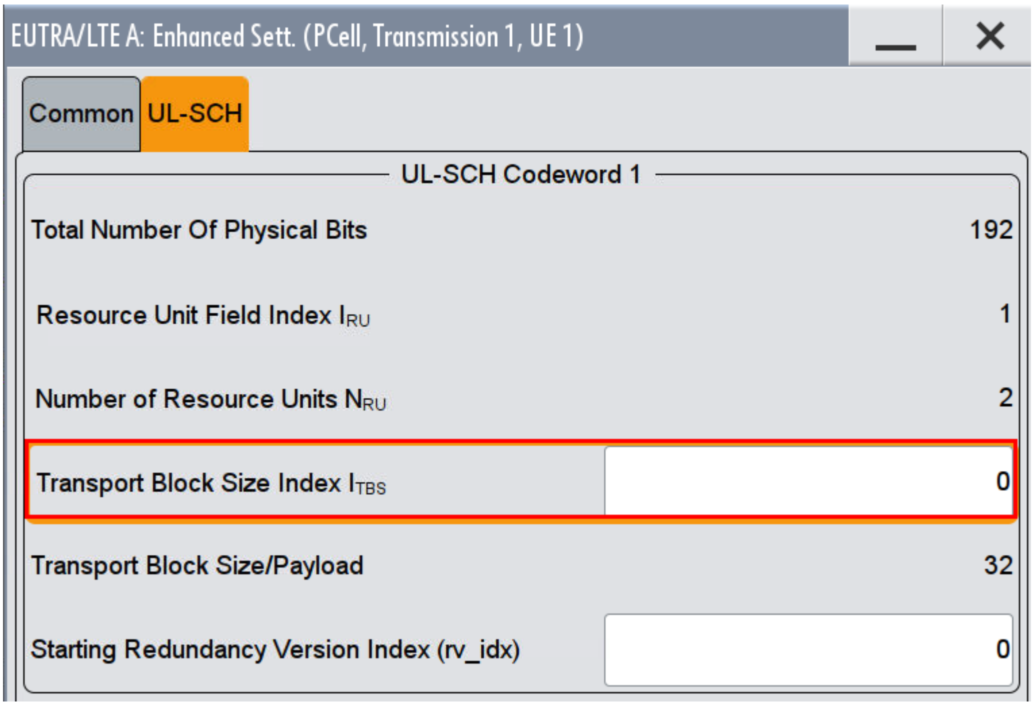


Figure 3-34: Setting for transport block size index.

3.2.3 Additional LTE Signal Generation

The SMW can simultaneously generate an NB-IoT signal (as UE1) and an LTE signal (as UE2) for in-band or guard band mode. In this example, the NB-IoT resides in resource block 10 of a 10 MHz LTE signal. The UE2 transmits a PUSCH with two RB's with an offset of 2 RB's, and ten RB's with an offset of 20 RB's. In addition, a PUCCH is also transmitted. Figure 3-31 shows a graphical view.

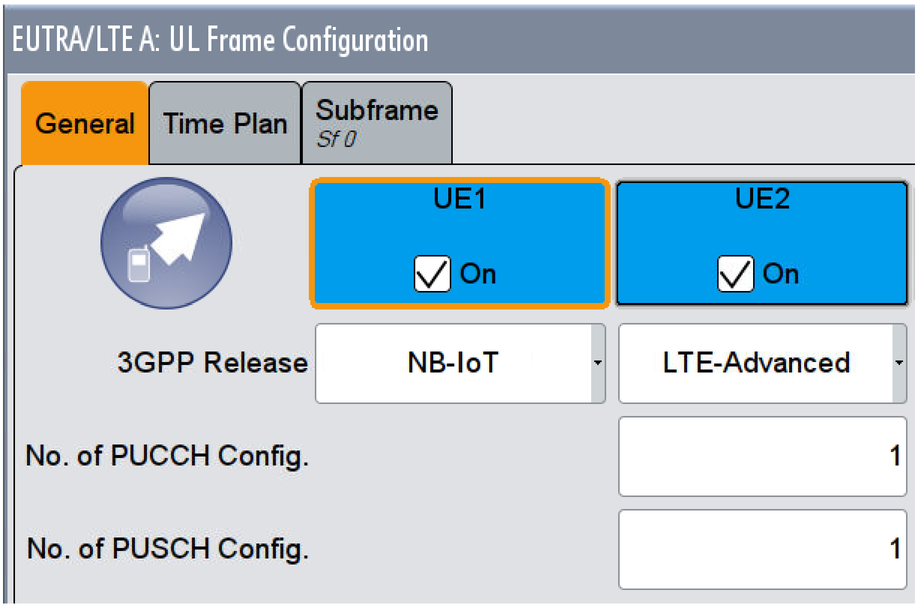


Figure 3-35: In-band operation with a 10 MHz LTE signal.

To achieve different power levels for the individual UE's (and thus different levels between the NB-IoT and the LTE signal), click on the UEx field and set the relative power:

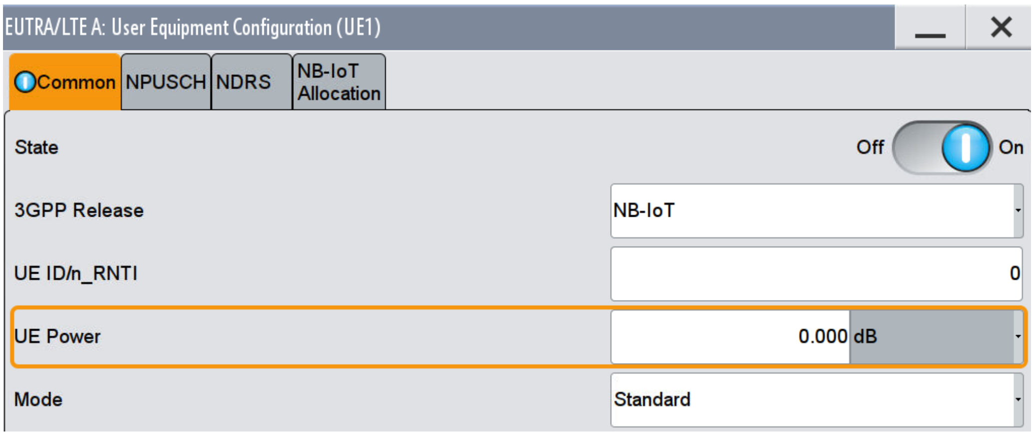


Figure 3-36: UE individual power (relative)

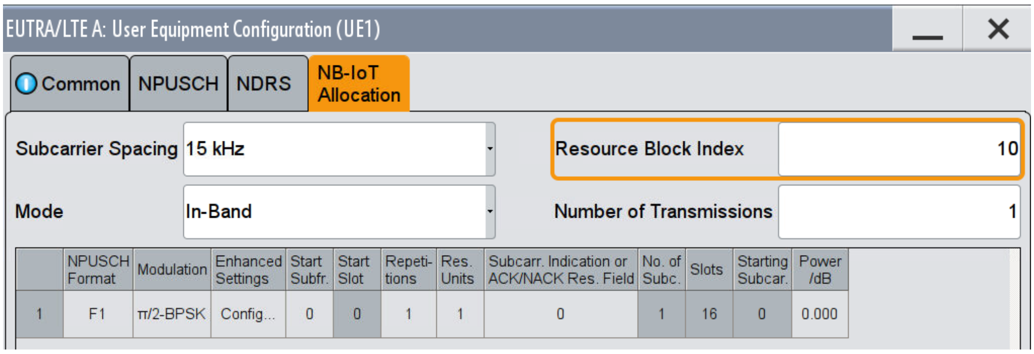


Figure 3-37: The NB-IoT signal occupies RB 10.

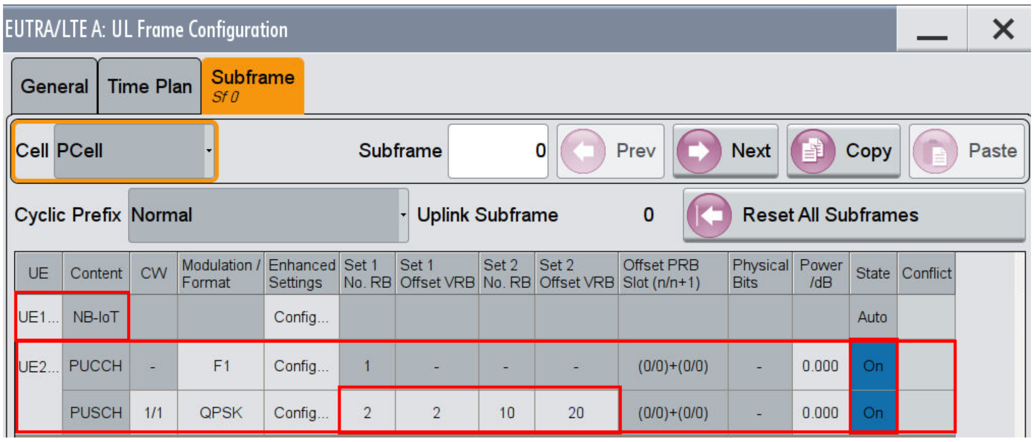


Figure 3-38: The LTE signal consists of two PUSCHs and one PUCCH (from UE2).

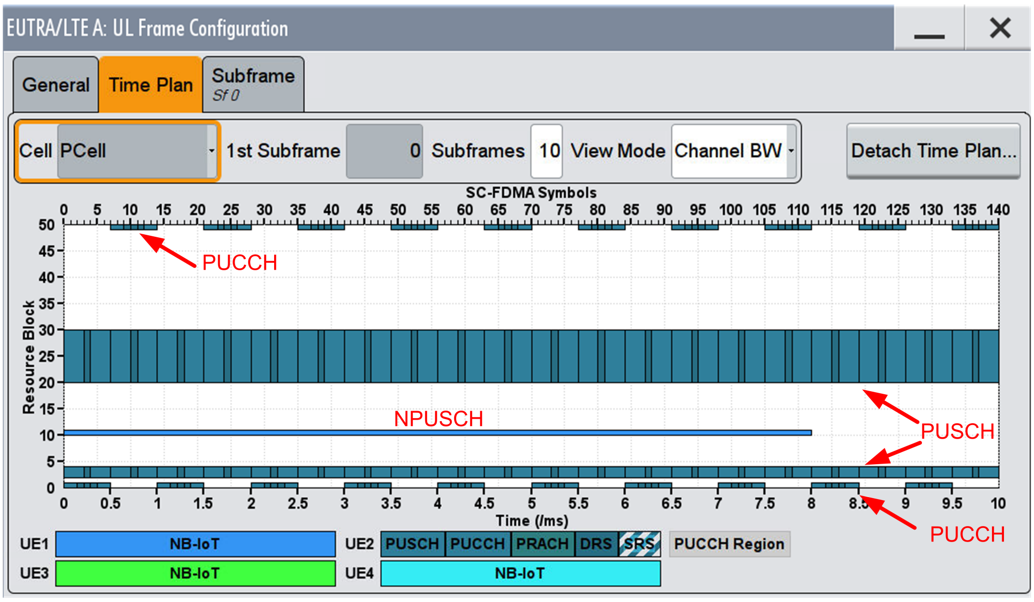


Figure 3-39: Graphical view of an NB-IoT signal with a 10 MHz LTE signal.

3.2.4 Channel Simulation: Fading and AWGN

The SMW-B14 and SMW-K62 options enable the SMW to support channel simulation for receiver testing. In addition to individual settings, it offers predefined baseband fading profiles for all relevant wireless standards. The fading profiles under LTE are relevant for NB-IoT. The SMW can also apply additional white Gaussian noise (AWGN) to the signal.

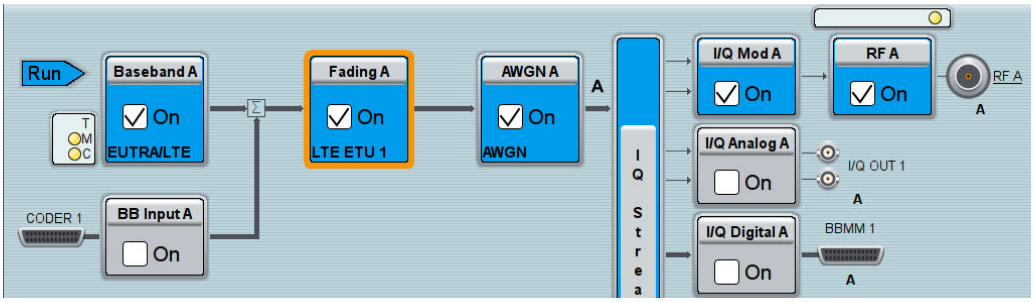


Figure 3-40: The SMW supports fading and AWGN options.

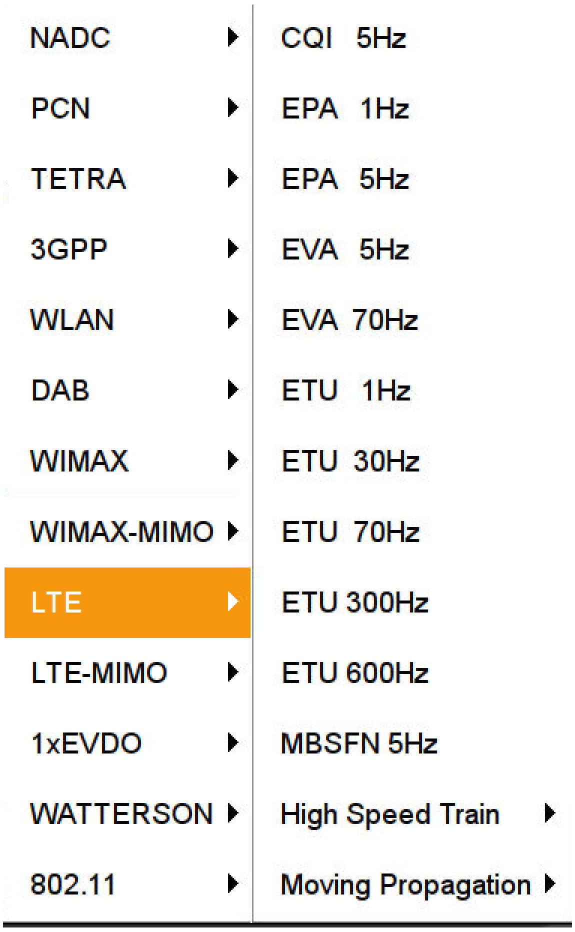


Figure 3-41: Predefined fading profiles for LTE and therefore NB-IoT. ETU 1 Hz and EPA 5 Hz are mandatory for receiver conformance tests.

4 NB-IoT Measurements at the User Equipment (UE)

Measurements at the user equipment include UE transmitter and receiver tests.

4.1 Transmitter Measurements (Uplink)

The VSE vector signal explorer software provides the analysis capabilities of a signal and spectrum analyzer on a PC. It remotely controls a data collection instrument (e.g. FSW, FSV(A), FPS or RTO) and then analyzes the data. The VSE also supports numerous digital communications standards. The VSE-K106 enables NB-IoT analysis. For further information on VSE operation, please refer to the manual [4] and [5].

The VSE supports two different NB-IoT types of measurement:

- Demodulation measurements
  - EVM and frequency error.
- Spectrum measurement
  - Adjacent channel power (ACLR)
  - Spectrum Emission Mask (SEM)

To switch between the measurements, open the **Meas Setup|Select Measurement** menu.

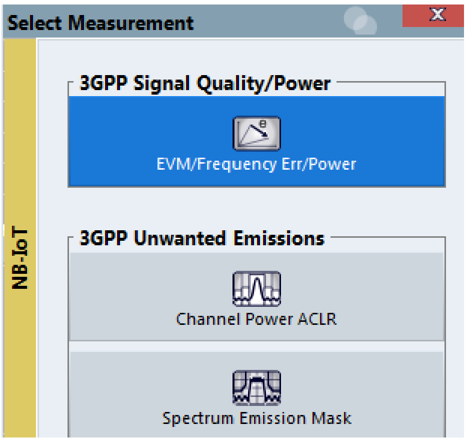


Figure 4-1: Switching between demodulation (e.g. EVM) and spectrum measurements (ACLR) for NB-IoT.

Test setup

A spectrum analyzer records the UE's transmitter signal. The VSE software runs on a separate PC. It controls the spectrum analyzer, performs the measurements and clearly displays the results. Figure 4-2 shows the test setup.

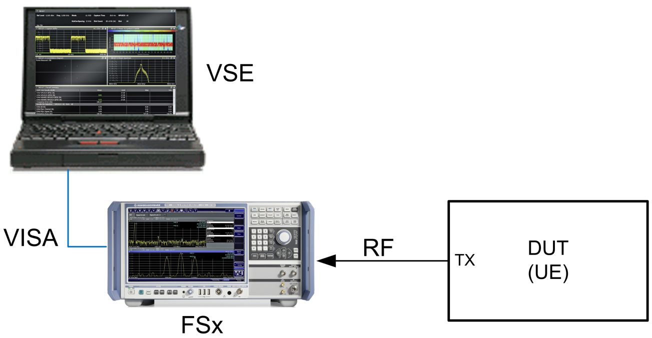


Figure 4-2: Setup for TX tests on the UE.

4.1.1 NPUSCH Measurements

The VSE software is used to measure the NB-IoT uplink signal of the UE transmitter. On the **Signal Description** tab, set the **Mode** to *FDD Uplink*. Choose the **Subcarrier Spacing** used (15 kHz or 3.75 kHz). The VSE automatically finds and displays the NPDSCH configuration. You can also manually configure the settings. Make sure that you correctly set the frequency (see Chapter 5, "Appendix", on page 58).

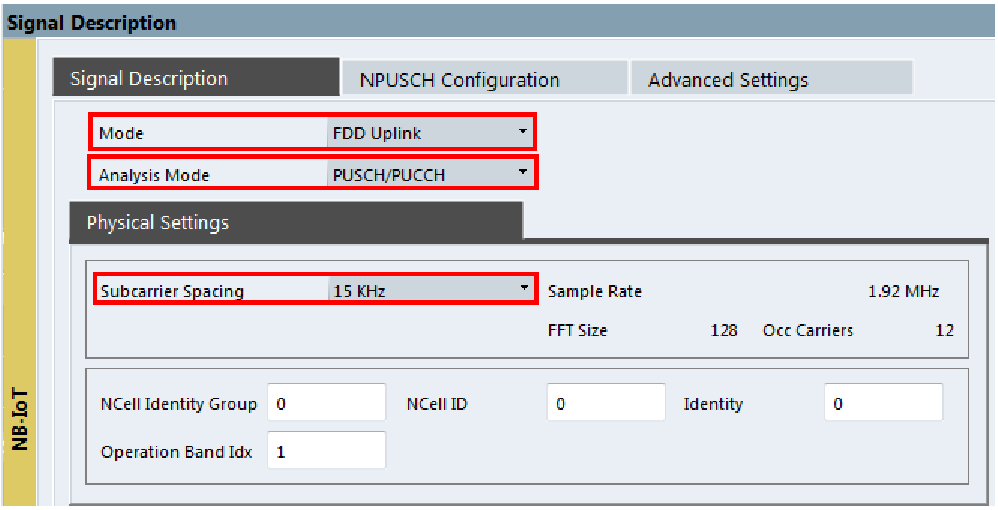


Figure 4-3: FDD uplink mode is required to perform measurements on the UE transmitter. The VSE supports both subcarrier spacings.

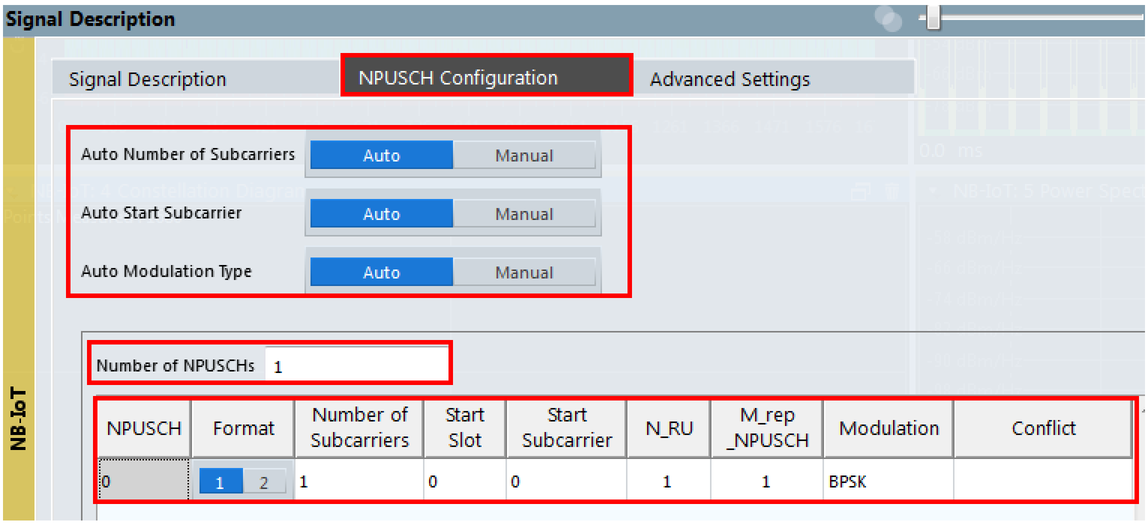


Figure 4-4: The VSE automatically recognizes the correct NPUSCH configuration.

The VSE provides an overview of the measurements:

- Top left: spectrum over time
- Top right: time plan (only the bottom carrier is occupied in this example)
- Lower left: constellation diagram (QPSK in this example)
- Lower right: power spectrum (only one carrier is occupied in this example)
- Bottom: a table with an overview of the scalar measurement values

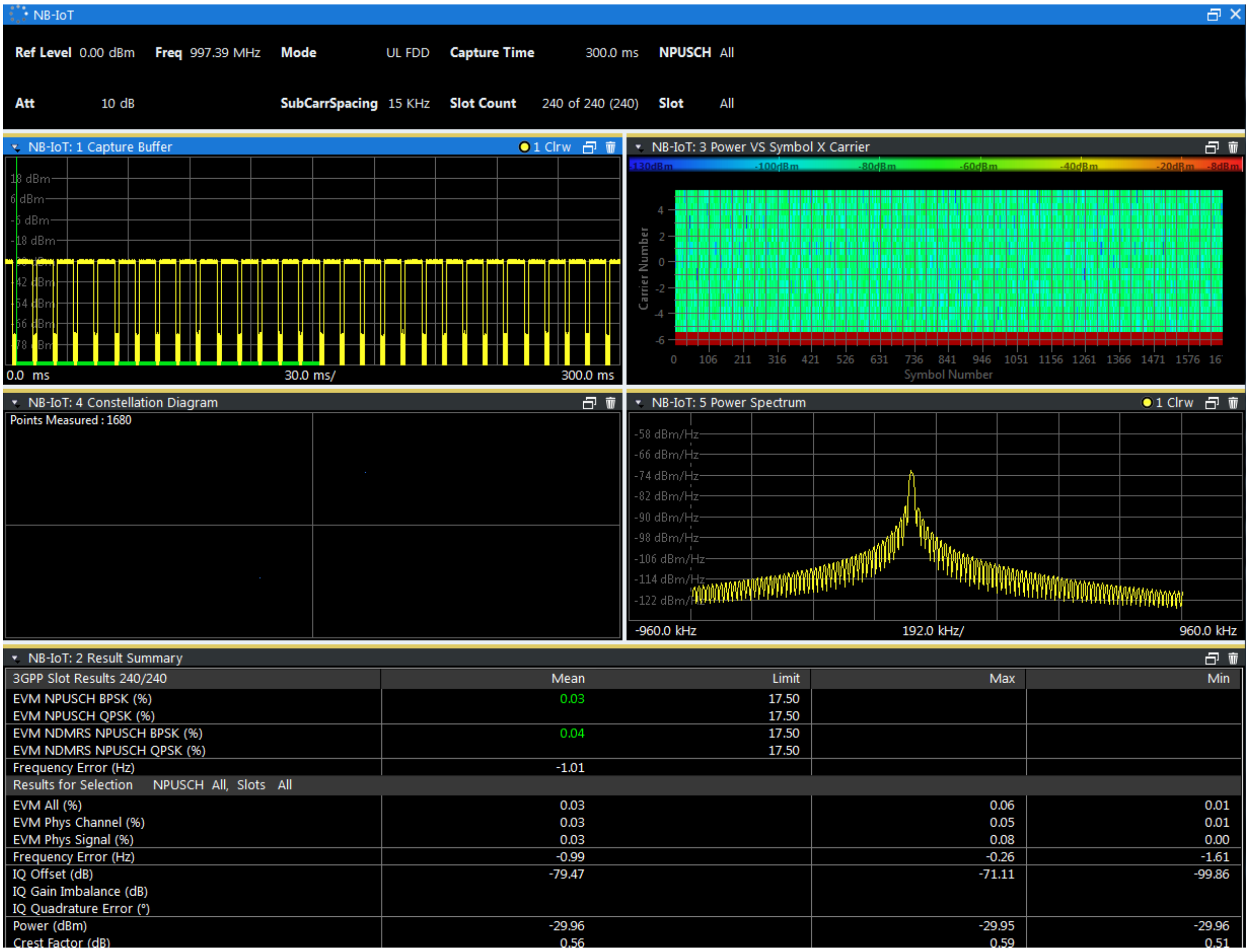


Figure 4-5: Overview of the uplink TX measurement in the VSE. It clearly displays all relevant measurement values.

4.1.2 NPRACH Measurements

On the **Signal Description** tab, set the **Mode** to *FDD Uplink*and the **Analysis Mode** to *PRACH*. In the tab **Advanced Settings**, you can configure more details under **NPRACH Structure**. Make sure that you correctly set the frequency (see Chapter 5, "Appendix", on page 58).

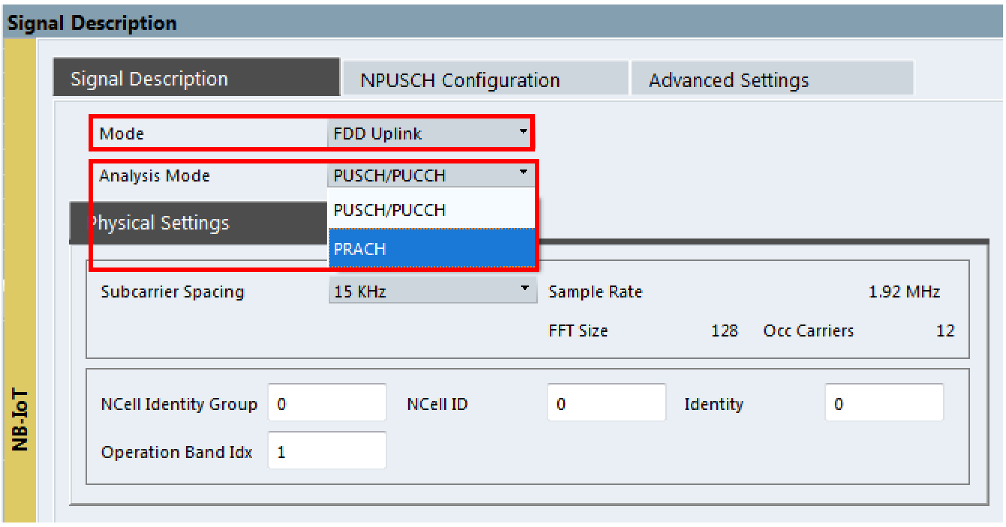


Figure 4-6: FDD uplink mode is required to perform NPRACH measurements on the UE transmitter.

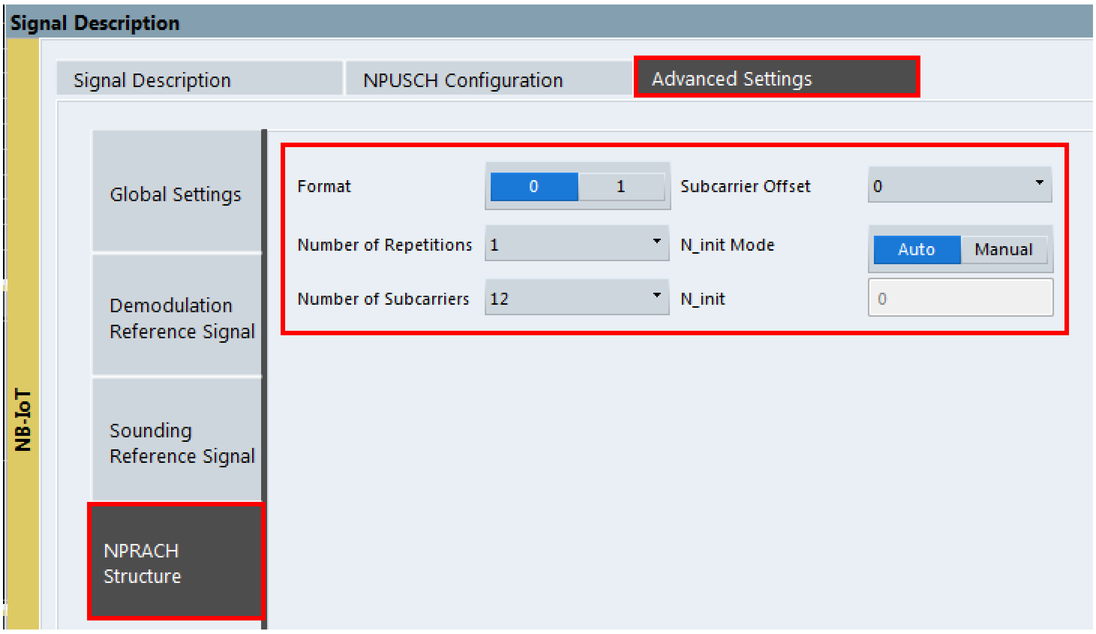


Figure 4-7: Advanced Settings for the NPRACH Structure

The VSE provides again an overview of the measurements:

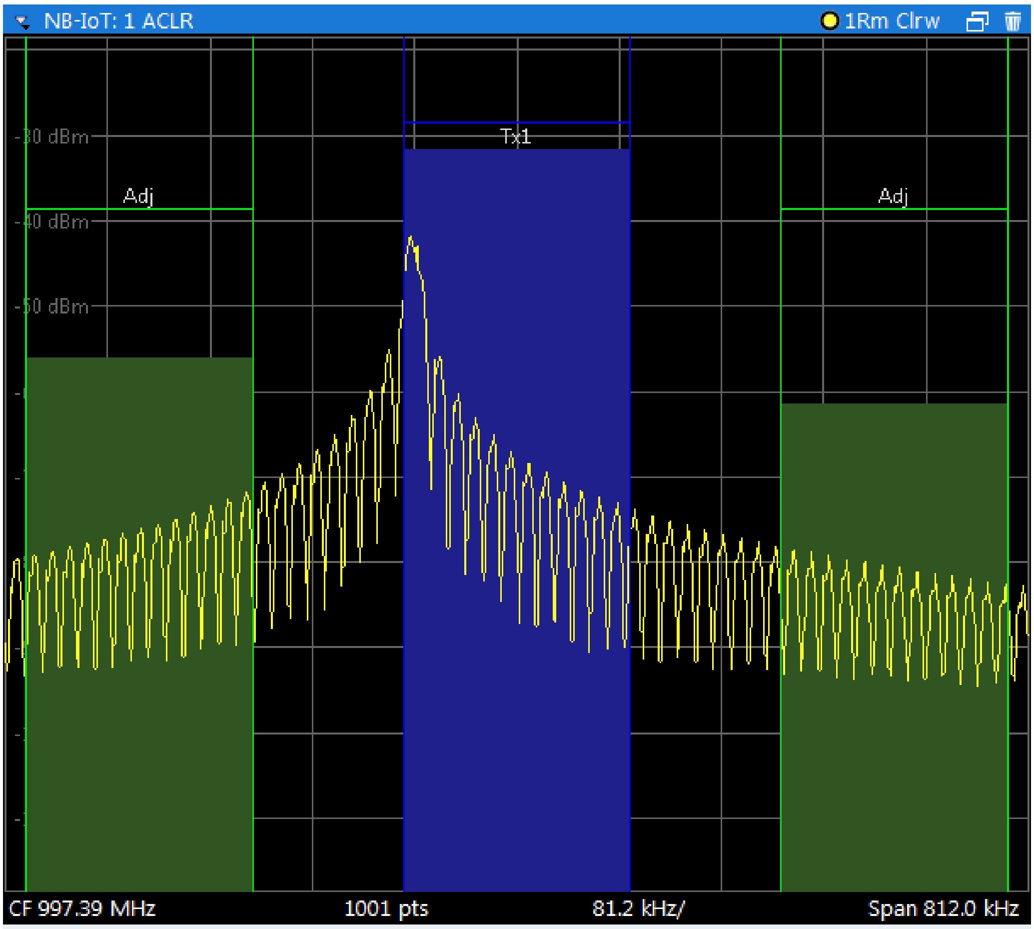
- Top left: spectrum over time
- Top right: time plan
- Lower left: constellation diagram
- Lower right: power spectrum (in this example the NPRACH hops)
- Bottom: a table with an overview of the scalar measurement values

Figure 4-8: Overview of the uplink TX measurement in the VSE. It clearly displays all relevant measurement values.

4.1.3 Spectrum Measurement: ACLR

Select the **Channel Power ACLR** measurement.

The VSE automatically sets the relevant parameters for ACLR measurements.



Channel	Power	
Tx1 (Ref)	-31.72 dBm	
Tx Total	-31.72 dBm	
Channel	**Lower**	**Upper**
Adj	-24.32 dBc	-29.85 dBc

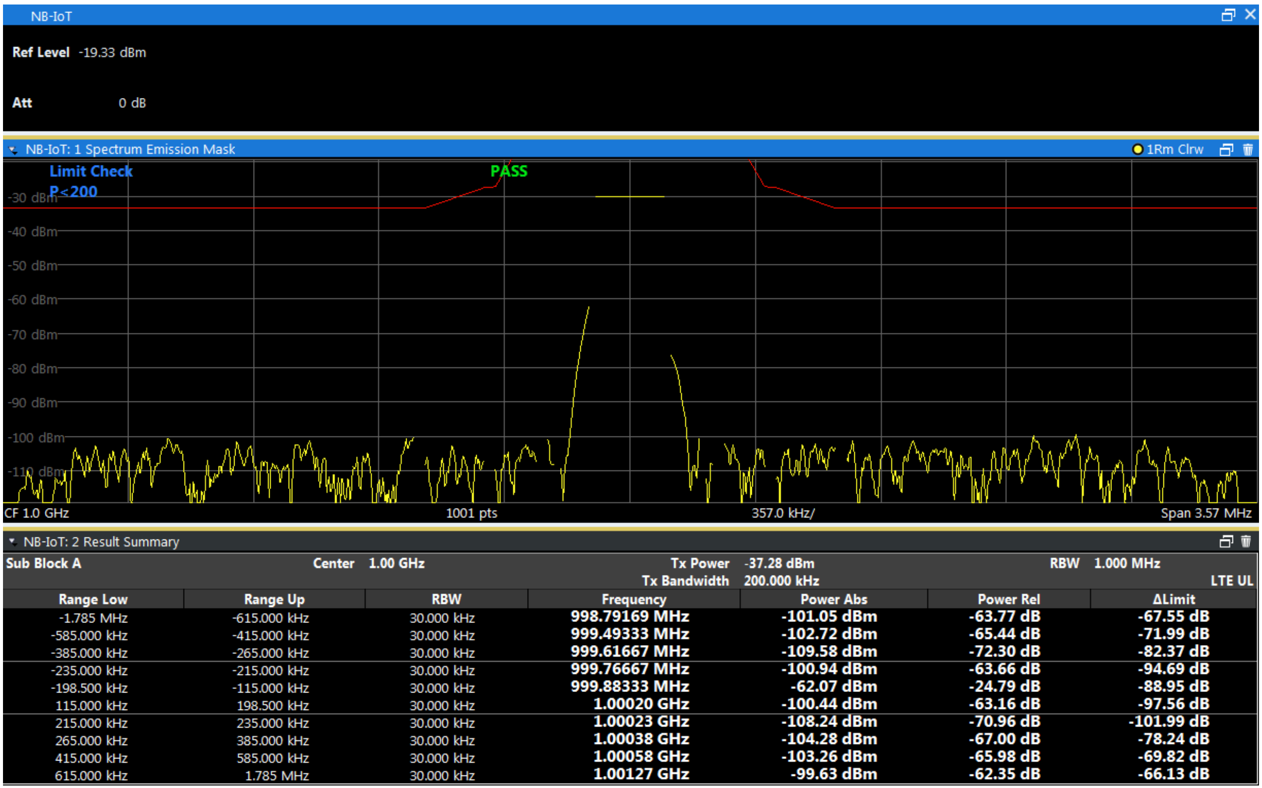
Figure 4-9: ACLR measurement in the uplink: only one subcarrier is used in this example.

4.1.4 Spectrum Measurement: SEM

Select the **Spectrum Emission Mask** measurement.

The VSE automatically sets the relevant parameters for SEM measurements.

Figure 4-10 shows a SEM test. The **Result Summary** displays the results of the individual ranges. The global limit check is displayed along the top.



Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-1.785 MHz	-615.000 kHz	30.000 kHz	998.79169 MHz	-101.05 dBm	-63.77 dB	-67.55 dB
-585.000 kHz	-415.000 kHz	30.000 kHz	999.49333 MHz	-102.72 dBm	-65.44 dB	-71.99 dB
-385.000 kHz	-265.000 kHz	30.000 kHz	999.61667 MHz	-109.58 dBm	-72.30 dB	-82.37 dB
-235.000 kHz	-215.000 kHz	30.000 kHz	999.76667 MHz	-100.94 dBm	-63.66 dB	-94.69 dB
-198.500 kHz	-115.000 kHz	30.000 kHz	999.88333 MHz	-62.07 dBm	-24.79 dB	-88.95 dB
115.000 kHz	198.500 kHz	30.000 kHz	1.00020 GHz	-100.44 dBm	-63.16 dB	-97.56 dB
215.000 kHz	235.000 kHz	30.000 kHz	1.00023 GHz	-108.24 dBm	-70.96 dB	-101.99 dB
265.000 kHz	385.000 kHz	30.000 kHz	1.00038 GHz	-104.28 dBm	-67.00 dB	-78.24 dB
415.000 kHz	585.000 kHz	30.000 kHz	1.00058 GHz	-103.26 dBm	-65.98 dB	-69.82 dB
615.000 kHz	1.785 MHz	30.000 kHz	1.00127 GHz	-99.63 dBm	-62.35 dB	-66.13 dB

Figure 4-10: The VSE cares about the correct settings automatically. Please note that there is a gap in the measurement range defined by the specification.

4.2 Receiver Tests (Downlink)

Rohde & Schwarz vector signal generators offer many options for generating signals for various communications standards. In addition to the NB-IoT signals as part of Release 13 of the 3GPP LTE-A standard, Rohde & Schwarz generators support all major standards such as 5G air interface candidates, LTE MIMO, 3GPP FDD/HSPA/HSPA+, GSM/EDGE/EDGE evolution, CDMA2000® /1xEV-DO, WLAN IEEE 802.11a/b/g/n/j/p/ac/ad and Bluetooth.

- The SMW supports a multipath concept with excellent RF characteristics, real-time baseband signals plus fading/AWGN.

- As a cost-effective alternative, the SGT offers an ARB generator to play predefined I/Q files (e.g. files generated by WinIQSIM2).

In the following, the SGT with WinIQSIM2 is mentioned only. The user interface of WinIQSIM2 - as it is used for waveform generation for the SGT - and the user interface of the SMW for configuration of the NB-IoT signals is identical. Both generators are mentioned as SMx.

The WinIQSIM2 K415 option enables generation of NB-IoT signals in line with 3GPP Release 13 and supports uplink and downlink signals. The K412 and SMW-413 options unlock LTE-Advanced in line with Releases 11 and 12. LTE also requires the K255 basic LTE option. For further information on SGT operation and WinIQSIM2, please refer to the manuals [7] and [8].

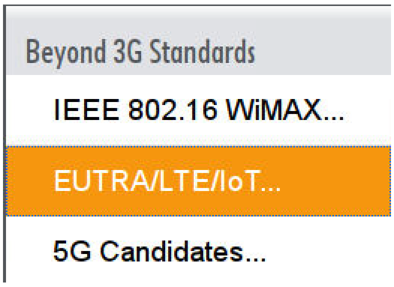


Figure 4-11: In the SMW, the NB-IoT signals are in the EUTRA/LTE/IoT part.

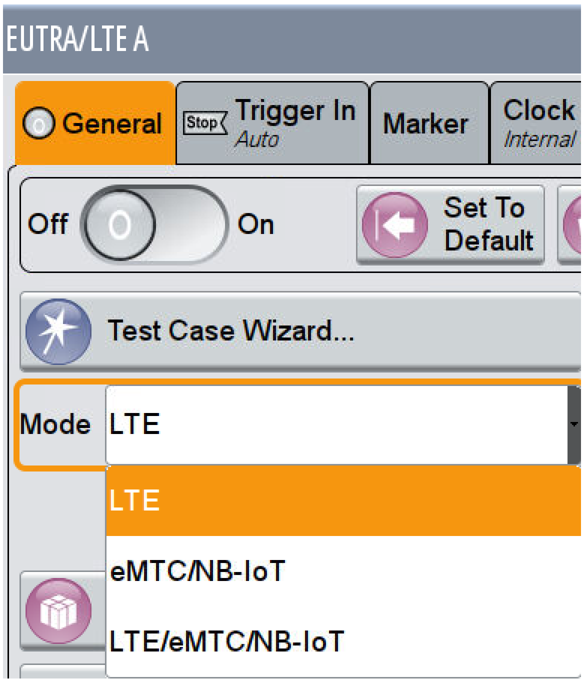


Figure 4-12: Switch to choose LTE/eMTC/NB-IoT (only available when all necessary options are installed).

Test setup

The signal generator provides a downlink signal for UE receiver testing. The SMW can also simulate the channel (fading and AWGN; see Chapter 3.2, "Receiver Testing (Uplink)", on page 25). Figure 4-13 shows the test setup.

The DUT calculates the throughput.

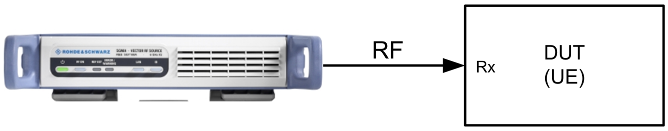
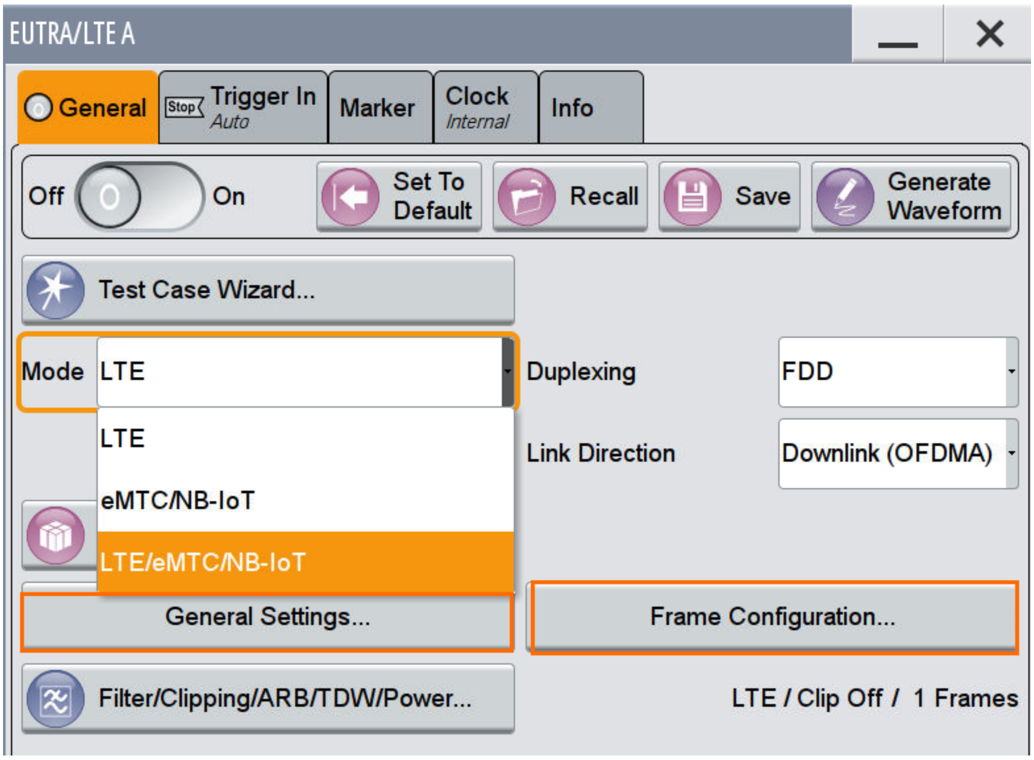


Figure 4-13: Setup for UE receiver testing.

4.2.1 General Settings

The SMx can generate the signal of an eNodeB with multiple users in an LTE/NB-IoT baseband. One baseband only is needed to generate simultaneously an NB-IoT signal and an LTE signal for receiver tests.

To test an UE receiver, set the **Link Direction** to *Downlink (OFDMA)*.



Click **General Settings**, open the **Physical** tab and select the correct *Channel Bandwidth*:

- **200 kHz**: standalone mode
- **LTE bandwidths:** in-band or guard band mode

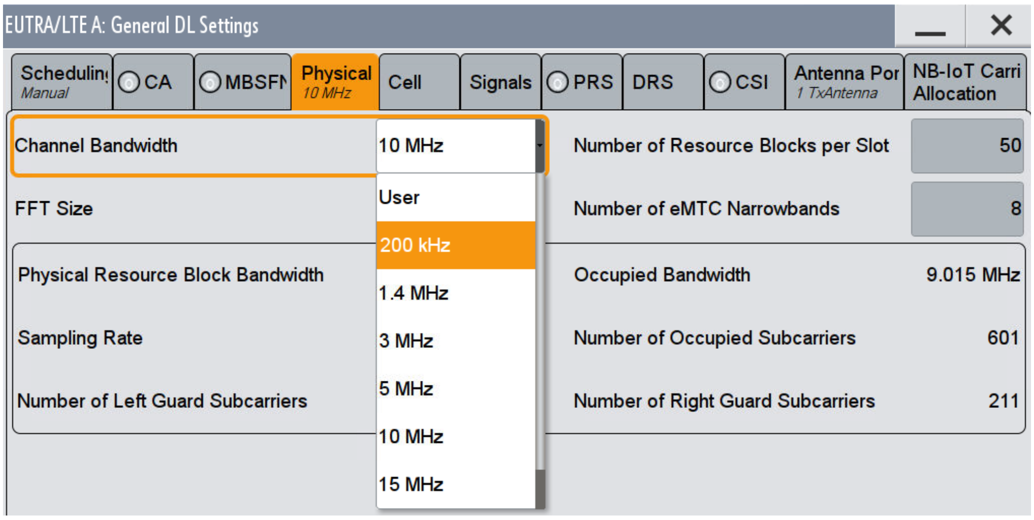


Figure 4-14: Choosing the channel bandwidth: 200 kHz is the standalone mode; all other LTE bandwidths lead to in-band or guard band operation. (The 1.4 MHz bandwidth is not defined for NB-IoT operation.)

The **NB-IoT Carrier Allocation** tab provides information about the NB-IoT carrier.

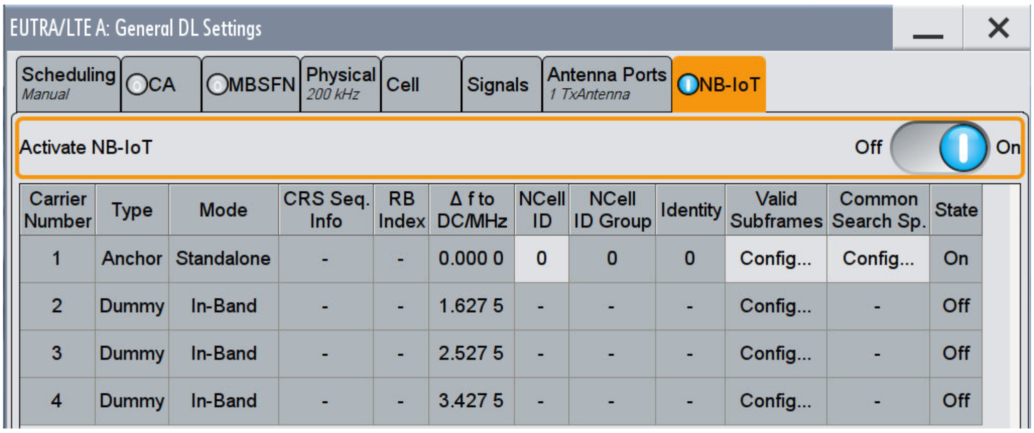


Figure 4-15: The individual NB-IoT carriers.

Click **Frame Configuration** for additional settings. The SMx can simultaneously operate signals for up to four (4) users, including mixed NB-IoT and LTE signals (see Figure 4-16). The SMx can also generate dummy data for non-allocated resources.

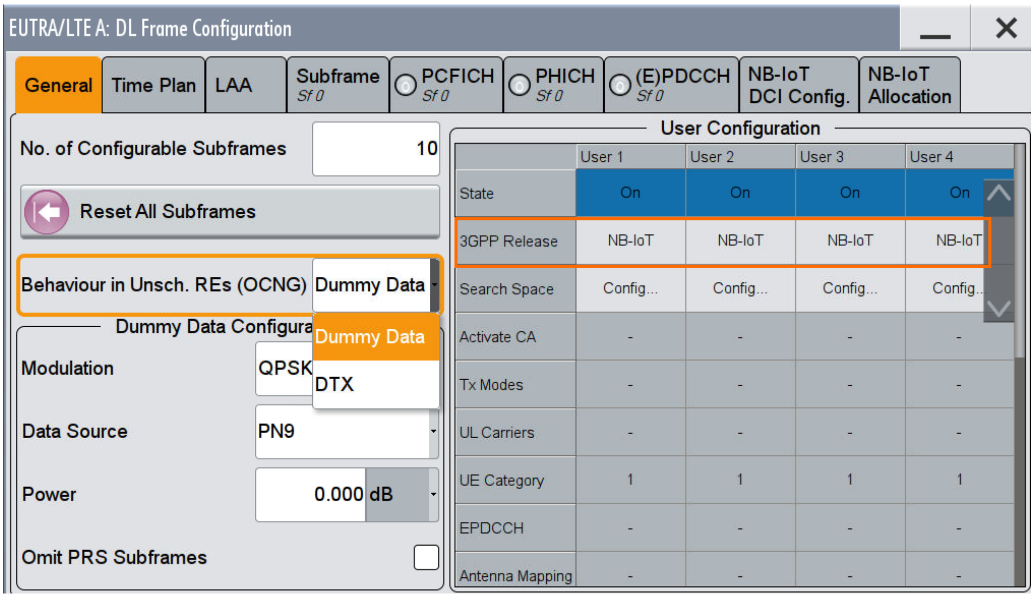


Figure 4-16: The downlink frame configuration with up to four users.

On the **NB-IoT DCI Config** tab, select **DCI Format**:

- **N0** allocates the UE resources that it can use to send data on the NPUSCH.
- **N1** notifies the UE when to expect data on the NPDSCH.
- **N2** is for paging and direct indication.

Use **Content Config** to set additional parameters such as the number of repetitions.

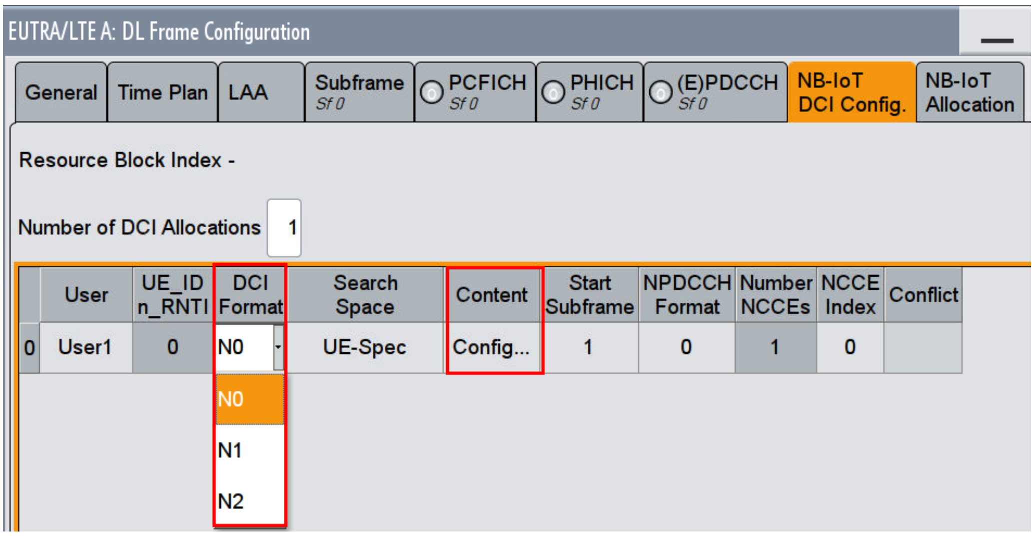


Figure 4-17: The various DCI formats.

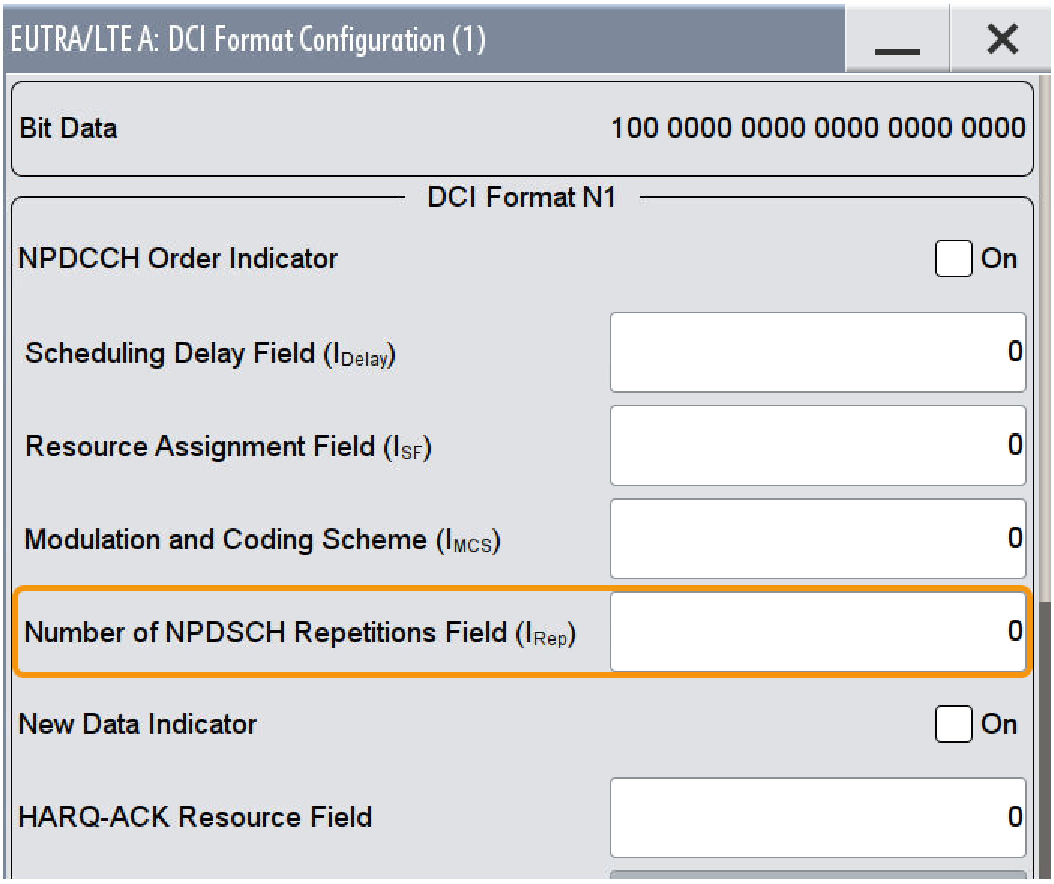


Figure 4-18: Additional parameters in DCI format (N1 in this example).

N0

The NPDCCH transmits information to the UE telling it when it can send data in the NPUSCH. The NPDSCH does not transmit any user data in DCI format N0. The NPDSCH transports the SIB1-NB only in every 20th subframe. Figure 4-19 shows an example of allocations for N0. Figure 4-20 shows the corresponding time plan.

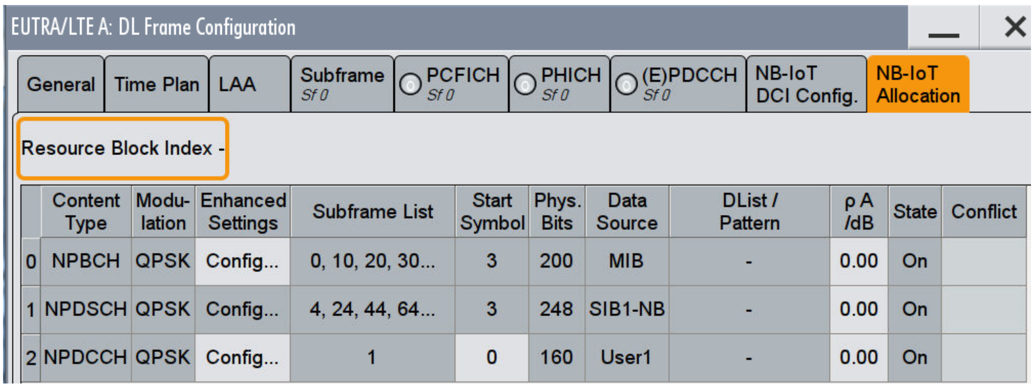


Figure 4-19: An example of allocations for DCI N0. The NPDSCH periodically sends the SIB1-NB, but does not transmit any user data. The NPDCCH tells the UE when it can send an NPUSCH in the uplink.

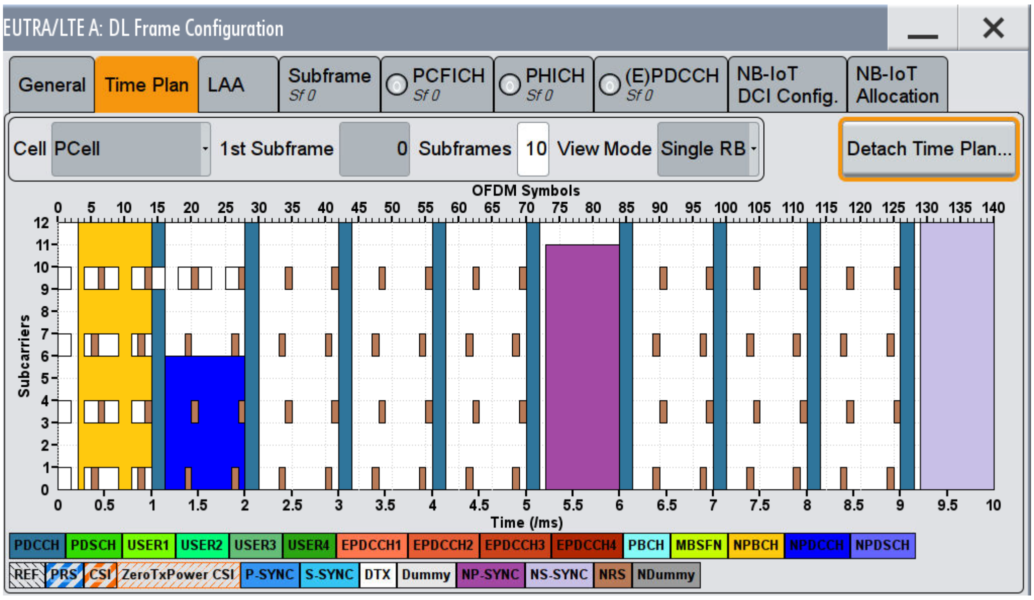
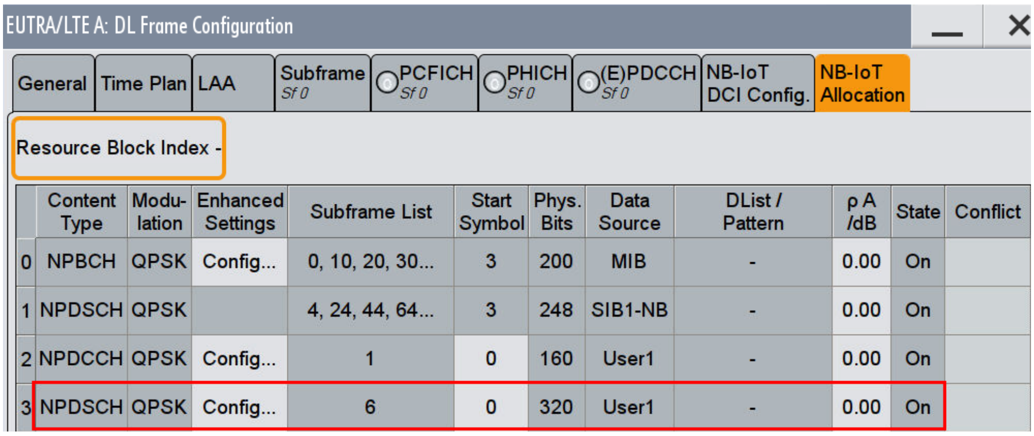


Figure 4-20: Graphical view of the allocation example for DCI N0.

N1

The NPDSCH does transmit user data in DCI format N1. The NPDCCH transmits information to the UE telling it when to expect data in the NPDSCH. In the example, the user data is transmitted in NPDSCH subframe 6. The NPDSCH transports the SIB1-NB only in every 20th subframe. Figure 4-21 shows an example of allocations for N1. Figure 4-22 shows the corresponding time plan.



	Content Type	Modu-lation	Enhanced Settings	Subframe List	Start Symbol	Phys. Bits	Data Source	DList / Pattern	ρ A /dB	State	Conflict
0	NPBCH	QPSK	Config...	0, 10, 20, 30...	3	200	MIB	-	0.00	On	
1	NPDSCH	QPSK		4, 24, 44, 64...	3	248	SIB1-NB	-	0.00	On	
2	NPDCCH	QPSK	Config...	1	0	160	User1	-	0.00	On	
3	NPDSCH	QPSK	Config...	6	0	320	User1	-	0.00	On	

Figure 4-21: An example of allocations for DCI N1. The NPDSCH transmits user data.

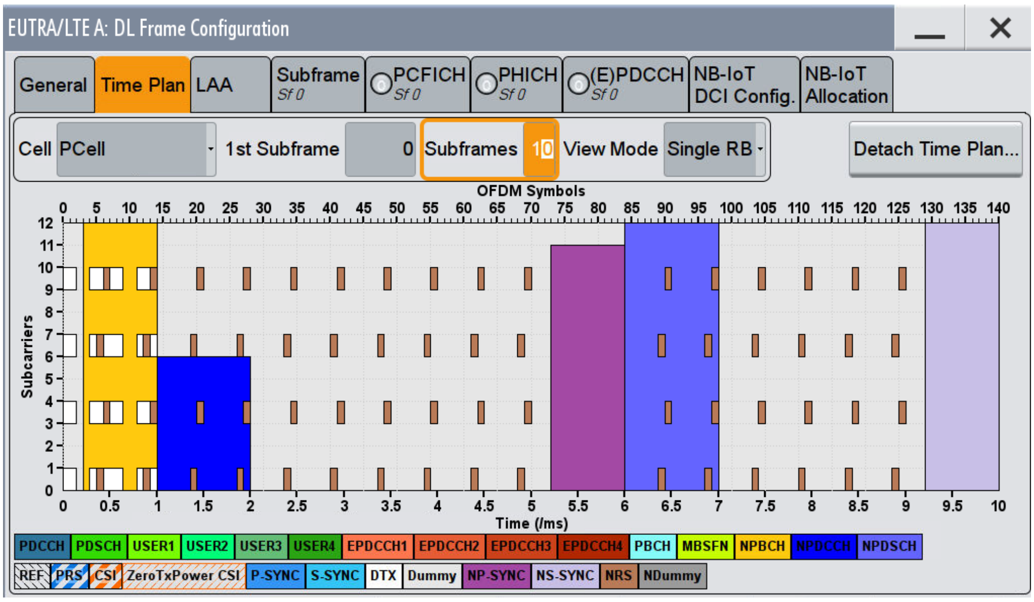


Figure 4-22: Graphical view of the allocation example for DCI N0. The NPDSCH with user data is in subframe 6.

4.2.2 Transmit Diversity

NB-IoT does not support spatial multiplexing, i.e. multiple streams in the downlink, but it does permit the use of transmit diversity (2 x 1 MISO).

To operate two transmit antennas, open (before you configure the NB-IoT) **System Configuration** and select *1 x 2 x 1*. When *Coupled Sources* is selected, the SMW automatically configures the second baseband.

Since the settings are basically the same as the NB-IoT settings, only the differences are described here.

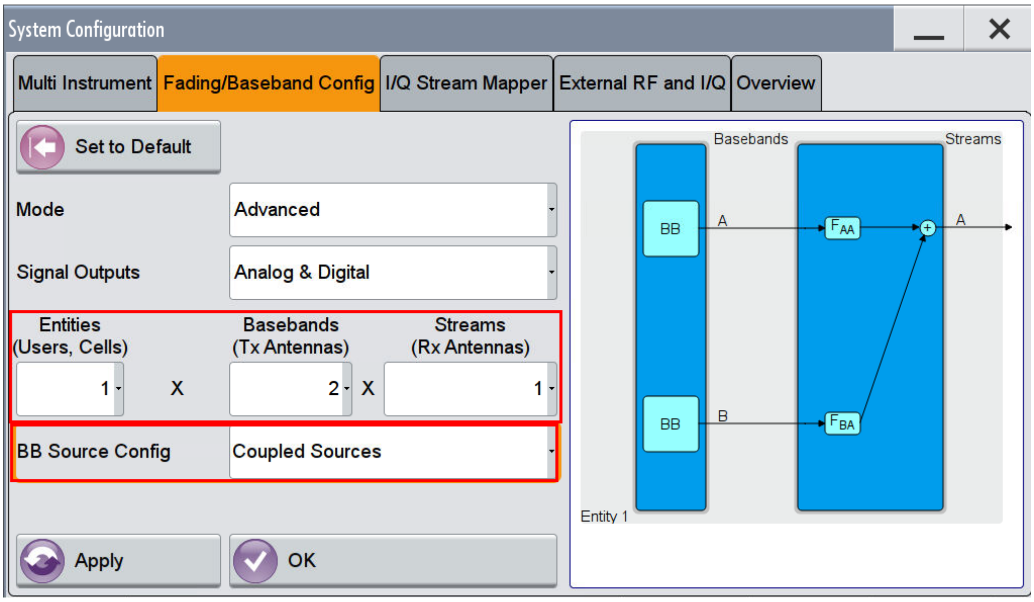


Figure 4-23: System configuration: the SMx generates two transmit signals and automatically configures the second baseband.

Under **General Downlink Settings**, set the **NB-IoT MIMO Configuration** to *2 TxAntennas* and activate antenna ports 2000 and 2001.

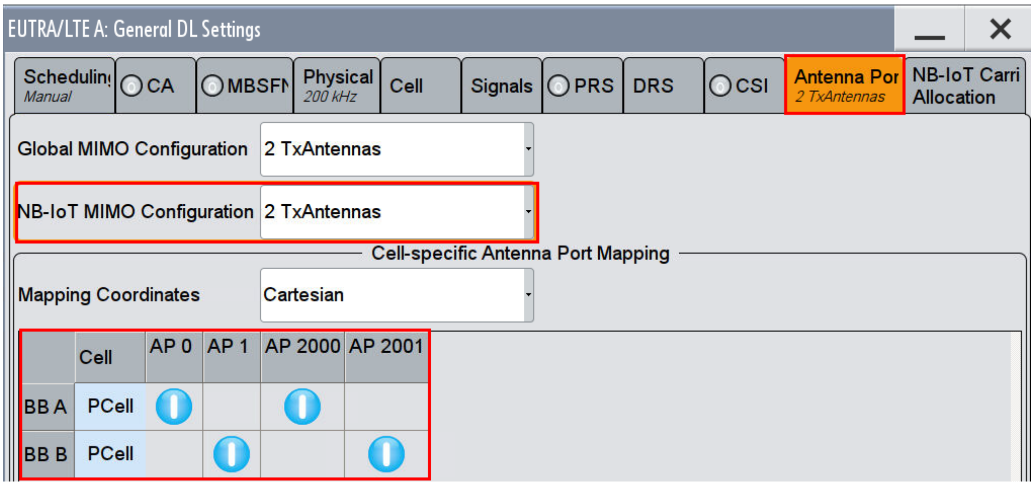


Figure 4-24: Two antennas for NB-IoT enable TX diversity with antenna ports 2000 and 2001.

In **DL Frame Configuration under Enhanced Settings**, click **Config....** for NPBCH, NPDCCH and NPDSCH and set the **Precoding Scheme** to *Tx Diversity*.

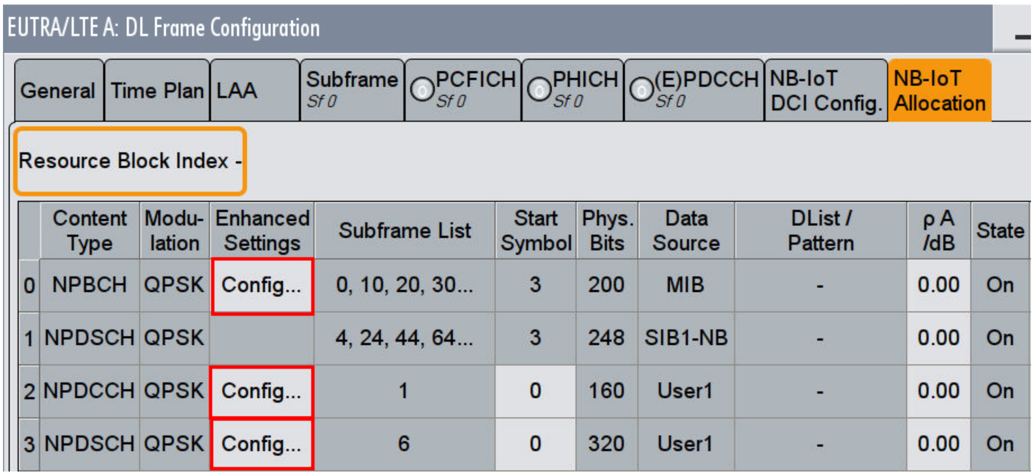
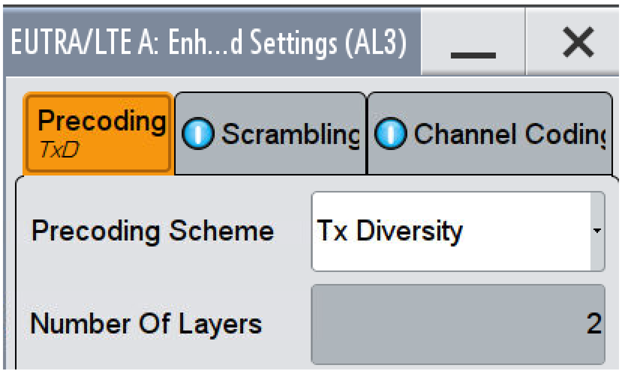


Figure 4-25: The NBPCH, NPDCCH and NPDSCH can be transmitted with TX diversity. TX diversity is located under Enhanced Settings.



4.2.3 Additional Receiver Tests

The goal of NB-IoT is a simple and cheap UE. Thus the UE typically supports NB-IoT only and for receiver tests the generation of NB-IoT signals is sufficient. Anyhow, it may make sense to test the behavior of the receiver with other signals in parallel. Both, the SMW and the SGT together with WinIQSIM2 are able to generate mixed signals.

- WinIQSIM2 is able to generate LTE in parallel to NB-IoT for in-band and guard band operation.
- With the possibility to use multi carrier signals (MC), WinIQSIM2 also supports the parallel generation of different signals like LTE, GSM or W-CDMA in neighbor channels.

For more information on multi-carrier in WinIQSIM2 see [8].

5 Appendix

5.1 NB-IoT at a Glance

	NB-IoT (UE Category NB1)
Deployment	standalone in-band LTE guard band LTE
PHY	new PHY, similar to LTE, greatly simplified
Channel bandwidth (UE)	200 kHz
Data rate	downlink: 250 kbit/s uplink: 20 kbit/s (single-tone)
Downlink	OFDMA (15 kHz)
Uplink	single-tone (15 kHz / 3.75 kHz) SC-FDMA (15 kHz)
Duplex mode	half-duplex FDD
UE transmit power	23 dBm or 20 dBm
Voice support	no

5.2 NB-IoT Allocation Frequencies for In-Band and Guard Band

Uplink

In the in-band and guard band modes, the center frequency of the LTE channel as well as the RB used by NB-IoT are often specified.

The center frequency of the NB-IoT signal is derived from the offset to the center frequency of the LTE channel. The frequency offset is equal to the number of RB's multiplied by the RB width i.e., RB's * 180 kHz. For LTE channel bandwidths with an odd number of RB's (3 MHz, 5 MHz and 15 MHz), the center lies between two RB's instead of the middle of an RB. This makes it necessary to add the width of half an RB (90 kHz).

If, for example, in a 5 MHz LTE channel on the 1930 MHz uplink frequency, RB 8 is reserved for NB-IoT, then the NB-IoT frequency is: Center Frequency$_{LTE}$ – (4 * 180 kHz + 90 kHz) = 1930 MHz – 810 kHz = 1929.19 MHz.

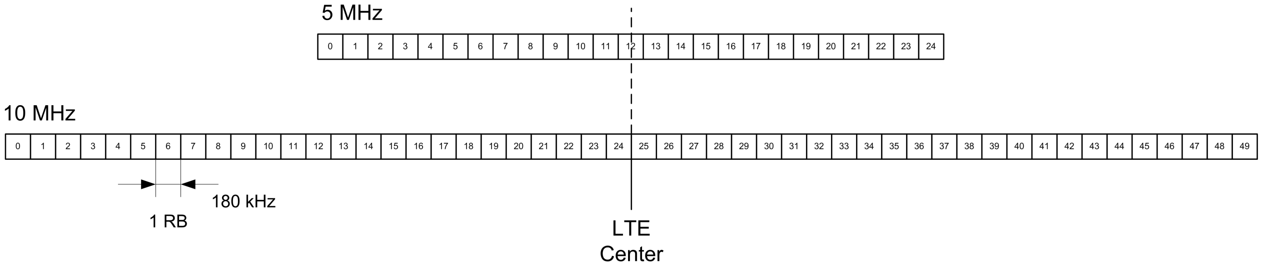


Figure 5-1: Resource block offset for 5 MHz and 10 MHz.

Table 5-1: Possible RB offset for the different LTE bandwidths.

LTE channel bandwidth in MHz	Number of RB's	RB center	Possible offset in in-band	Possible offset in left guard band RB	Possible offset in right guard band RB
3	15	7	±7	–3...–1	15...17
5	25	12	±12	–8...–1	25...33
10	50	between 24 and 25	±24	–17...–1	50...66
15	75	37	±37	–47...–1	75...121
20	100	between 49 and 50	±50	–35...–1	100...134

Downlink

NB-IoT primarily uses a 100 kHz channel grid. In in-band mode, however, the existing LTE RB allocations are applied to maintain compatibility with LTE. This can produce a frequency offset of up to 47.5 kHz in the downlink. Only RB's with a frequency offset of 7.5 kHz or less are allowed for establishing connections with cells. These RB's are known as **anchor** carriers (see Table 2-1).

In the downlink, for in-band operation, both the SMx and the VSE automatically determine the NB-IoT frequency when the RB's are entered.

For guard-band operation, the SMx automatically determines the NB-IoT frequency when the RB's are entered. In the VSE the calculation is:

LTE channel bandwidth in MHz	first possible left guard band RB	first possible right guard band RB	First guard band RB offset to DC in kHz
3	-1	15	1447.5
5	-1	25	2347.5
10	-1	50	4597.5
15	-1	75	6847.5
20	-1	100	9097.5

The calculation of the offset is:

Δf = frequency offset first guard band RB + relative RB * 180 kHz

Example: In a 5 MHz channel RB 28 is used in the guard band: Δf = 2347.5 kHz + (28 -25) * 180 kHz = 2887.5 kHz

5.3 References

[1] Ericsson: Ericsson Mobility Report, June 2016

[2] Rohde & Schwarz: **Narrowband Internet of Things**, White Paper, 1MA266

[3] Rohde & Schwarz: **Cellular IoT eMTC and NB-IoT**, User Manual, SMW-K115

[4] Rohde & Schwarz: **LTE NB-IoT Measurement Application (Downlink)**, User Manual, VSE-K106

[5] Rohde & Schwarz: **LTE NB-IoT Measurement Application (Uplink)**, User Manual, VSE-K106

[6] Technical Specification Group Radio Access Network: **E-UTRA Base station conformance testing, Release 13**, 3GPP TS 36.141

[7] Rohde & Schwarz: **SGT100A: SGMA Vector RF Source**, User Manual

[8] Rohde & Schwarz: **WinIQSIM2: Signal Generation Software**, User Manual

5.4 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

5.5 Ordering Information

Please visit the Rohde & Schwarz product websites at www.rohde-schwarz.com for ordering information on the following Rohde & Schwarz products or contact your local Rohde & Schwarz sales office for further assistance.

Vector signal generators

- SMW200A vector signal generator
- SGT100A vector signal generator

Signal and spectrum analyzers

- VSE Vector Signal Explorer software
- FSW signal and spectrum analyzer
- FSV3000 signal and spectrum analyzer
- FSVA3000 signal and spectrum analyzer

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