Testing LTE-A Releases 11 and 12
Application Note

Products:

- R&S® SMW200A
- R&S® CMW500
- R&S® TS8980
- R&S® FSW
- R&S® FSV3000
- R&S® FSVA3000
- R&S® FPS

LTE is under continuous development. Release 10 (LTE-Advanced) introduced carrier aggregation (CA) as the primary enhancement. Releases 11 and 12 add several new components to LTE. Some are enhancements to existing features (such as improvements to CA), while others are completely new concepts, such as coordinated multipoint (CoMP).

This application note summarizes the Rohde & Schwarz test solutions for LTE-Advanced according to Releases 11 and 12 using vector signal generators, signal and spectrum analyzers and the wideband radio communication tester.

Note:

The most current version of this document is available on our homepage:
http://www.rohde-schwarz.com/appnote/1MA272.

Application Note

Bernhard Schulz

1.2019 – 1MA272_2e

ROHDE&SCHWARZ

Contents

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

- The R&S®SMW200A vector signal generator is referred to as the SMW.
- The R&S®FSW signal and spectrum analyzer is referred to as the FSW.
- The R&S®FSV3000 spectrum analyzer is referred to as the FSV.
- The R&S®FSVA3000 spectrum analyzer is referred to as the FSA.
- The R&S®FPS spectrum analyzer is referred to as the FPS.
- The FSW, FSV3000, FSVA3000 and FPS are referred to as the FSx.
- The R&S®CMW500 wideband radio communication tester is referred to as the CMW500.
- The R&S®TS8980 LTE RF Test System is referred to as the TS8980.

1 Introduction

Since end 2009, LTE mobile communication systems according to Releases 8 and 9 are commercially deployed. LTE Release 10 added major features (e.g. carrier aggregation (CA)). Especially CA has been integrated in commercial networks.

LTE is under continuous development. Releases 11 and 12 add several new components to LTE. Some are enhancements to existing features (such as improvements to CA), while others are completely new concepts, such as coordinated multipoint (CoMP). Releases 11 and 12 are still called LTE-Advanced.

You can find a complete basic set of White Papers and Application Notes regarding LTE Releases 8 to 12:

- Release 8

  White Paper: UMTS Long Term Evolution (LTE) Technology Introduction
- Release 9

  White Paper: LTE Release 9 Technology Introduction

  Application Note: Testing LTE Release 9 Features
- Release 10

  White Paper: LTE-Advanced Technology Introduction

  Application Note: Testing LTE-Advanced
- Release 11

  White Paper: LTE- Advanced (3GPP Rel.11) Technology Introduction
- Release 12

  White Paper: LTE- Advanced (3GPP Rel.12) Technology Introduction

The different LTE-Advanced technology components are illustrated in Fig. 1-1. They naturally have different market requirements and also require different testing strategies.

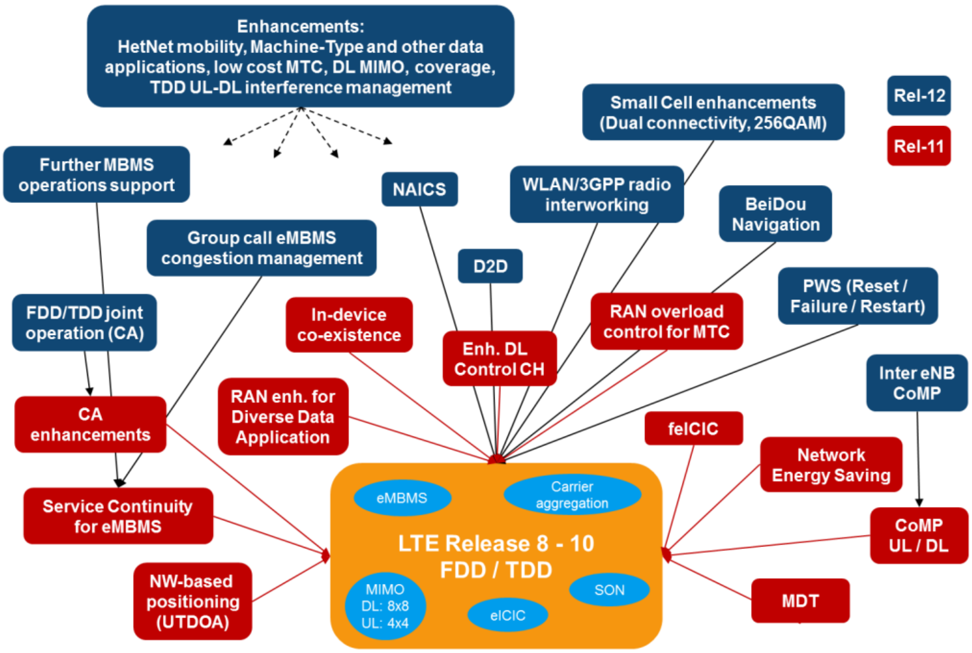


Fig. 1-1: LTE technology component dependencies: red Release 11 and blue Release 12.

Section 2 explains briefly the single features; section 3 of this application note discusses the testing aspects of each technology component in LTE-Advanced and describes available test solutions in the Rohde & Schwarz product portfolio.

2 LTE-A Features in Rel. 11 and 12

Releases 11 and 12 introduced a number of new features. This chapter summarizes the features that are relevant for Rohde & Schwarz instruments. For more information, refer to the white papers [2] and [3] mentioned in Chapter 1.

2.1 UE Categories

The following tables summarize the UE categories in Release 12. Up through Rel. 11, the category defined both downlink and uplink characteristics; Release 12 specifies more flexible downlink categories that correspond to various uplink characteristics.

Category 0 was newly added. It supports cost-efficient configuration in half-duplex mode for machine type communication (MTC). Fig. 2-1 shows the logical relationships between the various categories. The number of component carriers (CC) in the tables indicates the minimum required number of CC's to achieve the maximum data rate.

UE categories in Release 8…11						
Rel	**Category**	**DL max data**	**UL max data**	**Number of CC's**	**MIMO layer**	**Highest modulation scheme** **DL - UL**
8	1	10	5	1	1	64 QAM – 16 QAM
	2	50	25	1	2	64 QAM – 16 QAM
	3	100	50	1	2	64 QAM – 16 QAM
	4	150	50	1	2	64 QAM – 16 QAM
	5	300	75	1	4	64 QAM – 64 QAM
10	6	300	50	1 or 2	2 or 4	64 QAM – 16 QAM
	7	300	100	1 or 2	2 or 4	64 QAM – 16 QAM
	8	3000	1500	5	8	64 QAM – 64 QAM
11	9	450	50	2 or 3	2 or 4	64 QAM – 16 QAM
	10	450	100	2 or 3	2 or 4	64 QAM – 16 QAM
	11	600	50	2, 3 or 4	2 or 4	64 QAM – 16 QAM Rel 12: 256 QAM – 16 QAM
	12	600	100	2, 3 or 4	2 or 4	

Table 2-1: UE categories in Release 8…11.

UE downlink categories Release 12						
Downlink Category	DL max data	Supported UL cat	UL max data	Number of CC's	MIMO layer	Highest modulation scheme DL - UL
0	1	0	1	1	1	64 QAM – 16 QAM
6/7	300	5,13	75,150	1 or 2	2 or 4	64 QAM – 64 QAM
9/10	450	5,13	75,150	2 or 3	2 or 4	64 QAM – 64 QAM
11/12	600	5,13	75,150	2, 3 or 4	2 or 4	256 QAM – 64 QAM
13	400	3,5,7,13	50,75,100,150	1 or 2	2 or 4	256 QAM – 16 / 64 QAM
14	4000	8	1500	5	8	256 QAM – 64 QAM
15	750…800	3,5,7,13	50,75,100,150	2 or 4	2 or 4	256 QAM – 16 / 64 QAM
16	1000…1050	3,5,7,13	50,75,100,150	2 or 5	2 or 4	256 QAM – 16 / 64 QAM

Table 2-2: UE downlink categories in Release 12.

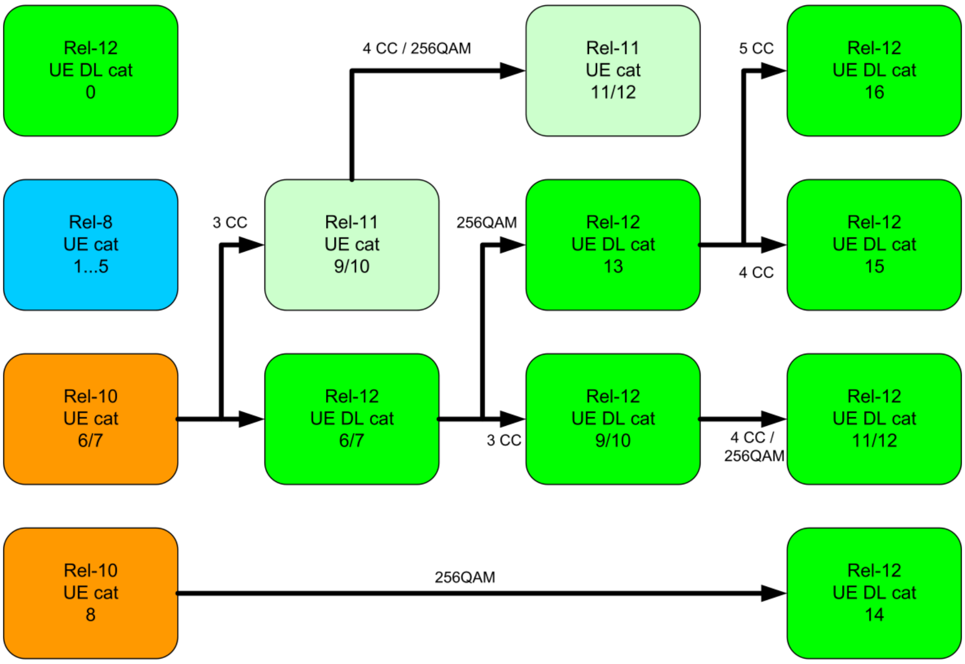


Fig. 2-1: UE categories - Logical dependencies.

2.2 Release 11 features

2.2.1 Carrier aggregation enhancements

Carrier aggregation (CA) was first introduced in Release 10. Release 11 included several enhancements.

2.2.1.1 Multiple Timing Advances (TAs) for Uplink Carrier Aggregation

If a UE sends two carriers in the uplink to two physically separate receivers (e.g. one eNB and one remote radio head (RRH)), they will be received at different times. To compensate this, the base stations can send different timing advance commands to the UE for the different uplink carriers. The eNodeB thus instructs the UE to transmit the two carriers at different times.

2.2.1.2 Non-contiguous intra-band carrier aggregation

A gap between the carriers (or between the subblocks) is now possible for the first time. This is represented by W_{Gap}.

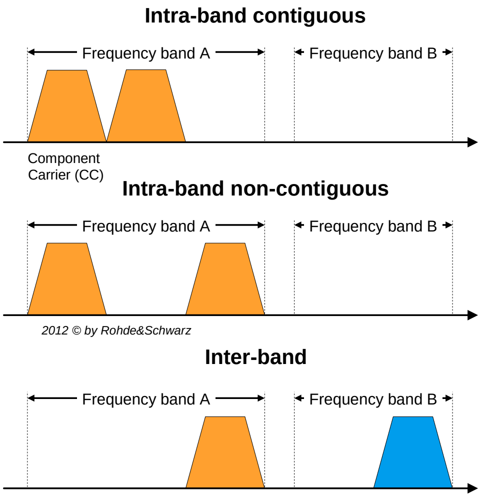


Fig. 2-2: CA scenarios.

This has consequences for the following tests:

- Base station tests
  - Timing error
  - ACLR and a new cumulative ACLR (CACLR) within the GAP
- Different UE tests

2.2.1.3 TDD: Additional Special Subframe Configuration and different UL/DL configurations

Effective with Release 11, two TDD carriers can use differing UL/DL configurations (from the set of known configurations 0…6).

In addition, two new special subframe configurations are available:

- Special Subframe Configuration 9, normal cyclic prefix
- Special Subframe Configuration 7, extended cyclic prefix

The additions allow a balanced use of DwPTS and GP, i.e. enhance the system flexibility while maintaining the compatibility with TD-SCDMA.

2.2.2 Coordinated Multi-Point Operation (CoMP)

CoMP is one of the most important new features in Release 11. Like all other features, the purpose of CoMP is to reduce or prevent interference. The basic idea behind

CoMP is that two cells (eNodeB) or one cell and an RRH coordinate how to supply a UE. This involves the coordinated use of multiple physically separate antennas. CoMP in Rel 11 requires an ideal connection between the transmission points (TP) or receiving points (RP), i.e. fiber-optic connections.

Downlink

The downlink includes the following schemas:

- Joint Processing (data available at all TPs)
  - Dynamic Point Selection (DPS)
    This is the most important function within CoMP because it is the most effective. In this case, only one TP transmits, although the transmitting TP can change with every subframe.
  - Joint Transmission (JT)
    In this case, the data is transmitted by all TPs, either at the same time (e.g. multipath propagation) or separately (SU-MIMO). It is also possible to transmit both coherently (all TPs precode jointly, e.g. 4x2 MIMO) or non-coherently (all TPs precode individually, e.g. each 2x2 MIMO).
- Coordinated Scheduling / Beamforming (data available at only one TP)
  - Scheduling (CS)
    In this case, a TP can reduce the transmit power in order to improve the communication of another TP to another UE.
  - Beamforming (CB)
    In this schema, the TPs coordinate the beamforming so that the UEs have good coverage and interfere as little as possible with the other communications.

Uplink

- Joint Reception

  The data (PUSCH) is received by all RPs.
- Coordinated Scheduling / Beamforming

  In this case, the RPs coordinate the scheduling and precoding, but the PUSCH is received by only one RP.

In general, TPs and RPs are decoupled in the uplink, i.e. the TP does not necessarily also have to be the RP any longer. Virtual cell IDs (VCID) have been introduced for this purpose.

In order to support CoMP, the transmission mode TM10 was introduced. It is similar to TM9 and supports up to 8-layer PDSCH. The main difference is the new DCI format 2D.

2.2.3 Enhanced PDCCH (E-PDCCH)

New functions in Release 11 such as CoMP require additional capacity on the control channel. This is why the E-PDCCH was newly introduced. It is based on the PDCCH and is backward compatible. In order to provide additional capacity, resource blocks from the PDSCH are used. Either two, four or eight blocks can be allocated within the system bandwidth. The information can also be continuously transmitted across the complete subframe. The information is UE specific and beamforming of the E-PDCCH is also possible.

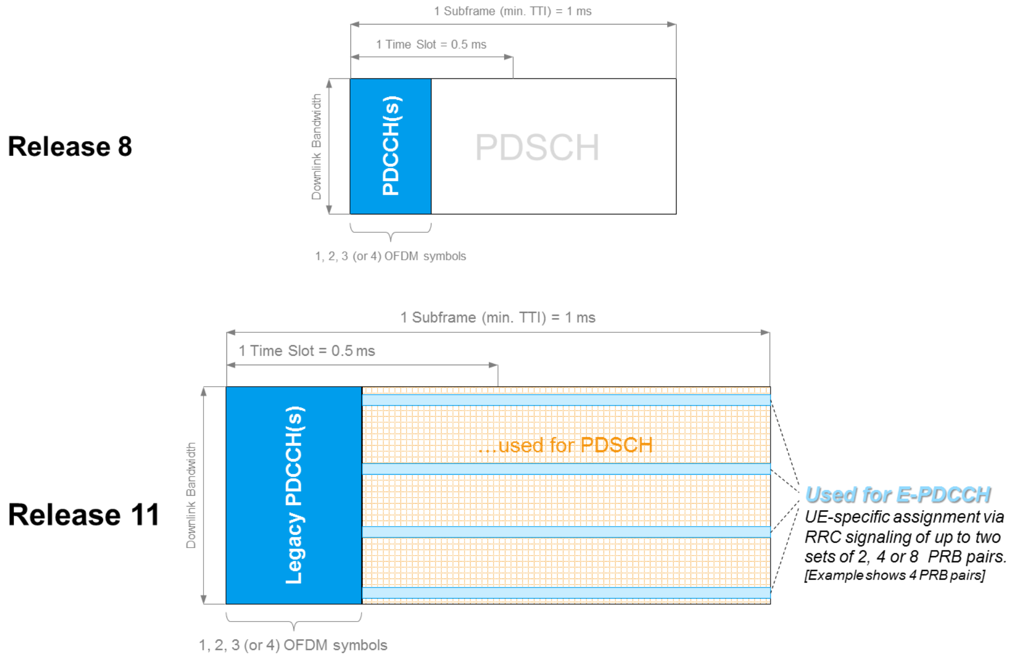


Fig. 2-3: E-PDCCH structure compared to PDCCH.

2.2.4 Further enhanced non CA-based ICIC (feICIC)

Generally inter-cell interference coordination (ICIC) has the task to manage radio resources such that inter-cell interference is kept under control. Up to Release 10 the ICIC mechanism includes a frequency and time domain component. The frequency domain ICIC manages radio resource, notably the radio resource blocks, such that multiple cells coordinate use of frequency domain resources. For the time domain ICIC, subframe utilization across different cells are coordinated in time through so called Almost Blank Subframe (ABS) patterns.

The main enhancement in Release 11 was to provide the UE with Cell specific Reference Symbol (CRS) assistance information of the aggressor cells in order to aid the UE to mitigate this interference. Thus, it was necessary to define signaling support indicating which neighbor cells have ABS configured.

The information element RadioResourceConfigDedicated may optionally (from Rel. 11 on) include a neighCellsCRSInfo field, which includes the following information of the aggressor cell(s):

- Physical Cell ID.
- Number of used antenna ports (1, 2, 4).
- MBMS subframe configuration.

Furthermore in case of strong interference the UE may not be able to decode important system information transmitted. From Release 11 System Information Block Type 1 (SIB1) information may be optionally included in the RRCConnectionReconfiguration message. If the UE receives the SIB1 via dedicated RRC signaling, it needs to perform the same actions as upon SIB1 reception via broadcast.

2.3 Release 12 features

2.3.1 Small cell enhancements

2.3.1.1 Higher Order Modulation (256QAM)

Up to Release 10 the LTE technology applies QPSK, 16QAM and 64QAM (optional in uplink) modulation. For small cells in addition 256QAM modulation is available in the downlink, because high signal to noise/interference is potentially available at the UE.

2.3.1.2 Dual Connectivity

Dual Connectivity (DC) is a feature to avoid handovers between two basestations (eNodeB). Especially in heterogeneous networks with many pico cells, a travelling UE may cause many handovers. In DC instead of handovers, the UE stays connected to both eNodeB's. DC assumes different carrier frequencies in macro and pico cell and that the UE runs two MAC entities. Each cell acts either as a Master eNB (MeNB) or as a Secondary eNB (SeNB). Both cells cooperate via a non-ideal backhaul. For more information, see [4].

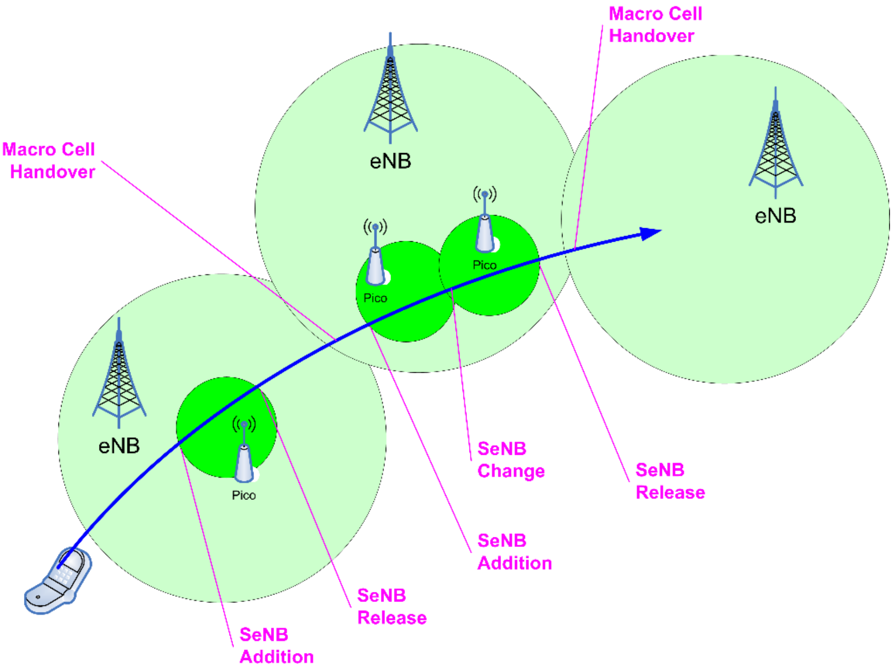


Fig. 2-4: Dual Connectivity: a travelling UE in a heterogeneous network

2.3.2 D2D communication

Up to now, Critical Communication (or Public Safety) uses its own networks like TETRA or APCO. Features for Public Safety communication are:

- Reliability and Resilience. Functioning satisfactorily over periods and under adverse circumstances
- Direct Communication between terminals
- Group Communication
- Off network communication
- Mission Critical Push-To-Talk (MCPTT) including group call communication with low call setup time

LTE Release 12 allows direct communication between UE's. The new feature set is called Device to Device (D2D) Communication. In Release 13 the functionality will be further enhanced.

Following scenarios are identified:

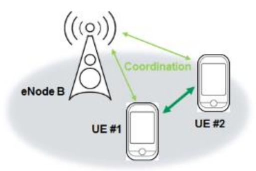
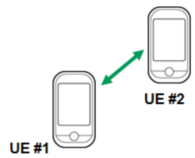
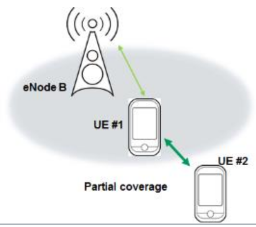
	Within network coverage (Intra-/Inter-cell)	**Outside network coverage**	**Partial network coverage**
Non-public safety use case	Discovery	-	-
Public safety use case	Discovery, Communication	Communication	Communication
			

Table 2-3: LTE Device-to-Device scenarios.

- Discovery

This feature identifies that two UEs are in proximity of each other. For two UEs in cellular coverage it may also be used for commercial purposes.

- Direct Communication

Direct Communication between two UEs. LTE resources from cellular traffic are reserved and used for this type of communication. This is only applicable for the public safety use case.

2.3.3 WLAN/3GPP Radio Interworking

Today's cellular phones also support WLAN. WLAN offloading in LTE makes it possible to handle some data traffic via WLAN in order to reduce the LTE load. If a UE with an LTE connection detects usable WLAN access points (APs), it must determine which data to transmit via which AP. Up through Release 11, the UE configuration was specific to the network operator. Starting with Release 12, an additional RAN-assisted solution is available. This transmits a list of preferred APs to the UE.

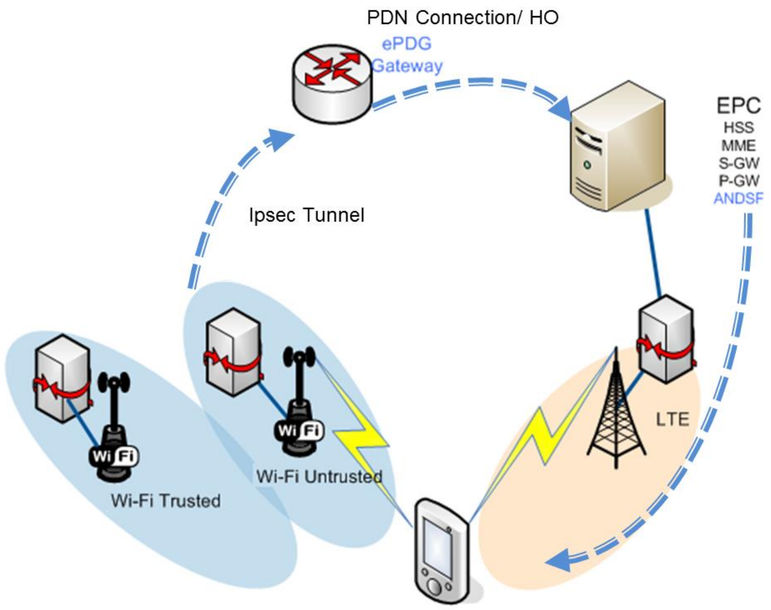


Fig. 2-5: WLAN offloading.

2.3.4 TDD-FDD joint operation in different bands

Starting with Release 12, the component carrier in carrier aggregation can use different duplexing methods, i.e. a carrier FDD in band 19 and the second carrier TDD in band 42.

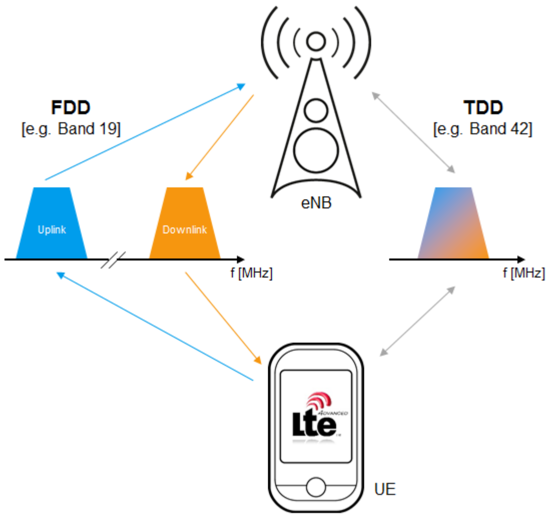


Fig. 2-6: Carrier aggregation with FDD and TDD.

2.3.5 Enhanced Interference Mitigation & Traffic Adaption (eIMTA)

eIMTA is an improvement to the LTE TDD mode. It allows a dynamic reconfiguration of UL/DL time slots within the LTE frame structure. Table 2-4 recalls the seven possible frame configurations. The TDD frame configuration in each cell is signaled in SIB1. eIMTA allows to reconfigure UL-DL in a more flexible way. The network sends a L1 signaling to the UE on PCell PDCCH to indicate which uplink-downlink configuration is used for one or more serving cell(s). This uplink-downlink configuration provided by the L1 signaling applies for a RRC-configured number of radio frames. The signaling is done via DCI Format 1C.

UL/DL Configuration	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Table 2-4: LTE TDD frame configuration.

2.3.6 Further downlink MIMO enhancements

To achieve a better throughput Release 12 introduces an enhanced **4Tx** codebook as further DL MIMO enhancements. The enhanced codebook is supported for all aperiodic reporting modes that are valid for transmission modes (TM) 8, 9, 10 only. For more information (e.g. the precoding tables) see [4].

2.3.7 Coverage Enhancements

The bottleneck in coverage in LTE networks are uplink medium data rate PUSCH and VoIP. Thus the introduction of **Enhanced TTI Bundling** improves the coverage by extending the cell range for low data rates.

The main differences compared to legacy TTI bundling are:

- Enhanced HARQ pattern for FDD
- HARQ RTT reduced from 16 ms to 12 ms
- More than 3 PRBs per subframe can be allocated (FDD and TDD)

The UE signals the eNodeB the support of the enhanced TTI bundling.

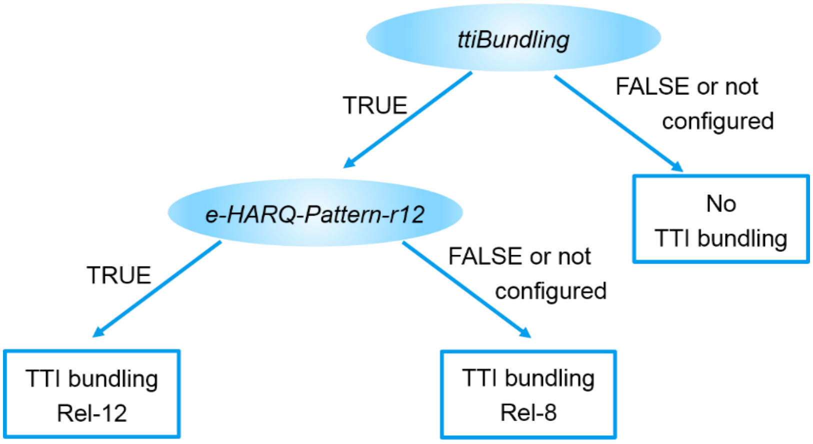


Fig. 2-7: Decision tree for TTI bundling.

3 Testing of LTE-A Releases 11 und 12

3.1 Baseband and RF signal generation

R&S signal generators offer many features that are particularly helpful when generating signals with multiple component carriers and MIMO according to LTE-Advanced requirements. This is especially true for the multi-channel concept of the SMW signal generator (Fig. 3-1) which combines up to four signal sources in one single instrument. The SMW includes up to two RF paths in the main instrument. In addition, the SMW can handle up to eight RF paths with additional RF sources like the SGS or SGT.

Fig. 3-1: SMW Vector Signal generator.

The multi-path concept of the SMW allows configuration of each baseband according to individual testing needs (see Fig. 3-2, example generating a LTE and UMTS signal) or different MIMO modes. With the option SMW-K75 higher order MIMO modes like 8x4, 4x8 and 4x4 for 2 component carriers (CC) are possible. As an option in addition fading is available.

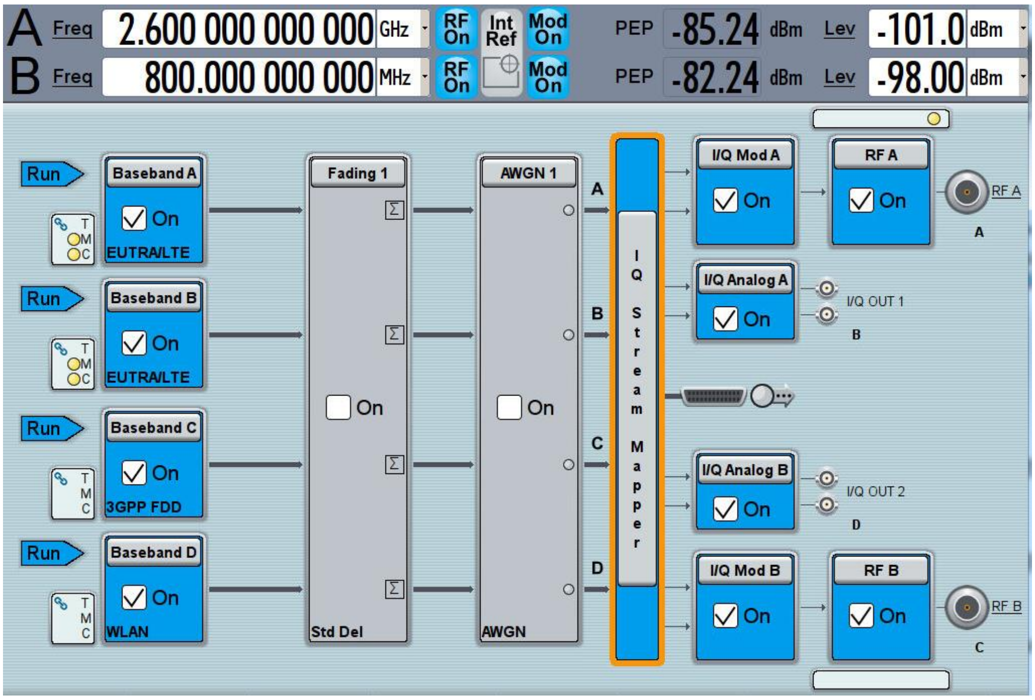


Fig. 3-2: SMW example with four different signals.

The options SMW-K112 and K113 allow testing of LTE-Advanced physical layer features in line with the 3GPP Release 11 and Release 12 standard. It covers downlink and uplink signal generation. SMW-K112 and SMW-K113 require the basic LTE functionality being installed on the equipment (SMW-K55 LTE option).

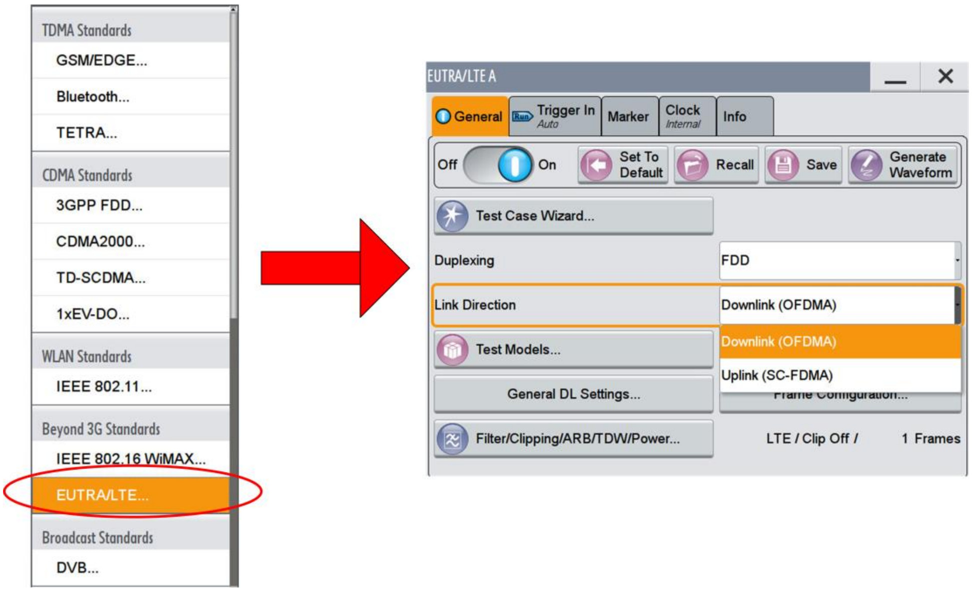


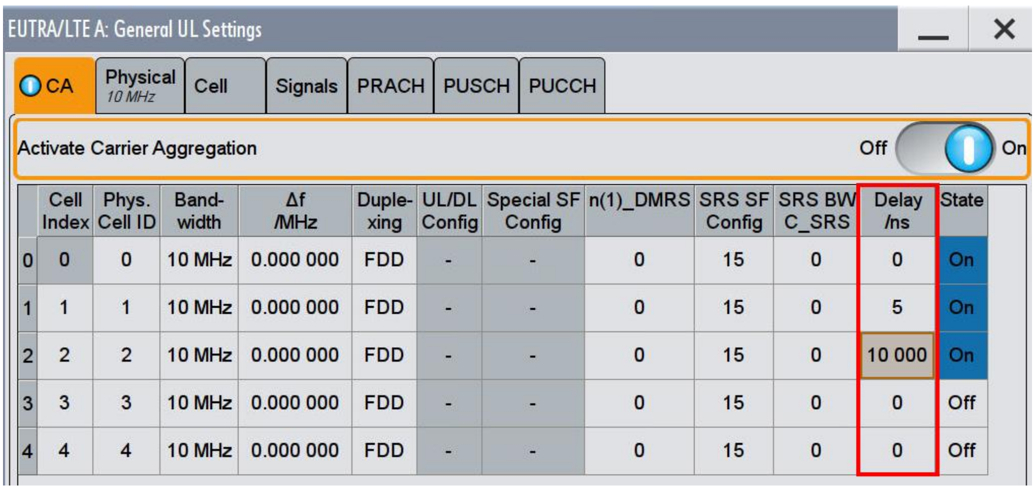
Fig. 3-3: Start of the LTE standard and Link Direction.

3.1.1 Carrier aggregation enhancements (Rel 11)

3.1.1.1 Multiple Timing Advances (TAs) for uplink carrier aggregation

The SMW supports two methods of transmitting two carriers at different times in carrier aggregation:

1. Static methods in the CA menu: An individual delay can be set here for each of the five CC's.



	Cell Index	Phys. Cell ID	Band-width	Δf /MHz	Duple-xing	UL/DL Config	Special SF Config	n(1)_DMRS	SRS SF Config	SRS BW C_SRS	Delay /ns	State
0	0	0	10 MHz	0.000 000	FDD	-	-	0	15	0	0	On
1	1	1	10 MHz	0.000 000	FDD	-	-	0	15	0	5	On
2	2	2	10 MHz	0.000 000	FDD	-	-	0	15	0	10 000	On
3	3	3	10 MHz	0.000 000	FDD	-	-	0	15	0	0	Off
4	4	4	10 MHz	0.000 000	FDD	-	-	0	15	0	0	Off

Fig. 3-4: Static delay of the individual uplink carriers in carrier aggregation.

2. As part of the SMW-K69 Realtime Feedback software option, two uplinks can be individually controlled with different commands. The baseband selector is required for multiplexing serial commands for different basebands to one feedback line. The baseband unit listens only to serial commands containing the set selector (e.g. 0 stands for Baseband A).

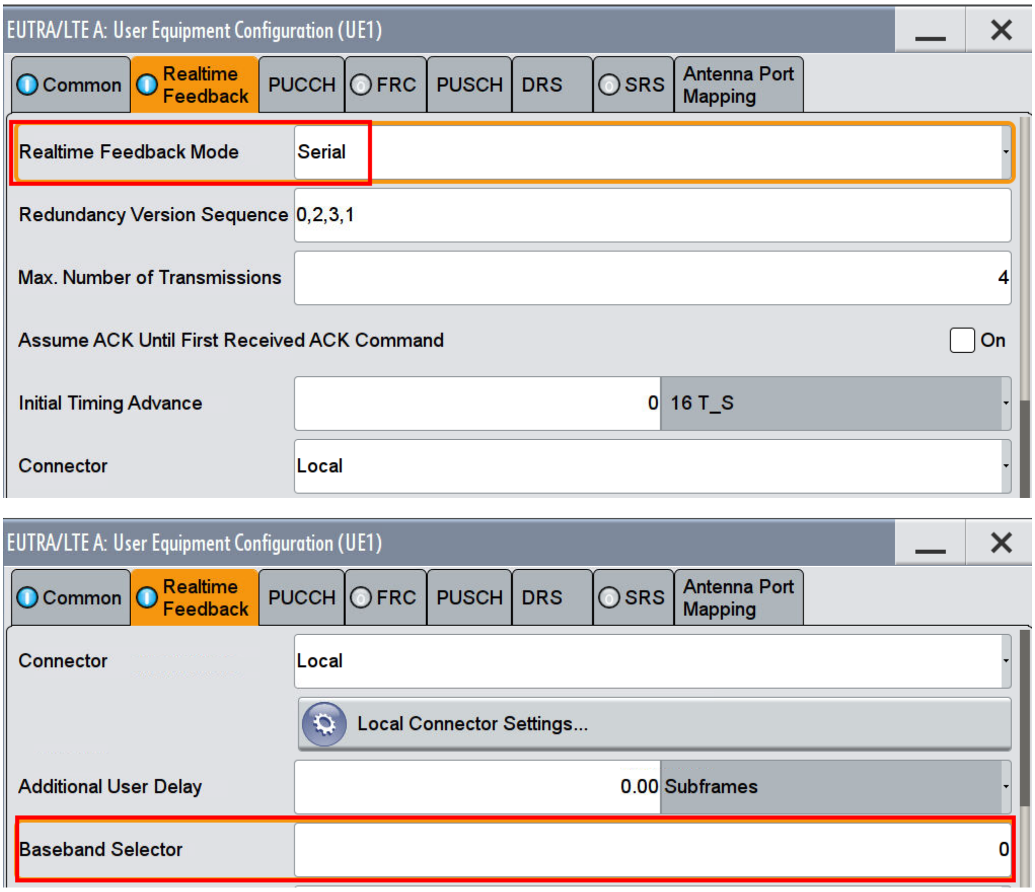


Fig. 3-5: Realtime feedback for carrier aggregation is possible for up to two CC's.

3.1.1.2 Non-contiguous intra-band carrier aggregation

The SMW supports non-contiguous carrier aggregation from the very first firmware version. One baseband can position up to five carrier freely in the bandwidth of the baseband.

3.1.1.3 TDD: Additional Special Subframe Configuration and different UL/DL configurations

The SMW supports the new special subframes in TDD. **TDD Special Subframe Config** can be found under **General Settings|Physical/TDD.** Fig. 3-6 shows an example in the downlink using configuration 9.

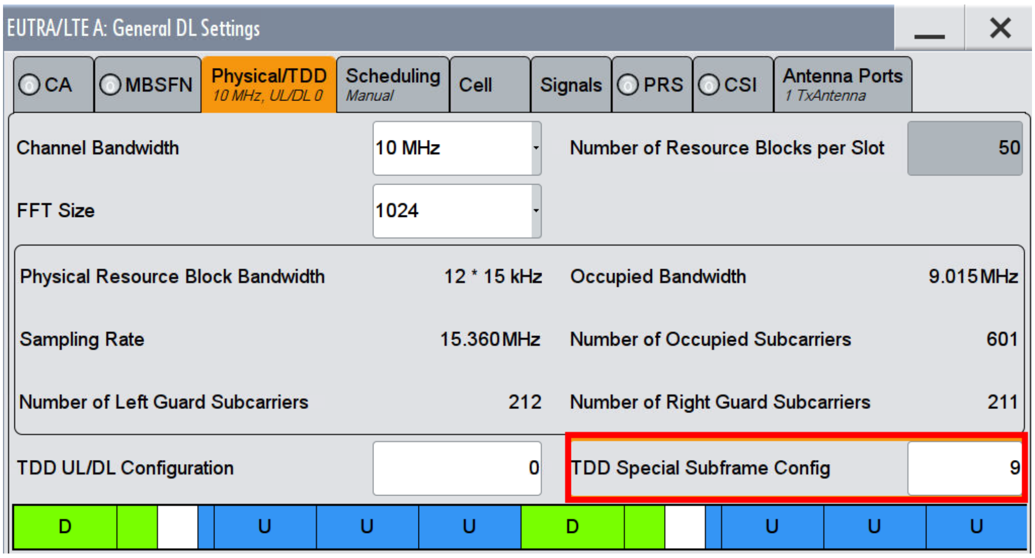


Fig. 3-6: TDD Special Subframe Configuration. Both configurations 7 and 9 are supported.

The SMW additionally allows different TDD configurations for carrier aggregation in the uplink.

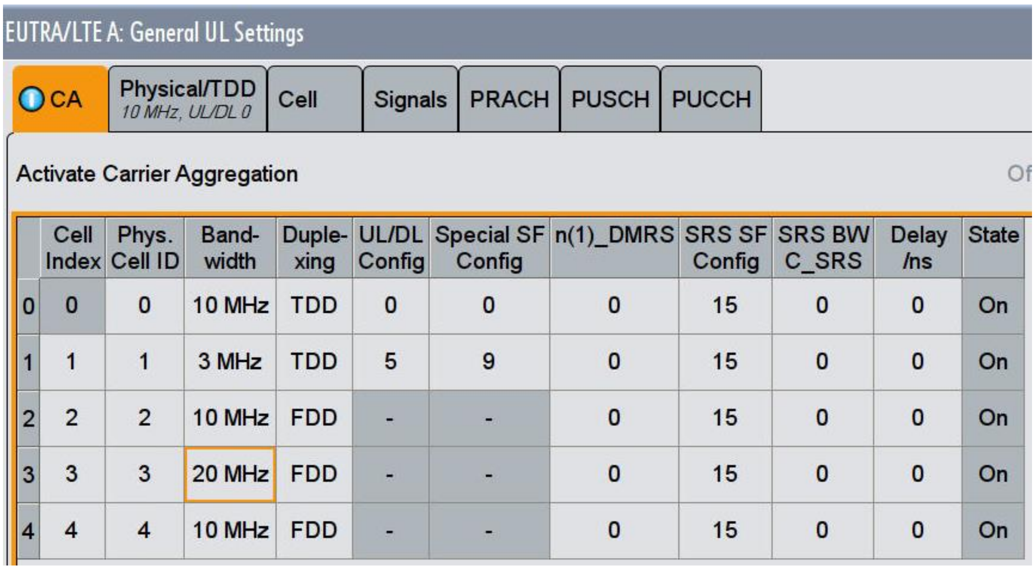


Fig. 3-7: Different TDD configurations in the uplink.

3.1.2 CoMP (Rel 11)

The SMW supports CoMP in the downlink, which includes DCI format 2D and TM10. Different combinations of component carriers and MIMO modes are possible together with fading as well. The SMW can handle up to four CC's with 2x2 MIMO each or up to two CC's with 4x4 MIMO. For the maximum numbers the setup requires additional external generators like the SGS or the SGT.

Set in the **System Configuration** a scenario with CA and MIMO, e.g. 2 x 2 x 2.

In the **DL Frame Configuration** tab **General** click on **Tx Modes** and enter *Mode 10* for all cells (Fig. 3-8).

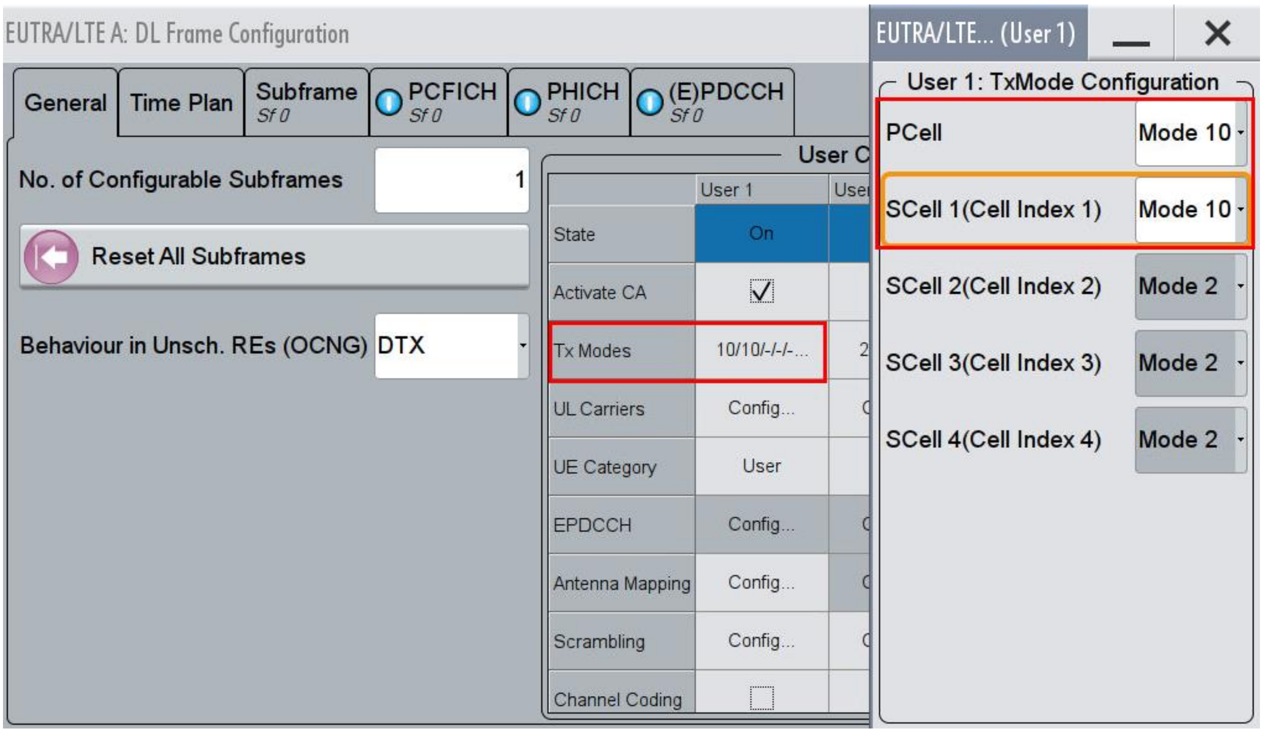


Fig. 3-8: SMW CoMP Transmission Mode 10

Set in the tab **(E)PDCCH** the **DCI format** to *2D (*Fig. 3-9*)*.

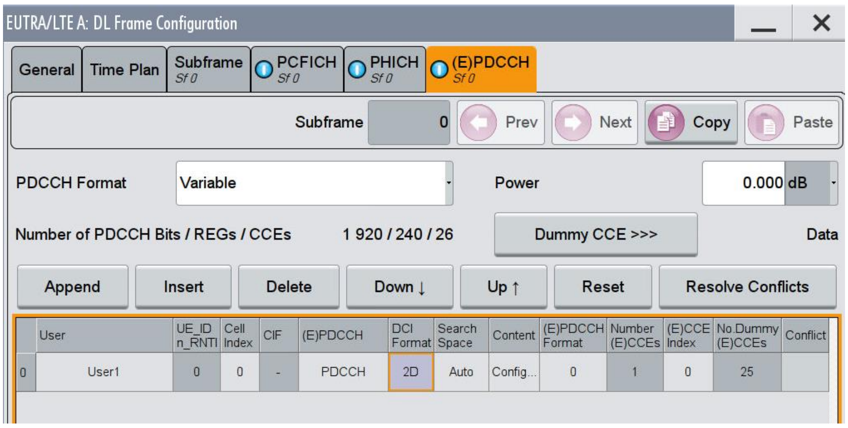


Fig. 3-9: SMW DCI format 2D

In the tab **Subframe** click **Configure Enhanced Settings** of the PDSCH ant set the **Precoding Scheme** to *Beamforming* and the **Transmission Scheme** to *Multi-Layer, CoMP (TM10) (*Fig. 3-10*)*.

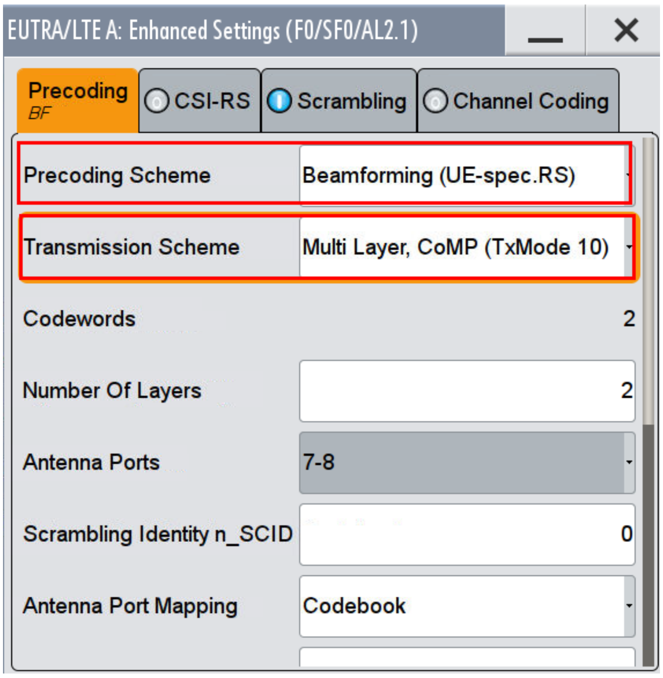


Fig. 3-10: SMW CoMP

Click on **Config Scrambling** to set the individual **DMRS Scrambling Identities (**Fig. 3-11**)**.

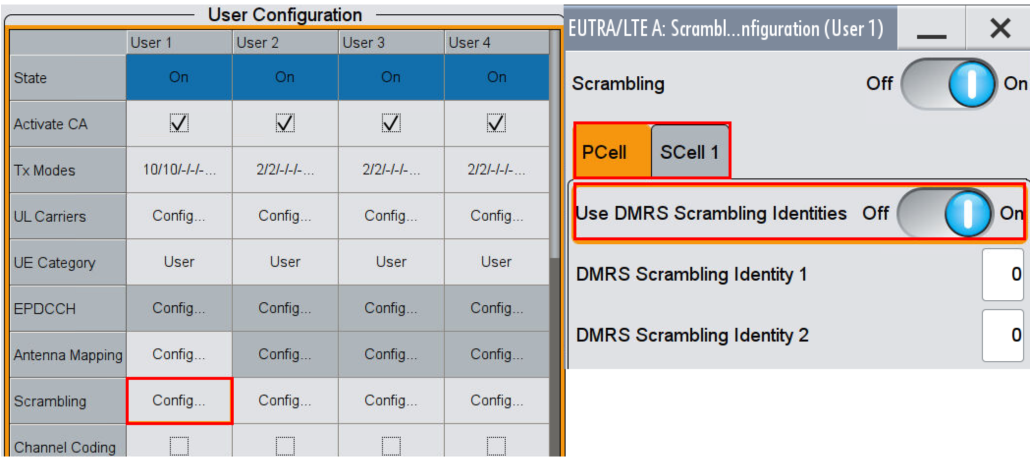


Fig. 3-11: SMW Scrambling Identities

3.1.3 E-PDCCH (Rel 11)

The SMW supports the E-PDCCH in the AUTO PDSCH scheduling modes, so the SMW sets the signal automatically to the right configuration.

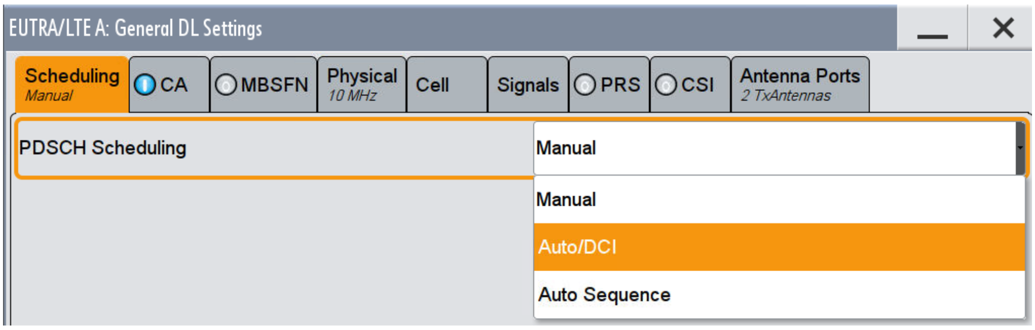


Fig. 3-12: EPDCCH is available in the AUTO scheduling modes.

Select in the **Frame Configuration** in the tab **General** in the *User Configuration* "Config EPDCCH".

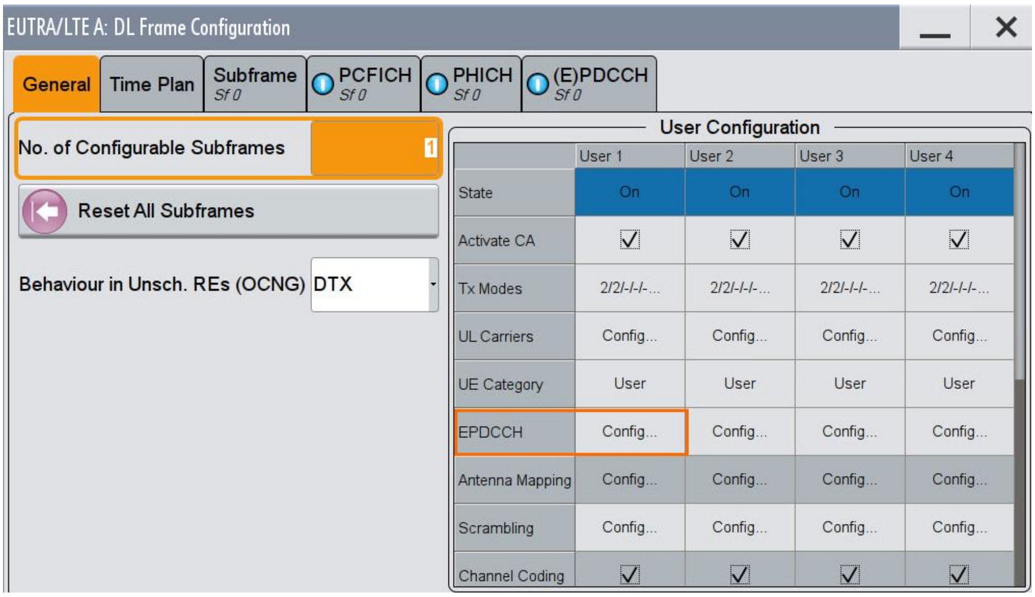


Fig. 3-13: EPDCCH in the User Configuration

Activate the EPDCCH and set the **Number of PRB pairs**, the **Resource Block Assignment** (for values see 3GPP TS36.213) and the **n^EPDCCH_ID**.

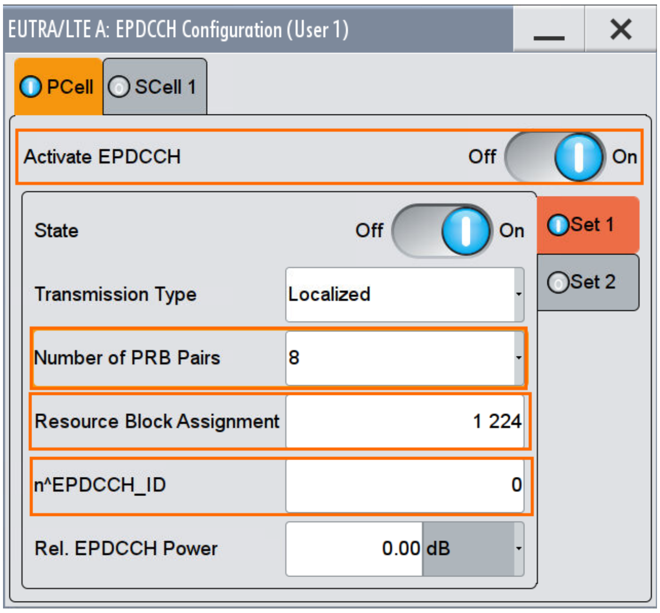


Fig. 3-14: Configuration of the EPDCCH

In the tab **(E)PDCCH** select *EPDCCH set x*, the wanted *DCI format* and the wanted *(E)PDCCH format*.

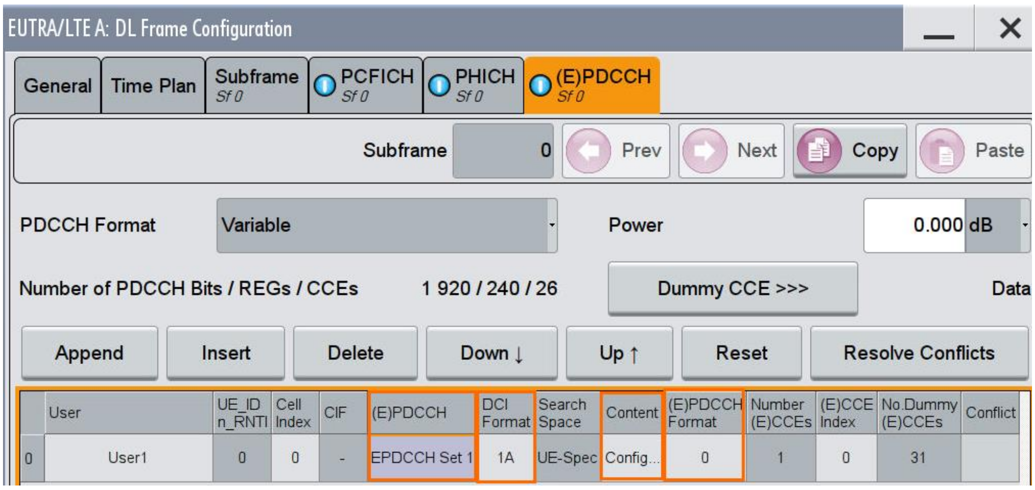


Fig. 3-15: Usage of the EPDCCH

Klick **Content Config** to set the wanted content to send.

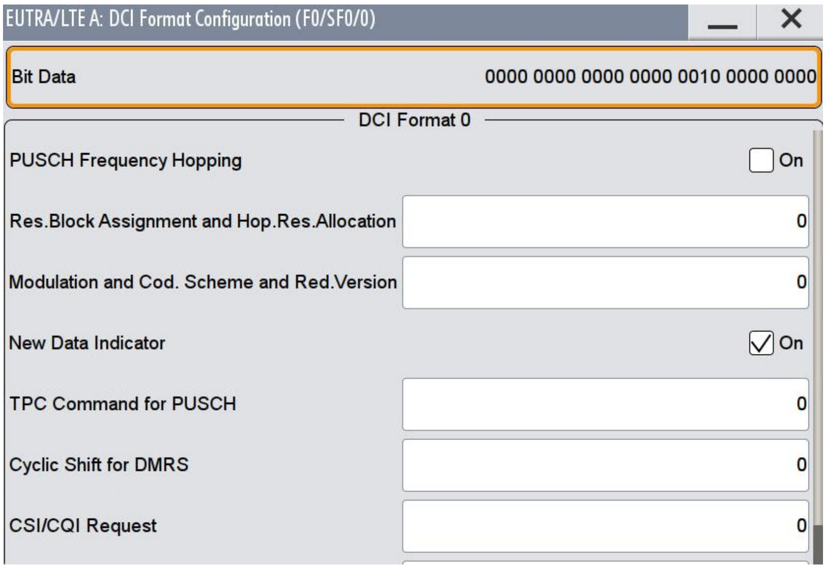


Fig. 3-16: DCI Format Configuration

Check the settings in the **Subframe** (Fig. 3-17) allocations and in the **Time Plan** (Fig. 3-18).

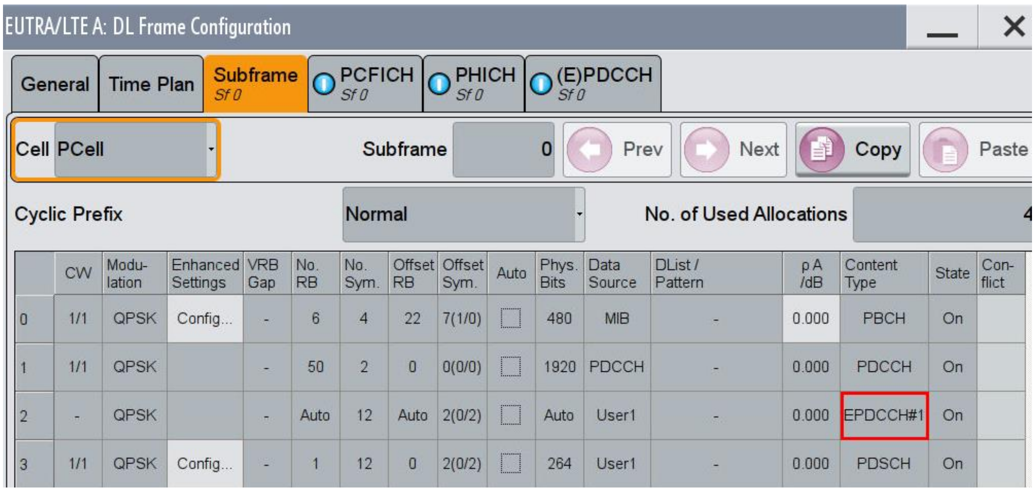


Fig. 3-17: Allocation with EPDCCH in the subframe

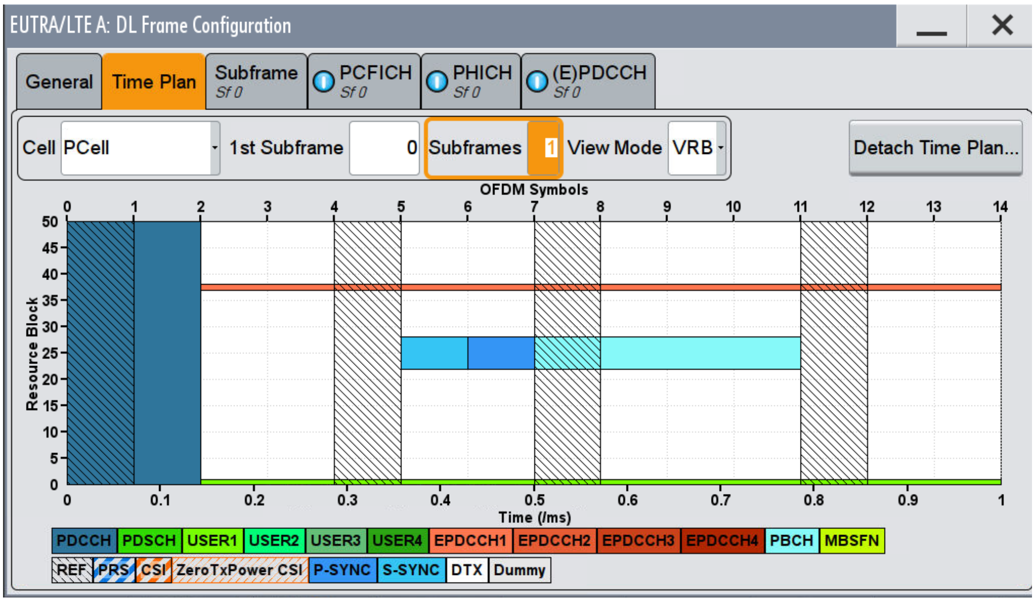


Fig. 3-18: The time plan allows easy checks at a glance. The EPDCCH is marked red.

3.1.4 UE categories (Rel 12)

The SMW supports up to 5 CC’s, up to 8 MIMO layers and all modulation modes in both the downlink (up to 256 QAM) and the uplink (up to 64 QAM). This makes it possible to implement all UE downlink categories from Release 12 along with the matching uplink categories individually.

3.1.5 Small Cell Enhancements (Rel 12)

3.1.5.1 Higher Order Modulation - 256QAM (Rel 12)

Small cells may support 256QAM in the downlink. Thus for the UE receiver tests the SMW supports 256QAM.

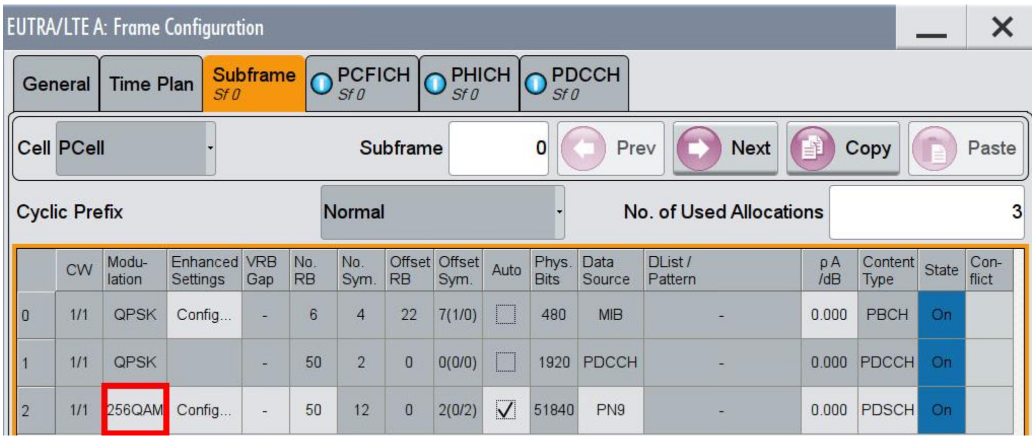
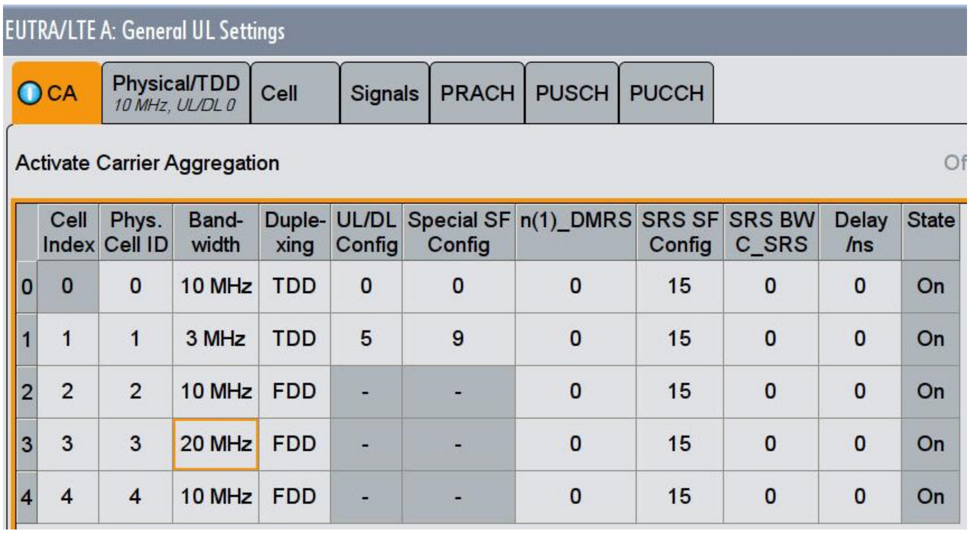


Fig. 3-19: 256QAM in the downlink.

3.1.6 TDD-FDD joint operation in different bands (Rel 12)

The SMW also supports mixed duplex configurations for carrier aggregation in the uplink. Fig. 3-20 shows an example with two TDD and three FDD carriers.



	Cell Index	Phys. Cell ID	Band-width	Duple-xing	UL/DL Config	Special SF Config	n(1)_DMRS	SRS SF Config	SRS BW C_SRS	Delay /ns	State
0	0	0	10 MHz	TDD	0	0	0	15	0	0	On
1	1	1	3 MHz	TDD	5	9	0	15	0	0	On
2	2	2	10 MHz	FDD	-	-	0	15	0	0	On
3	3	3	20 MHz	FDD	-	-	0	15	0	0	On
4	4	4	10 MHz	FDD	-	-	0	15	0	0	On

Fig. 3-20: joint TDD-FDD operation.

3.1.7 eIMTA (Rel 12)

The bit sequence for signaling the UL/DL reconfiguration sequence is signaled on Layer 1 on the PDCCH via DCI Format 1C. First in the **Frame Configuration**, set in tab **General** the eIMTA-RNTI for the user (example User 1). Second, set in tab PDCCH the User to **User X-eIMTA**. Last, set the desired bit sequence.

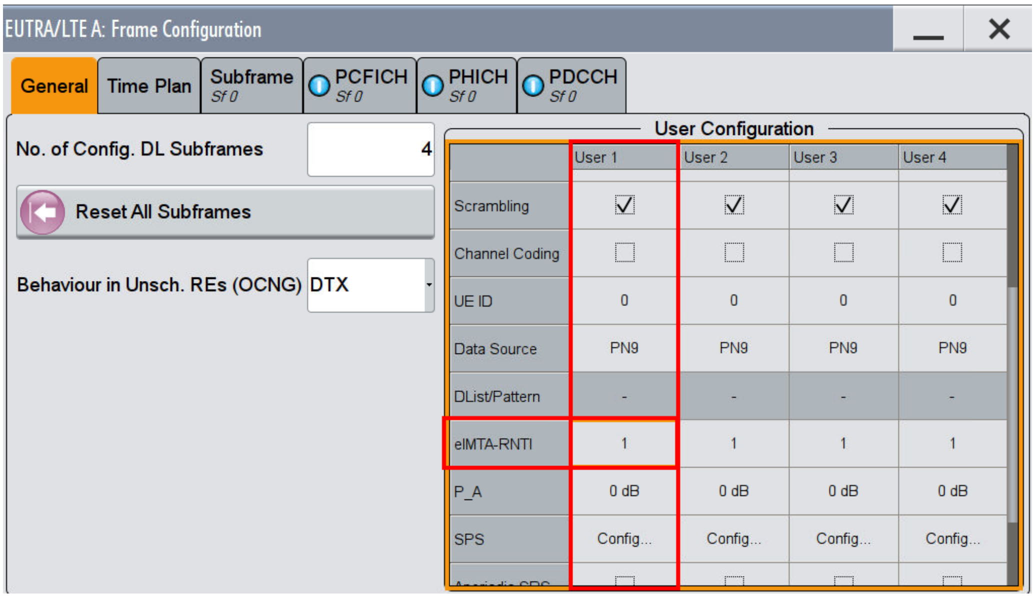


Fig. 3-21: The eIMTA-RNTI is used for CRC scrambling of the PDCCH (example user 1).

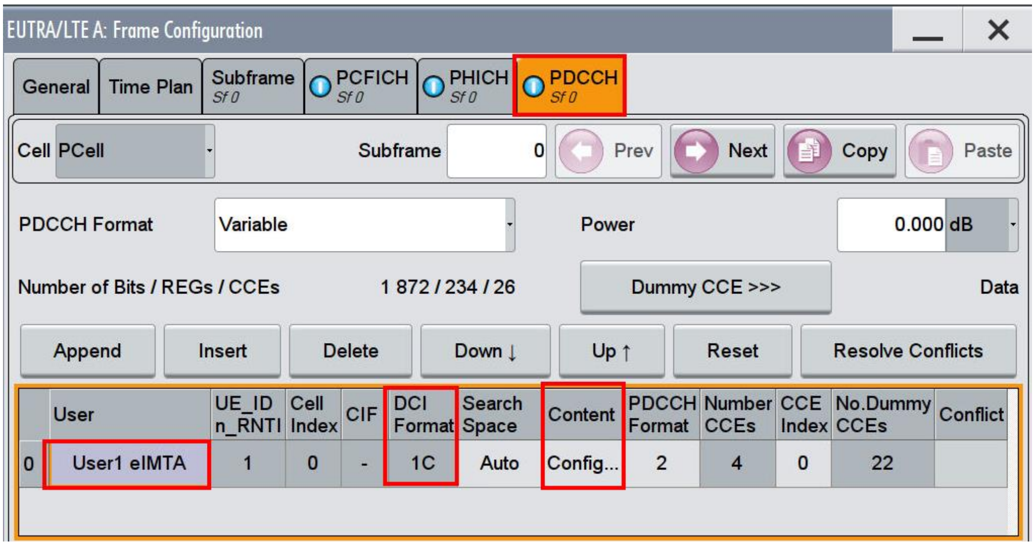


Fig. 3-22: Select eIMTA in the USER section in PDCCH. This sets DCI format 1C automatically.

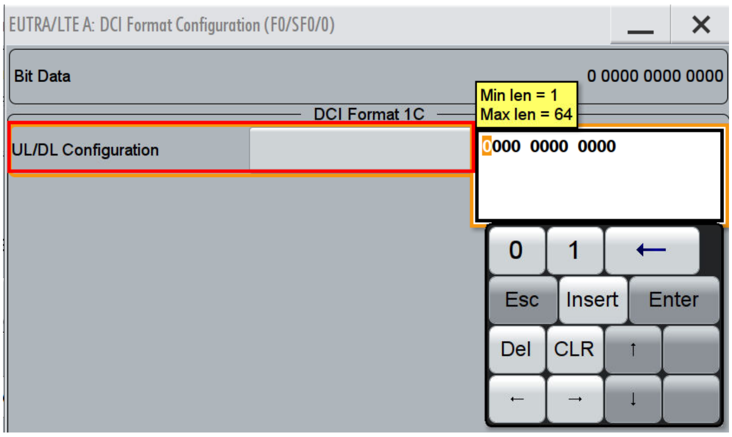


Fig. 3-23: Bit format to signal UL/DL reconfiguration in DCI Format 1C.

3.1.8 Further downlink MIMO enhancements (Rel 12)

The enhanced codebook is supported for four (4) Tx antennas in transmission modes (TM) 8, 9, 10 only.

Set in the **System Configuration** a 4 Tx antenna configuration. Klick in the **DL Frame Configuration** in the PDSCH allocation on **Config. Enhanced Settings**. Enable **Use Alternative Codebooks** (see Fig. 3-24).

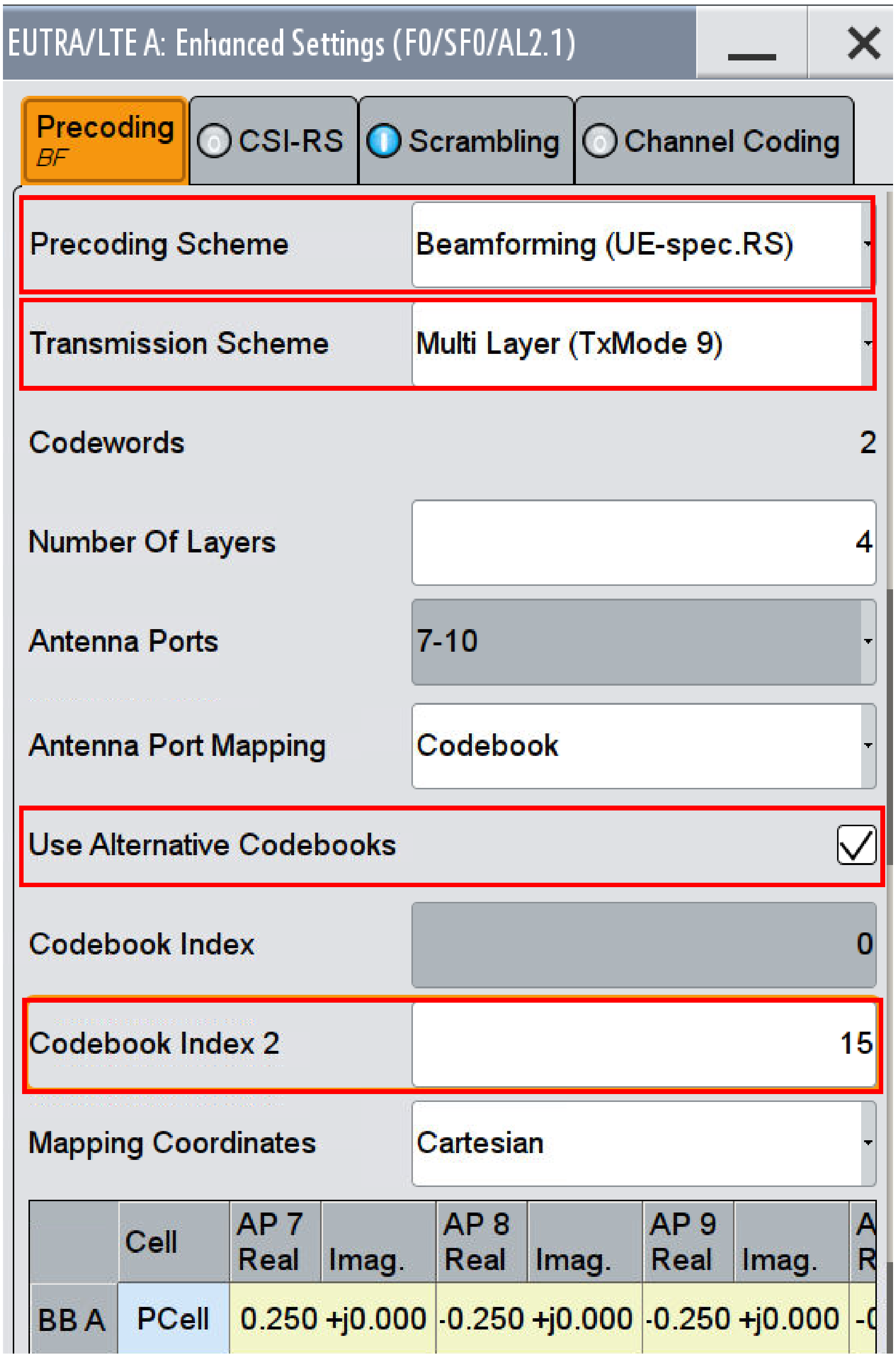


Fig. 3-24 enhanced 4 Tx codebook in the SMW

3.2 Signal Analysis

For measuring LTE(-A) signals, several different spectrum analyzers can be used for the tests described here:

- FSW
- FSV(R)
- FSVA
- FPS

The **E-UTRA/LTE measurements** software option is available for each of the listed analyzers. The following are available:

- FSx-K100 E-UTRA/LTE FDD downlink measurements
- FSx-K101 E-UTRA/LTE FDD uplink measurements
- FSx-K102 E-UTRA/LTE downlink MIMO measurements
- FSx-K104 E-UTRA/LTE TDD downlink measurements
- FSx-K105 E-UTRA/LTE TDD uplink measurements
- FSx-K103 Analysis of EUTRA LTE-Advanced and MIMO Uplink Signals

Test instruments can also be controlled via the external PC software application E-UTRA/LTE and LTE-Advanced Signal Analysis. The options are named FS-K10xPC. With the software in addition to the above mentioned spectrum analyzers, the oscilloscopes of the RTO family can be used.

In principle, there are two different measurement types:

- Spectrum measurements (e.g. ACLR, SEM, ...)
- Demodulation measurements (e.g. EVM, Frequency error, …)

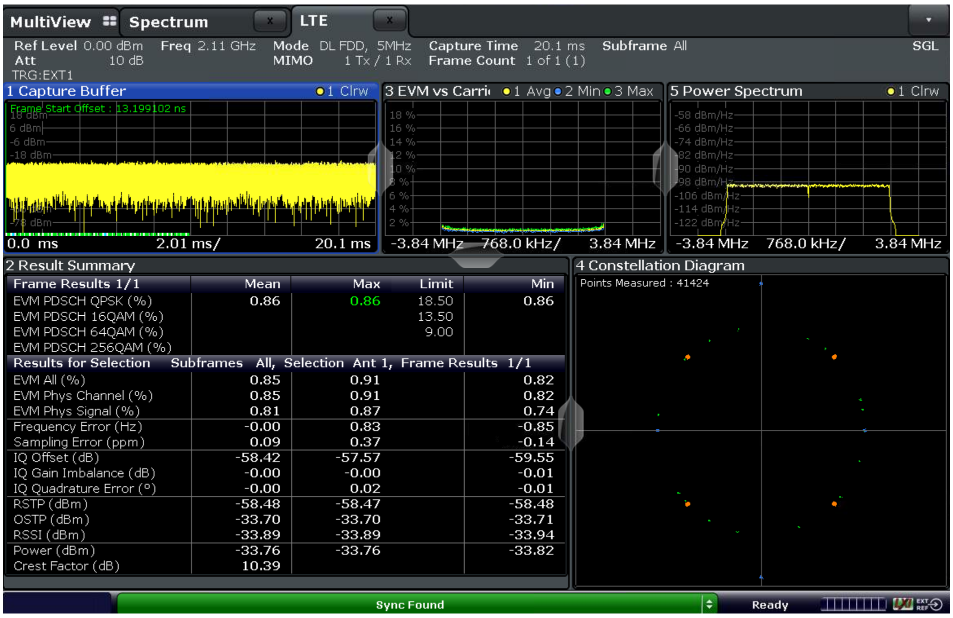


Fig. 3-25: LTE demodulation measurements on a single component carrier.

The FSW offers a Multi Standard Radio Analyzer (MSRA) option as well. With the MSRA mode, detailed investigations on multi-standard base stations can be done and interactions between technologies in different frequency bands can be detected. The MSRA mode is based on the analysis of I/Q data. It captures up to 200 Msamples of I/Q data at one moment in time (sufficient for 1 s over a bandwidth of 160 MHz) which can then be analyzed by different measurement applications (e.g. LTE, WCDMA and GSM). Each signal can be analyzed with the corresponding technology option (LTE and WCDMA in the example). Additionally the MSRA view displays both measurement results on a single screen. The type of measurements for each technology can be configured individually.

3.2.1 Carrier aggregation enhancements (Rel 11)

When a carrier aggregation signal comprising multiple component carriers is transmitted, each carrier needs to be tested on RF level the same way as single carrier LTE , e.g. EVM and frequency error measurements. In addition, measurements like Maximum power or ACLR have to be measured in multi-carrier configurations.

3.2.1.1 Non-contiguous intra-band carrier aggregation

ACLR

The transmitter test requirements for eNodeB for Adjacent Channel Leakage Power ratio (ACLR) applies outside the used RF bandwidth for single or multi-carrier configurations. In multi-carrier scenarios with certain gap sizes (spectrum between two wanted channels) the requirements also apply inside the unused gap. In addition, for multi-carrier special gap sizes the Cumulative Adjacent channel Leakage power ratio (CACLR) applies (see Table 3-1).

<table>
<tr><th colspan="5">ACLR</th></tr>
<tr><th colspan="2">Scenario</th><th colspan="2">ACLR</th><th rowspan="2">CACLR</th></tr>
<tr><th>Carrier</th><th>Gap</th><th>Inside gap</th><th>Outside RF bandwidth</th></tr>
<tr><td>Single Carrier</td><td>-</td><td>-</td><td rowspan="4">☑</td><td>☒</td></tr>
<tr><td rowspan="3">Multi-Carrier / CA</td><td>5 MHz ≤ Gap ≤ 15 MHz</td><td>☒</td><td>☑</td></tr>
<tr><td>15 MHz ≤ Gap < 20 MHz</td><td>☑</td><td>☑</td></tr>
<tr><td>Gap ≥ 20 MHz</td><td>☑</td><td>☒</td></tr>
</table>

Table 3-1: Overview ACLR measurements.

The FSx supports the ACLR for multi-carrier including the measurements inside the gap and the CALCR. Fig. 3-26 shows an example with two carriers.

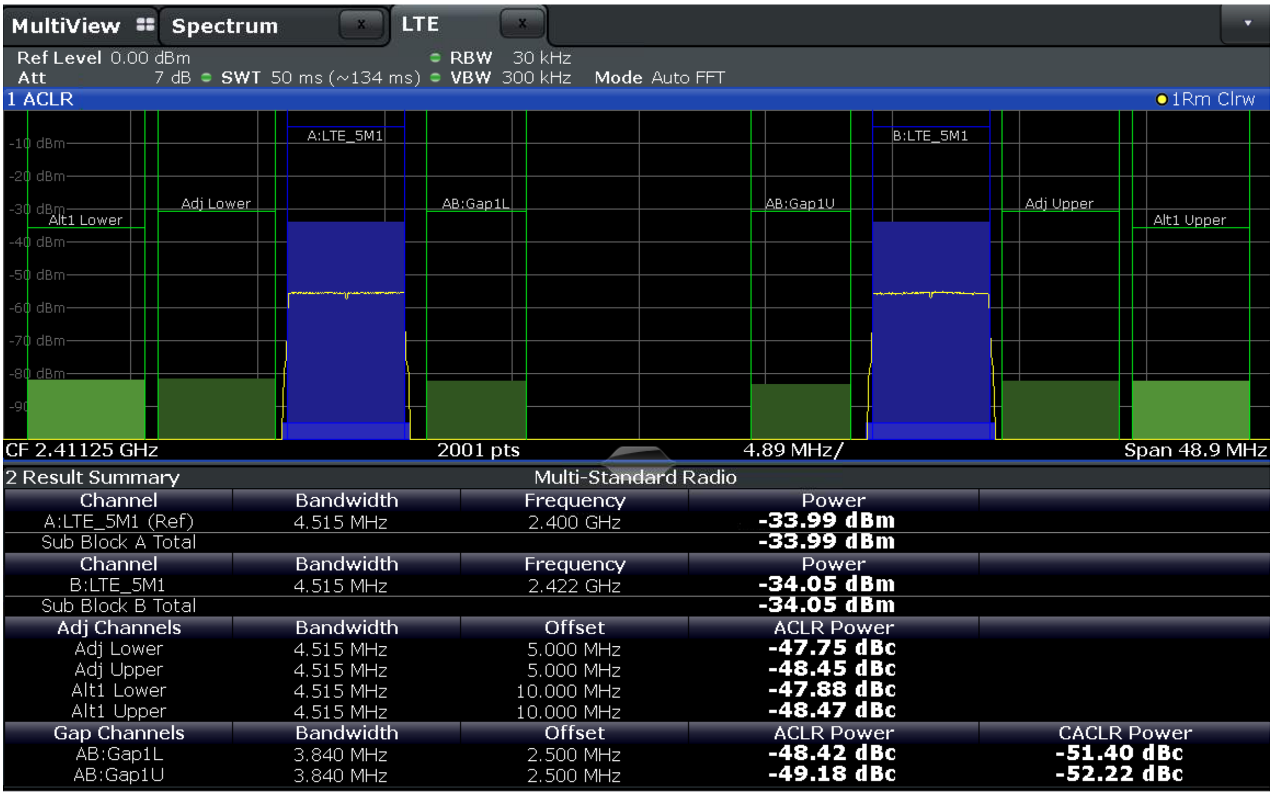


Fig. 3-26: ACLR with a measurement inside the gap. The FSW automatically measure the in-gap channels if necessary.

Timing Alignment Error

Infrastructure suppliers have to perform dedicated tests for carrier aggregation. One of them is the time alignment error measurement, short TAE. As frames of LTE signals at a base station antenna port are not perfectly aligned, they need to fulfill certain timing requirements. Table 3-2 lists the limits for various combinations. These requirements are independent of TX diversity or MIMO applied per component carrier.

Time alignment error limits	
Transmission combination	Limit
MIMO/TX diversity single carrier	90 ns
Intra-band CA with or without MIMO or TX diversity	155 ns
Intra-band non-contiguous CA with or without MIMO or TX diversity	285 ns
Inter-band CA with or without MIMO or TX diversity	285 ns

Table 3-2: Time alignment error limits; yellow marked the non-contiguous requirement [1].

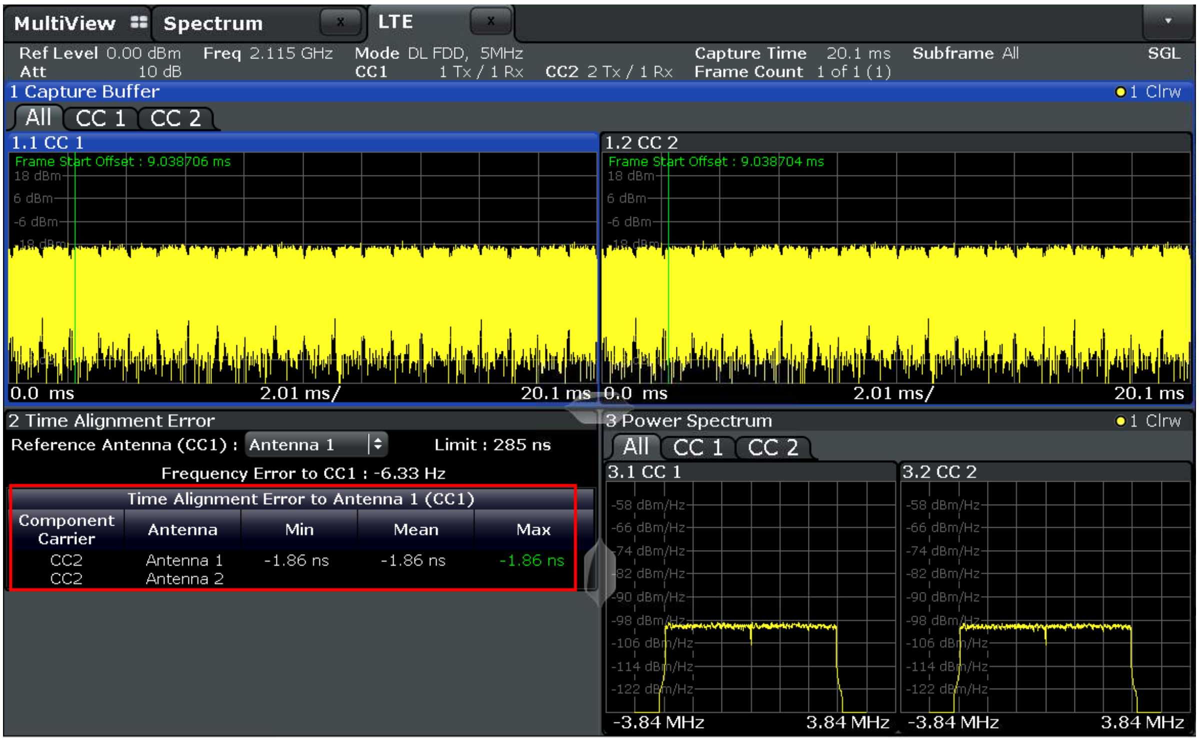


Fig. 3-27: Example for a time alignment measurement with CA

3.2.2 Small Cell Enhancements (Rel 12)

3.2.2.1 Higher Order Modulation - 256QAM

Small cells may support 256QAM modulation. As part of the eNodeB transmitter tests the FSx supports 256QAM EVM measurement as well.

2 Result Summary

Frame Results 1/1	Mean	Max	Limit	Min
EVM PDSCH QPSK (%)			18.50	
EVM PDSCH 16QAM (%)			13.50	
EVM PDSCH 64QAM (%)			9.00	
EVM PDSCH 256QAM (%)	0.56	0.56		0.56

Fig. 3-28: FSW Result summary: The EVM measurement supports 256QAM modulation.

3.3 CMW500

The CMW can be used as a protocol tester (message analysis) as well as a radio communication tester (call box, RF test).

In addition to LTE-A, the CMW offers other radio communication standards, including WCDMA, GSM, CDMA2000®, 1xEV-DO and so on. This makes it possible to test InterRAT scenarios, such as LTE handover to GSM or WCDMA.

Equipped with powerful hardware and various interfaces to wireless devices, the CMW can be used throughout all phases of LTE-A device development – from the initial module test up to the integration of software and chipset, as well as for conformance and performance tests of the protocol stack of 3GPP standard-compliant wireless devices.

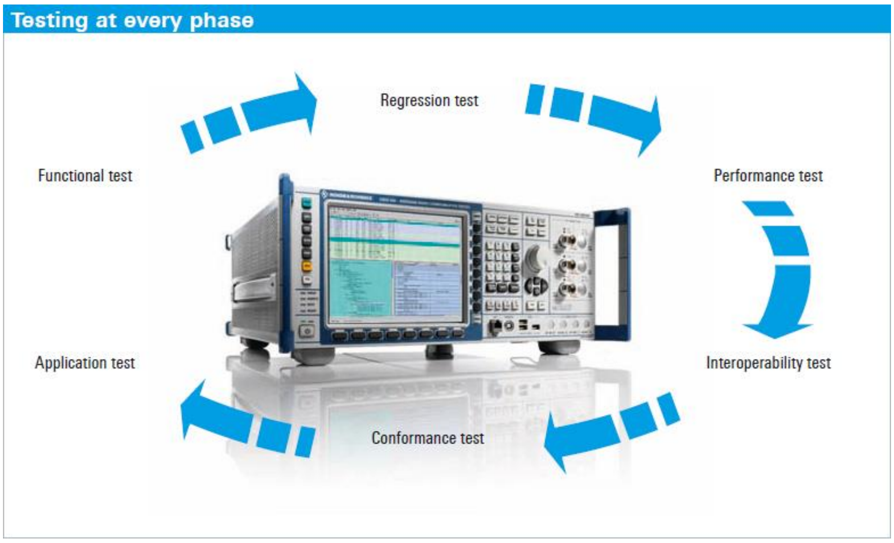


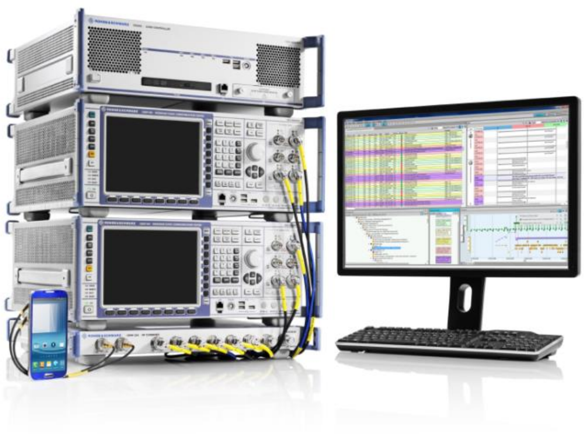
Fig. 3-29: Consistent hardware and software concept for all device development phases.

MIMO and Carrier Aggregation

The CMW (protocol tester and callbox) supports different transmission and MIMO modes like 8x2 MIMO and carrier aggregation up to five (5) component carriers (CC) and MIMO in parallel like CA with 4x4 MIMO. The CMW supports all possible frequency allocations in CA (intra-band contiguous, intra-band non- contiguous and inter-band). All CC's can be set up independently of each other.

Carrier Aggregation with CMWflexx

The CMWflexx (protocol tester and callbox) provides more than 2 CC's with MIMO each, therefore more than one CMW is used. The CMW Controller (CMWC) allows easy manual and remote control, it acts like one CMW with extended RF hardware.



3.3.1 CMW protocol tester

The device under test (a chip set or terminal) is connected to a network emulator, which simulates all required network functions and protocols. However, errors may occur in all layers (physical layer, Layer 2/3, application layer) and throughout the whole development cycle (R&D, conformance, production). Thus any test instrument needs to offer manifold analysis capabilities. Rohde & Schwarz offers the CMW500 wideband radio communication tester, which provides all necessary functions within a single test instrument.

Different bandwidths per component carrier, up to 20 MHz each, are supported. CMW500 supports all variances of carrier aggregation in one single instrument: intra-band (contiguous, non-contiguous) and inter-band. Already today the instrument supports all 3GPP frequency bands that are utilized for LTE.

First of all the tester and the DUT have to run throughout a successful LTE-A channel setup. I.e. the signaling procedure from starting with a LTE Rel8 setup and adding secondary component carriers (SCC's) has to be verified on all relevant protocol layers (PHY, MAC and RRC). This is typically be done using a CMW500 in protocol test configuration. Example scenarios are available for lower layer API (LLAPI) and medium layer API (MLAPI) as well as the graphical user interface CMWcards. Fig. 3-30 shows example physical layer scenarios using different configurations for primary and secondary cells as well as different transmission modes.

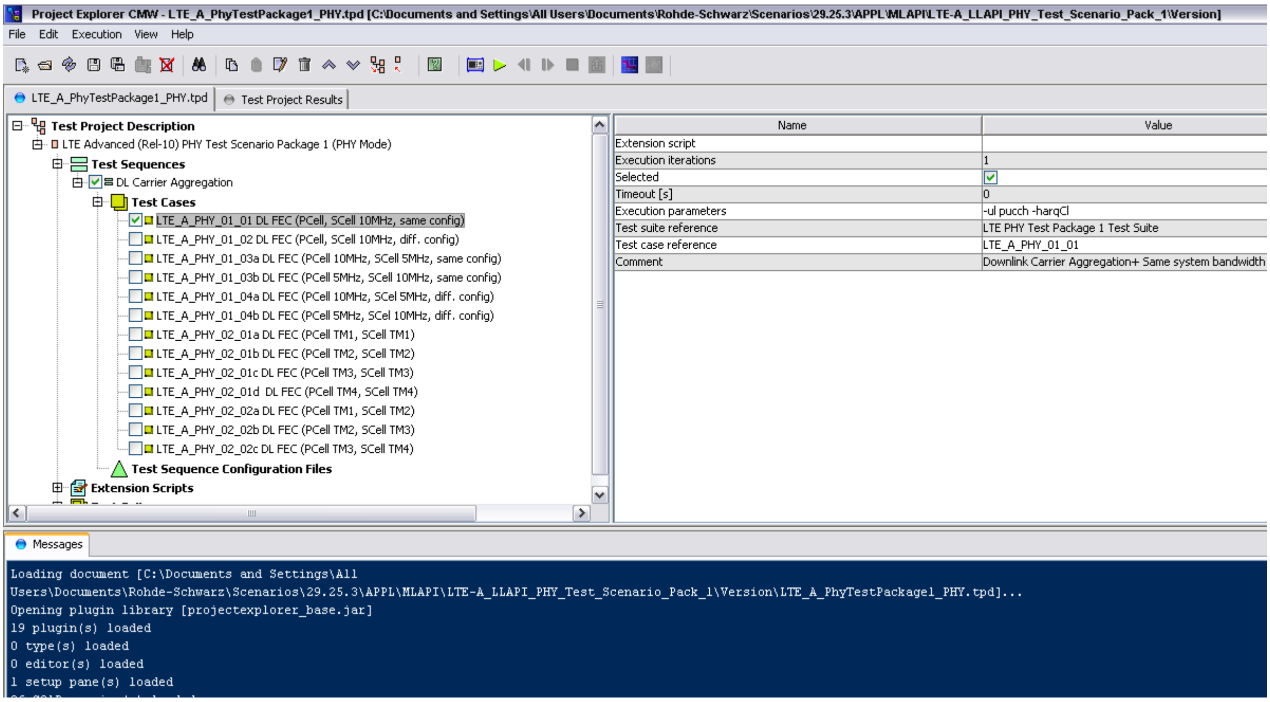


Fig. 3-30: Physical layer example scenario for carrier aggregation.

MLAPI

In order to verify the signaling communication on layer 2 and 3, MLAPI scenarios are available. These can be used as provided in various test scenario packages. Additionally existing scenarios may be modified according to the individual testing needs.

Following MLAPI scenarios packages with Release 11/12 features are available:

Scenario Packages Rel 11/12		
Name	**Description**	**Remark**
CMW-KF515	LTE Rel10/11 MLAPI Scenarios **eICIC** and **FeICIC**	94 scenarios
CMW-KF518	LTE Rel. 10/11 PHY Scenarios 3CA DL/CoMP/TM10	46 scenarios
CMW-KF519	LTE Rel. 10/11 MLAPI Scenarios 3CA DL/CoMP/TM10	74 scenarios
CMW-KF650	LTE Rel 12 MLAPI Scenario **PACK**, **LTE – WLAN Offloading**	
CMW-KU500	LTE Rel.12 TDD/FDD coexistance, 256QAM DL, Cat.0 and e-PDCCH MLAPI Scenarios	63 scenarios
CMW-KU503	LTE Rel. 9-12 MTC MLAPI Scenario **PACK**, MTC-, IoT-, M2M-Test Scenarios to test CAT0, EAB, Extended Wait Time	35 scenarios
CMW-KU506	LTE R12 MLAPI SCN Pack **D2D DISCOVERY**	24 scenarios
CMW-KU507	LTE R12 MLAPI **D2D** direct communication	13 scenarios
CMW-KU509	LTE R12 MLAPI **Dual Connectivity**	31 scenarios

Table 3-3: MLAPI Scenario Packages Rel 11/12.

In addition, MLAPI scenarios also allow user extendible KPI collection (BLER and SQI).

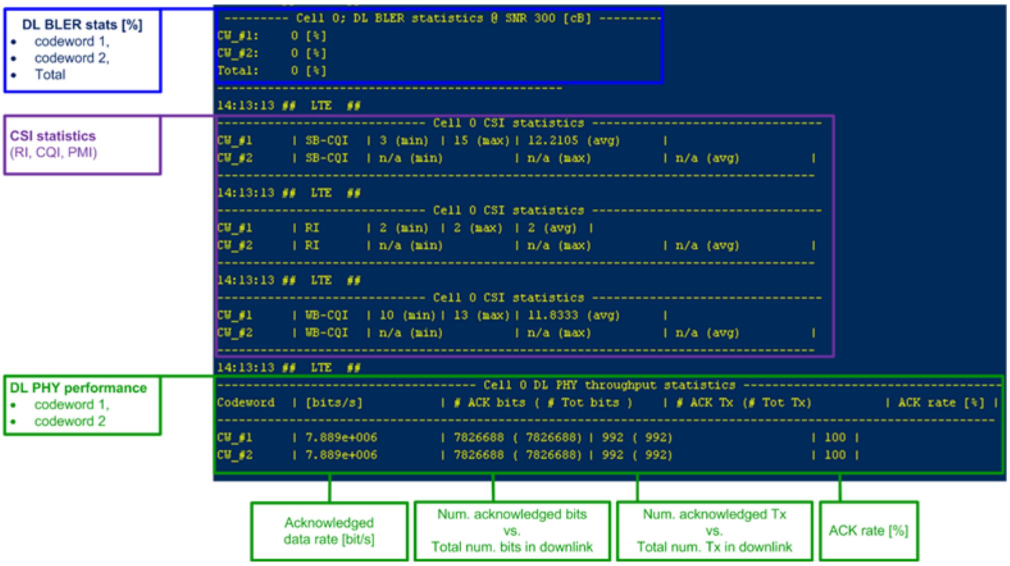


Fig. 3-31: MLAPI KPI collection.

CMWcards

CMWcards is a graphical test case creation tool for signaling and application tests on CMW500 mobile radio tester.

Create wireless signaling and application tests on the CMW500 wideband radio communication tester just by setting up a hand of cards – no programming required.

Thanks to the CMW500 tester's unrivaled multitechnology capability, CMW-KT022 CMWcards can be utilized to rapidly reproduce signaling scenarios for various wireless communications standards just like LTE, WCDMA, GSM as well as WLAN.

CMWcards includes test coverage for LTE-advanced up to Release 12 features such as LTE-WLAN offloading or LTE-FDD-TDD joint operation. Fig. 3-32 shows an example in CMWcards with LTE-WLAN Offloading.

Fig. 3-32: CMWcards Example for Release 12: LTE-WLAN Offloading.

CMWmars

Efficiently analyze recorded message logfiles. The convenient, intuitive CMWmars message analyzer user interface combined with various tools and views helps users quickly narrow down the root cause of signaling protocol and lower layer problems. The multifunctional logfile analyzer provides access to all information elements of all protocol layers for LTE, WCDMA, GSM, TD-SCDMA, CDMA2000® and WLAN, including the IP layer. CMWmars presents the logfile in various synchronized views that visualize the data from different perspectives, helping users to postprocess complex message logs in a very intuitive and easy way.

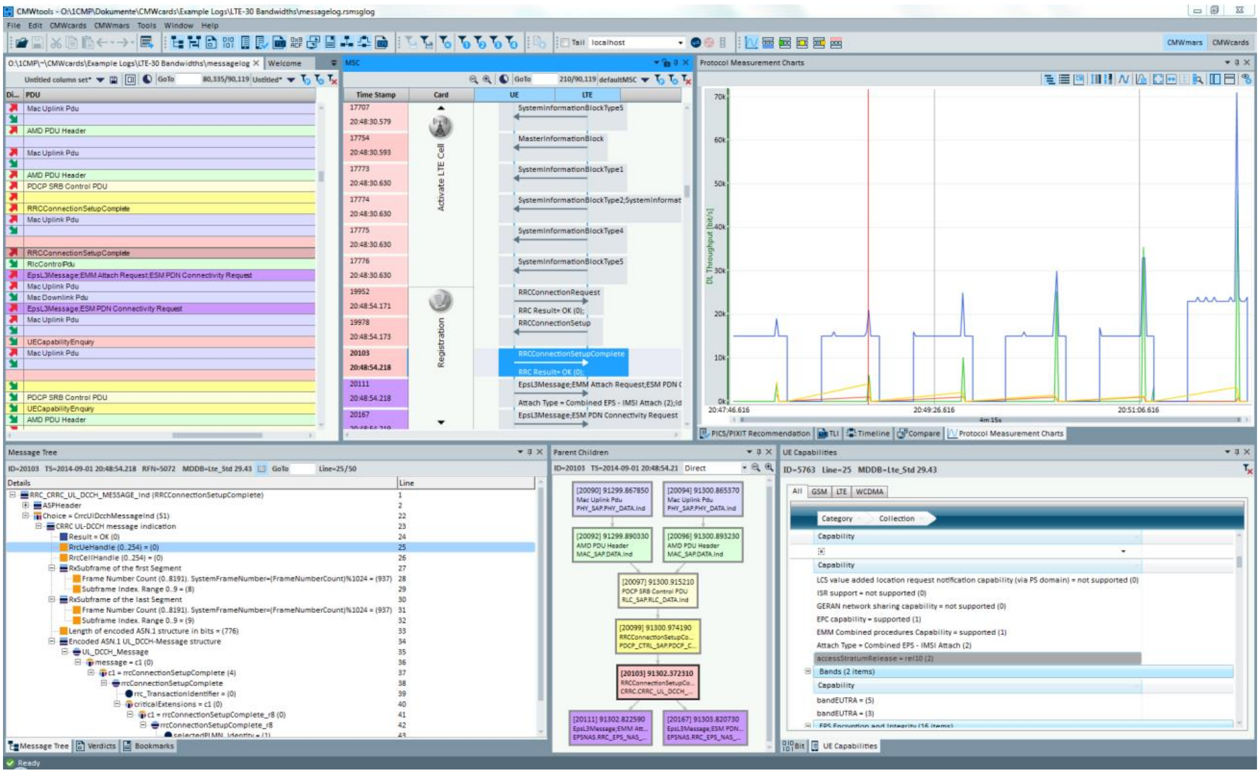


Fig. 3-33: Overview CMWmars.

Uplink – TX Measurements

Furthermore there is a need to verify the uplink signal transmitted by the device. All relevant measurements are available with the CMW500. The RF uplink measurements can be done in parallel to a MLAPI test scenario or in the RF tester environment. These measurements do not differ from LTE Release 8 uplink TX measurements if only one uplink carrier is used. The CMW also supports uplink carrier aggregation measurements and 64QAM in the uplink. For a short Tx measurement overview see next section.

3.3.2 CMW RF tester ("call box")

When used as an RF tester, the CMW provides a generator for the LTE downlink and an analyzer for the LTE uplink signal. The CMW can also emulate network operation (“signaling”) under realistic conditions for RF tests. The CMW supports carrier aggregation up to five (5) component carriers (CC) and MIMO in parallel like CA with 4x4 MIMO (CMWflexx).

Transmitter tests (TX)

Measurements on the TX side of the DUT are made possible with the LTE Multi Evaluation option (see Fig. 3-34).

The overview screen provides all measured results and scalar values for the essential measurements: UE power, error vector magnitude (EVM) root mean square (RMS) power, RB allocation table and spectrum measurements. Because measurements results are based on the same set of data, the individual results relate to each other, thus facilitating troubleshooting and debugging.

Fig. 3-34: Tx measurements of a DUT uplink signal using CMW500.

The overview display in multi-evaluation mode can be adapted to the individual testing needs. For example, it may be necessary to closely monitor only two measurement results, or just one measurement result with a comparison of maximum and average values. The overview display can be configured to meet individual needs.

These measurements do not differ from LTE Release 8 uplink TX measurements if only one uplink carrier is used. If two uplink carriers are used, the modulation measurements, e.g. EVM, can be done on each CC. Measurements like inband emission, power monitor and RB allocation table can be done at the same time. Spectrum measurements (Spectrum ACLR and Spectrum emission mask) are measured for the aggregated bandwidth for CC's together for intra-band contiguous uplink CA. 64QAM modulation in the uplink has been introduced in Rel. 8 as optional for UE's. The CMW supports the signaling and the measurement in the Tx Meas. Multi-Evaluation (see Fig. 3-35).

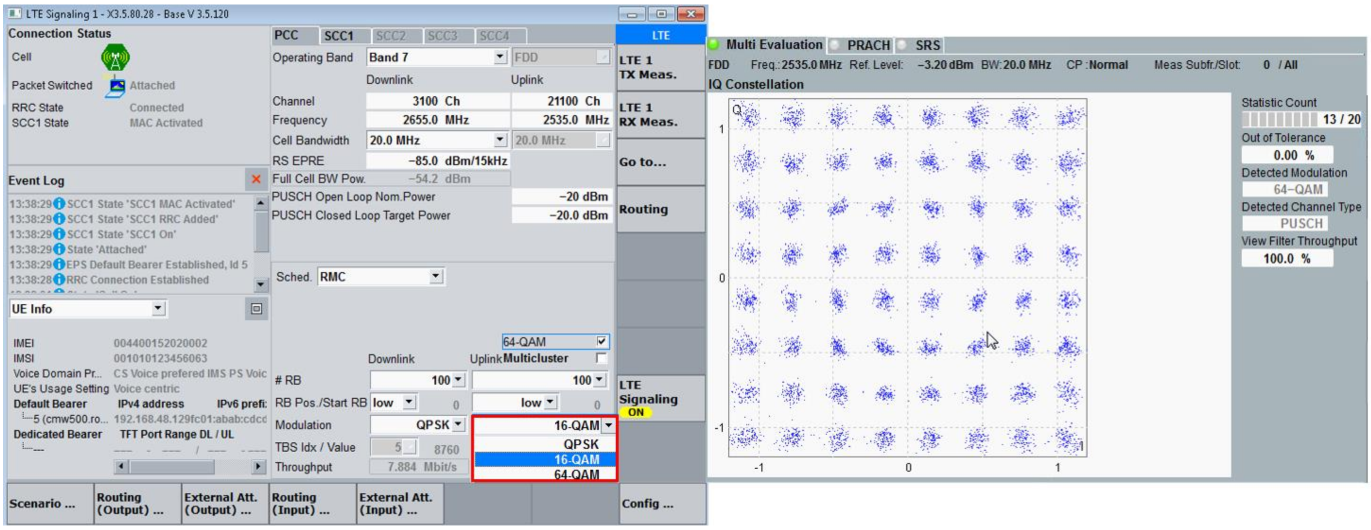


Fig. 3-35: CMW Uplink 64QAM

Signaling and receiver tests (RX)

The CMW can optionally provide signaling. The "LTE signaling" firmware application (option KS5xx) allows users to emulate an E-UTRA cell and to communicate with the UE under test. The UE can synchronize to the DL signal and register

This means that RX tests, e.g. ACK/NACK measurements (BLER, throughput), can be performed in test mode on the DUT.

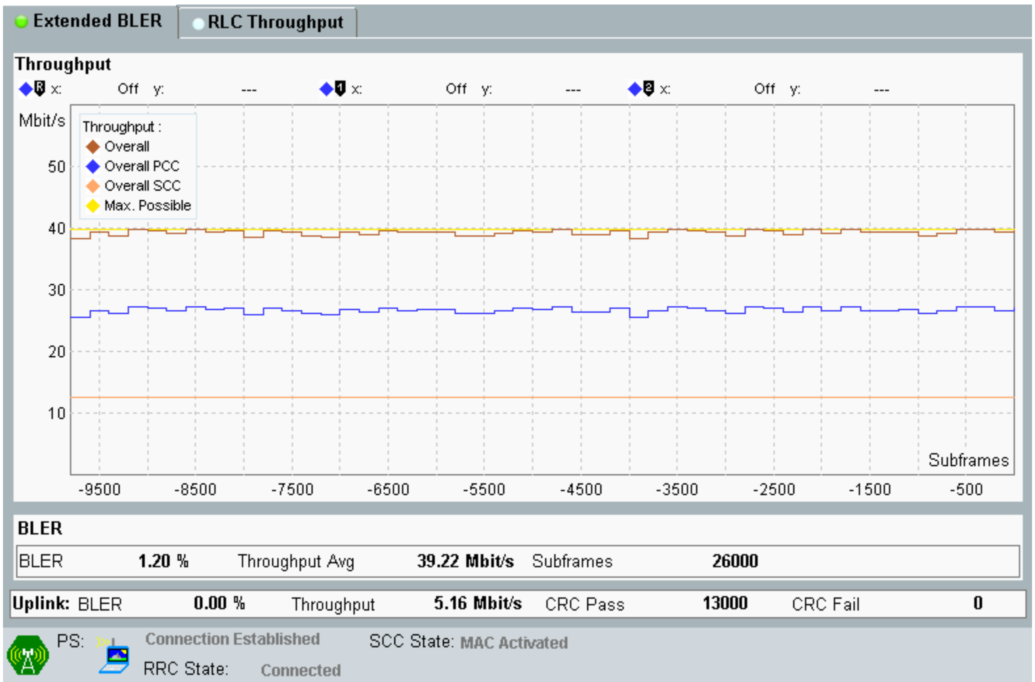


Fig. 3-36: LTE RX measurement for Carrier Aggregation. As an example, the throughput for two CC's and the overall throughput are displayed.

3.3.2.1 UE Categories (Rel 12)

LTE defines different UE categories 0…15. The CMW supports following UE categories:

- Downlink
  - 0…4
  - 6,7
  - 9…13
  - 15
- Uplink
  - 0…4
  - 6,7
  - 9…12

The UE typically reports its capabilities via signaling. UE category 0 (also called LTE MTC) requires option CMW-KS590.

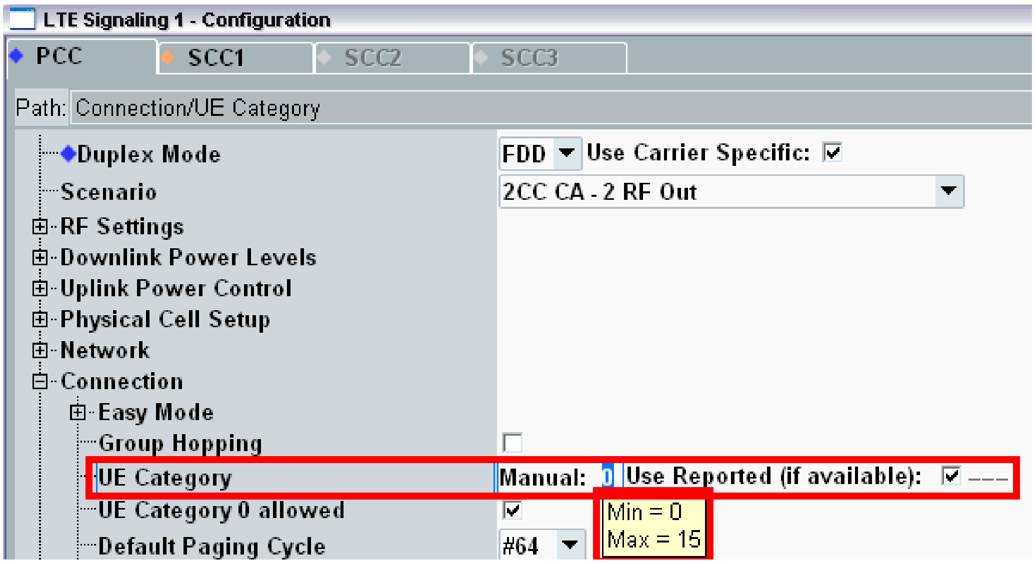


Fig. 3-37: UE categories 0…15 in the CMW.

3.3.2.2 Carrier aggregation enhancements (Rel 11)

Non-contiguous intra-band carrier aggregation

The CMW is capable of generating up to four CC's (PCC and SCC1…SCC3). In order to test non-contiguous intra-band configurations, the same band is selected for all CC's and the desired channels are set, e.g. Channel and/or Frequency. Fig. 3-38 shows an example with two CC's.

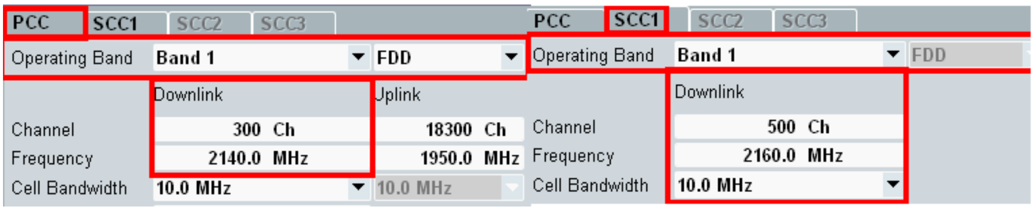


Fig. 3-38: Non-contiguous intra band CA. This example shows two carriers in band 1.

TDD: Additional Special Subframe Configuration and different UL/DL configurations

The CMW supports both the new special subframes and the different UL/DL settings in TDD. This is accomplished in the *TDD* section by selecting **Use Carrier Specific** for each CC. This makes it possible to set the **Uplink /Downlink Configuration** individually for each carrier. The setting for **Special Subframe** (7 and 9 are new) is also in the TDD section. Fig. 3-39 shows an example with two CC's.

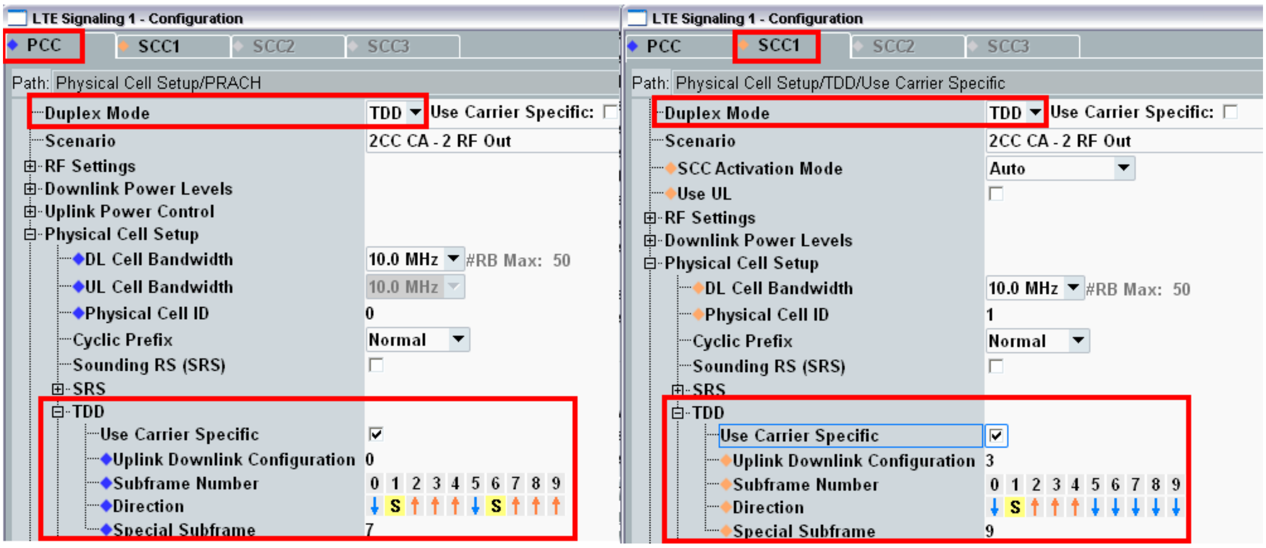


Fig. 3-39: Different UL/DL configuration und special subframe. In the example, 2 CC are configured to 0 and 3 and special subframes to 7 and 9.

3.3.2.3 Small cell enhancements (Rel 12)

Higher Order Modulation (256QAM)

As one of the main parameters, the modulation in the downlink can be already configured in the main LTE Signaling screen. 256QAM requires the Release 12 options CMW-KS504 (FDD) and – 554 (TDD).

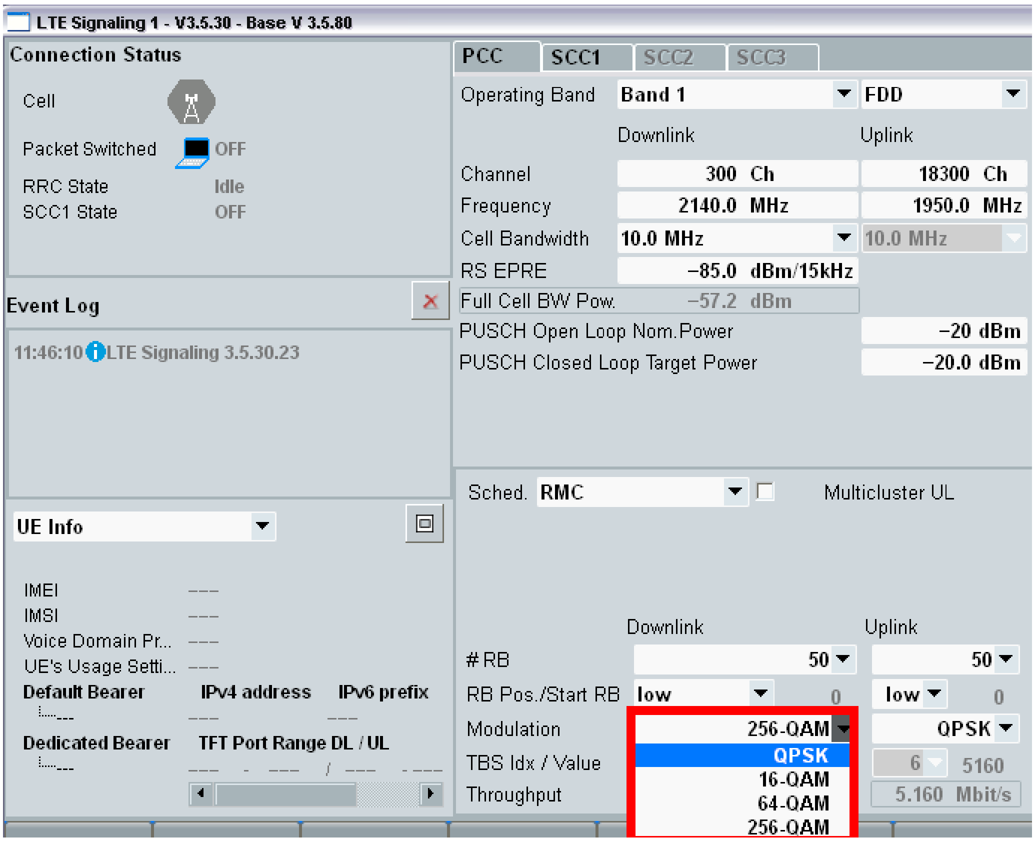


Fig. 3-40: 256QAM for small cells in the downlink.

3.3.2.4 WLAN/3GPP Radio Interworking (Rel 12)

The CMW supports WLAN offloading tests for LTE. This requires the following:

- 1 pc LTE Signaling option (advanced CMW-KS510)
- 1 pc WLAN Signaling option (advanced KS660)
- 1 pc DAU

In the DAU, the CMW-KA065 WLAN offloading untrusted option must be available. It implements the following features:

- ePDG Server
- IKE Signaling
- Multiple PDN offload support

The following important settings are made in the DAU:

- The IMS server must be started
- In the DNS server, the correct addresses must be set. These differ depending on provider and must match the settings on the SIM card.
- Authentication parameters and certificates

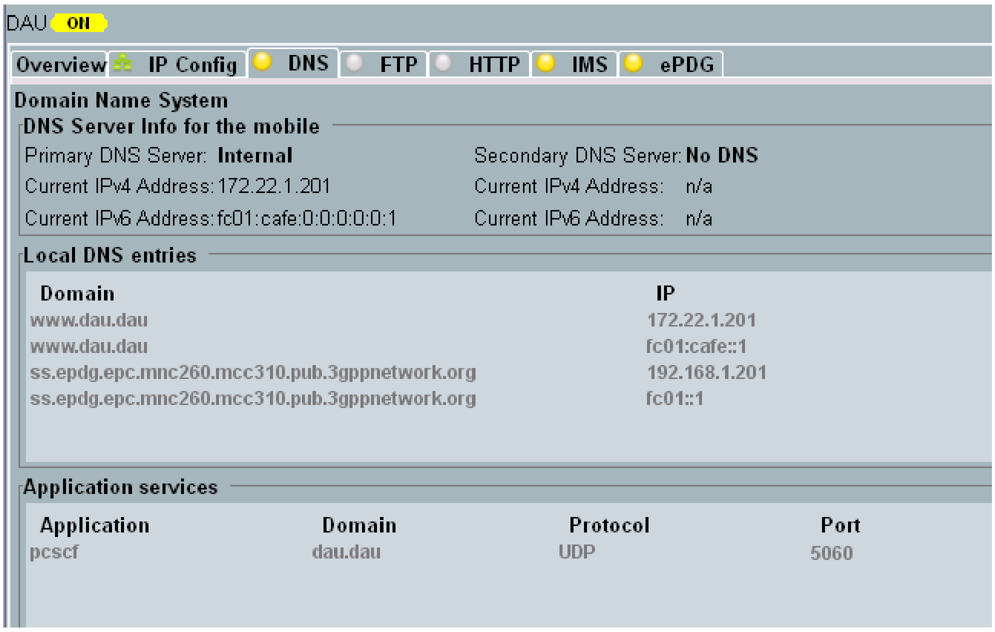


Fig. 3-41: DNS settings in the DAU. These settings differ depending on SIM card provider.

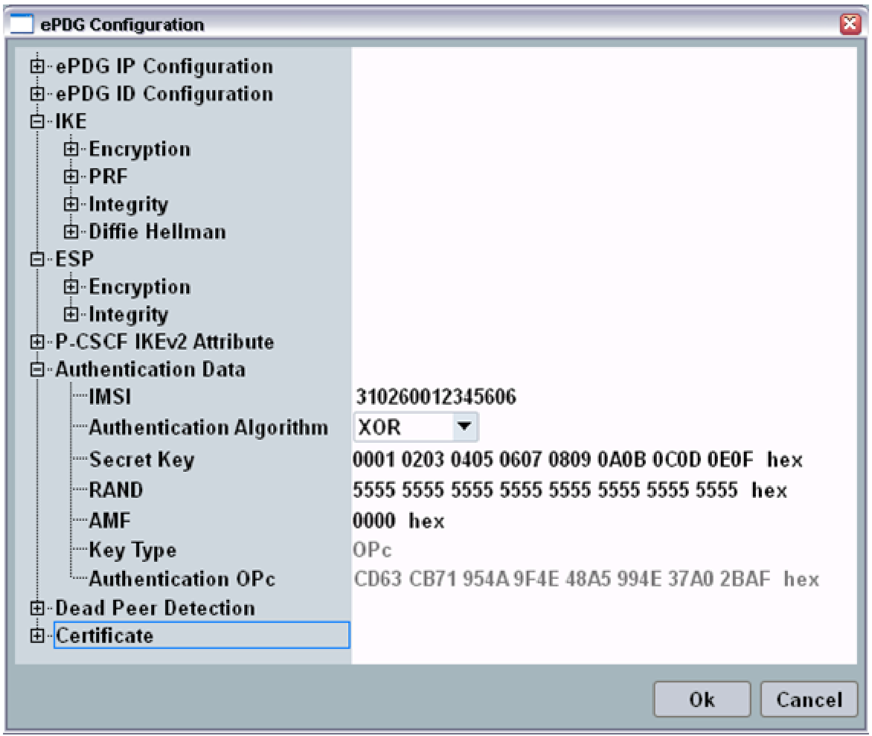


Fig. 3-42: eDPG settings.

During testing, the UE is registered both in LTE and in WLAN. As a result, the downlink level of the WLAN-APS should initially be very low (e.g. –100 dBm). The UE sets ups the connection in LTE. If the WLAN level is now set high (e.g. –16 dBm), the data should be transmitted via WLAN (see Fig. 3-43 and Fig. 3-44).

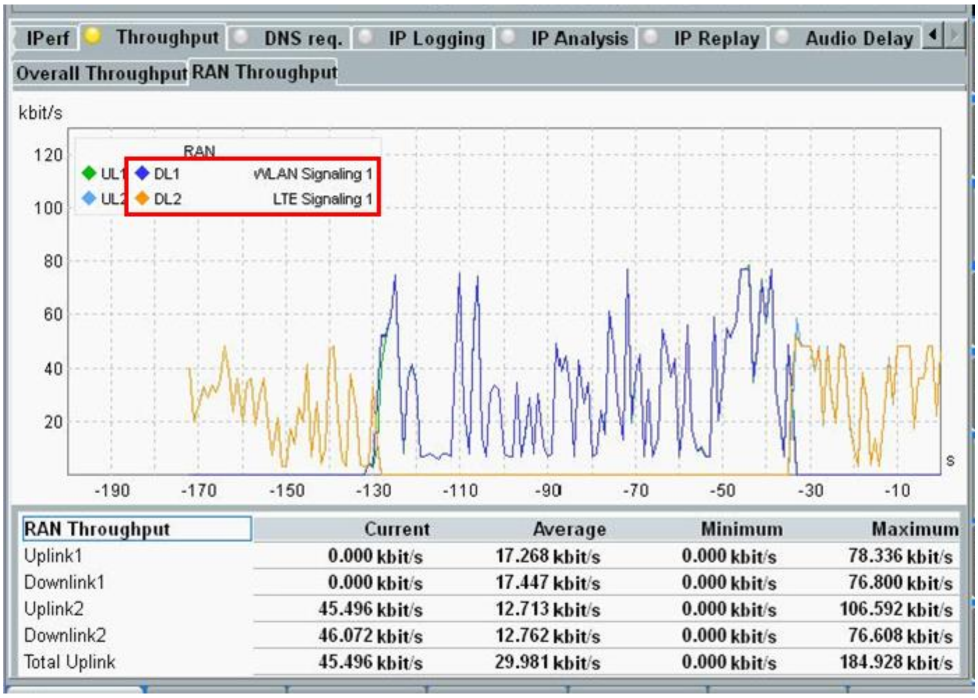


Fig. 3-43: Throughput measurement for LTE WLAN offloading. Orange shows the throughput in LTE and blue in WLAN. The points where the offloading switches are easily recognizable.

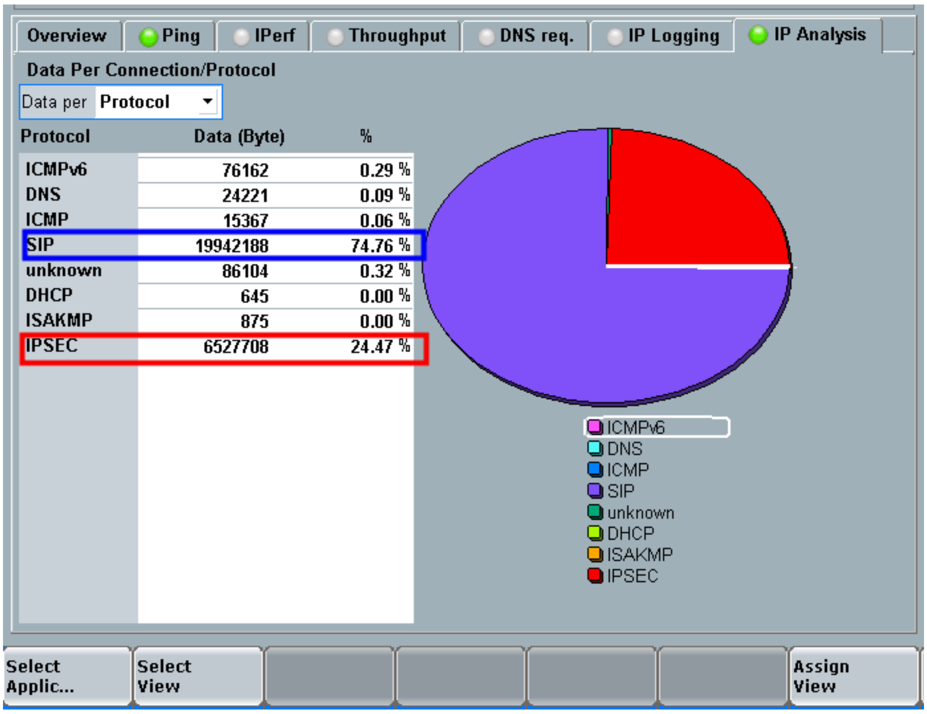


Fig. 3-44: IP analysis in LTE-WLAN offloading. WLAN traffic is via the IPSEC tunnel (red).

3.3.2.5 TDD-FDD joint operation in different bands (Rel 12)

The CMW supports different duplex modes in the individual CC's. To do this, under *Duplex Mode*, enable **Use Carrier Specific**. This makes it possible to define different settings for the individual CC's. TDD-FDD joint operation requires Release 10 options CMW-KS502 (FDD) and – 552 (TDD). Fig. 3-45 shows an example with two CC's; PCC uses FDD; SCC1 uses TDD.

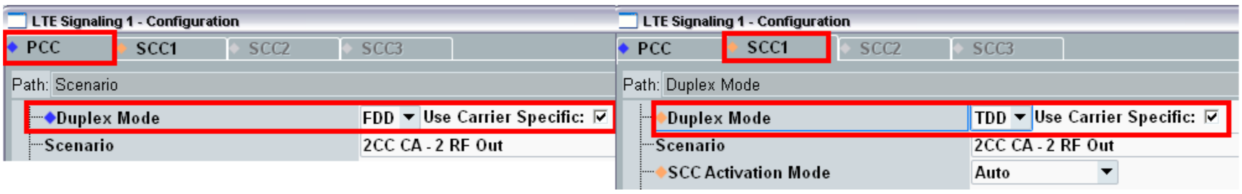


Fig. 3-45: Joint operation. In the example, CC1 uses FDD and CC2 uses TDD.

3.3.3 Data Application Unit (DAU) for CMW

The "Data Application Unit" (option B450x) makes it possible to test data transfer via TCP/IP or UDP/IP. It allows users to run Internet Protocol (IP) services on the CMW, such as file transfer and Web browsing. The DAU provides a common and consistent data testing solution on the CMW for all supported radio access technologies.

The DAU is required when testing End-to-End (E2E) IP data transfer as well as when using the instrument for protocol testing (U-plane tests). Together with the DAU, IP-based measurement (option KM050) applications allow users to test and measure the properties of the IP connection, such as network latency or performance. The measurements support Internet protocols IPv4 (option KA100) and IPv6 (option KA150 on top of KA100).

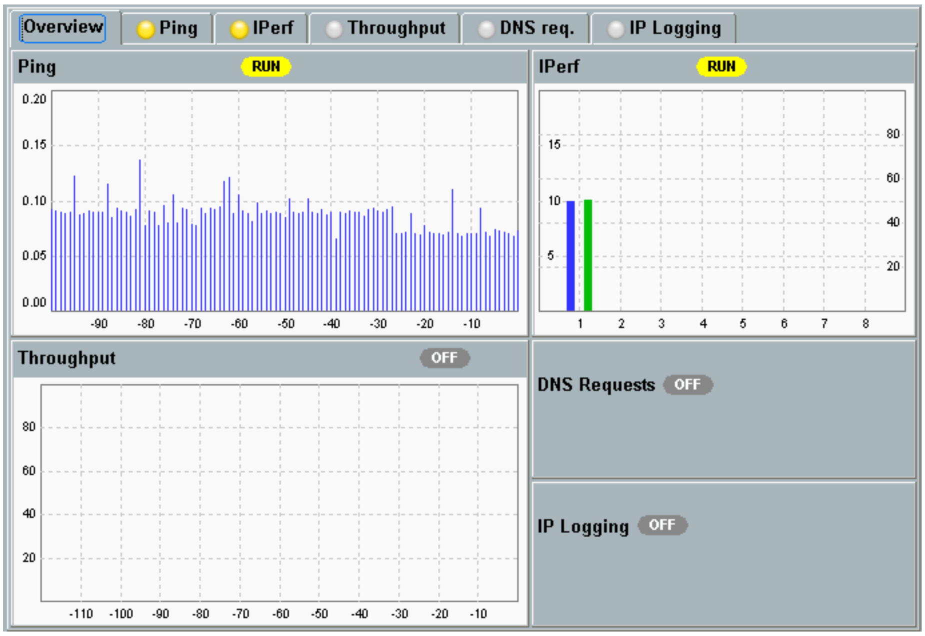


Fig. 3-46: Overview of the tests in the data application unit. PING, IPerf and Throughput at a glance.

3.3.4 Channel Simulation - fading

In order to simulate a channel for UE receiver tests, the CMW provides internal fading with predefined profiles as an option:

- Delay profiles (3GPP TS 36.101, Annex B.2.)
  - For 2x2 MIMO all with low, mid and high correlation:
    - EPA 5 Hz
    - EVA 5 Hz
    - EVA 70 Hz
    - ETU 30 Hz
    - ETU 70 Hz
    - ETU 300 Hz

- High speed train profile (HST) (3GPP TS 36.101, Annex B.3.)
- Multi-path profile for CQI tests (3GPP TS 36.521-1, section 9.3.)

Various options permit a variety of MIMO configurations; see the Ordering Information (4.3).

In addition, the CMW can be connected to the SMW via optional digital IQ interfaces. The SMW provides the MIMO matrix channels (e.g. 4x2), adds AWGN and fades all matrix channels. The MIMO cross components can be faded independently of one another (e.g. for CA with 2x2 MIMO). The SMW has predefined fading profiles for LTE in accordance to specification. In addition the fading parameters can be changed separately.

3.4 RF conformance Tests System TS8980

UEs have to pass various test phases during their development. In the early phase of R&D, the different components of the UE like baseband and RF part are tested independently from each other.

During this time radio communication testers, signal generators (SG) and signal analyzers (SA) are used typically in non-signaling test environments in order to investigate RF receiver and transmitter characteristics of the UE. Pure baseband tests can be done by using simulation and verification using the IQ-interface of the UE which is connected to the IQ-interface of channel emulators, SA and SG. As soon as a logical and physical call setup can be established, further tests on UE prototypes can be performed with the help of a signaling unit (SU) fitted to a radio communication tester like CMW.

Chipset and UE manufacturers will apply differing test specifications. There are internally defined specs which are based on knowledge and prior experience. This is a main part of the test area. Other tests are derived from i.e. the 3GPP test specifications like [TS 36.521]. As maturity of a UE design increases, more testing conditions are added. “House” test specifications as well as [TS 36.521] contain LTE test scenarios with fading and interference conditions. Additionally, extreme test conditions with varying environmental factors like supply voltage, humidity and temperature are defined for a UE.

Automated test systems like TS8980 with onboard components of SU, SG and SA are able to provide the widest range of such testing conditions. In a pre-conformance context, the user friendly flexibility to change testing parameters like effects of fading and interference as well as tools to find the real design limits in an automated and hence repeatable way are essential. After all, no flaw should pass unnoticed before entering the final stage to market: UE RF certification.

The type approval or certification of UEs according to GCF, PTCRB or a given set of Network Operator test plans is the next phase. GCF and PTCRB requirements typically consist of a subset of otherwise unchanged tests from the 3GPP test specifications.

Network Operator RF test plans usually consist of two types of tests

- those based on 3GPP with extensions and/or tighter limits, based on an operator’s own experience
- completely new tests as defined
  - to protect other services (like Digital TV, ATC Radar, Geolocation services)
  - ensure UE performance is not unduly compromised in the vicinity of such other services.

Reproducible and precise measurements are crucial for type approval test systems like the TS8980FTA. Apart from basic accuracy, built-in functions for user-guidance on and/or full automation of calibration is a pre-requisite for a test system to function as an arbiter of UE performance.

Fig. 3-47: The test system TS8980FTA-2.

The TS8980 family of test systems offers the most complete coverage in the industry for applications in GSM, WCDMA and LTE test. TS8980 is used by all leading test houses, first-rate chipset and UE manufacturers, and major network operators.

UTRA and E-UTRA Conformance test in line with GCF and PTCRB as used by labs accredited for certification of mobile devices are complemented by a very broad range of acceptance test packages as defined by many of the leading Network Operators.

The highly user friendly CONTEST graphical user interface gives control over test case execution, automation of DUT, Climatic chamber, DC supply and other external devices. The GUI also comes with a brace of functions for DUT management and standard-compliant result reporting as well as internal and external data base control for result handling, documentation and storage. It allows to perform the CA test cases according to the 3GPP test specification or to set the bandwidths and frequencies individually.

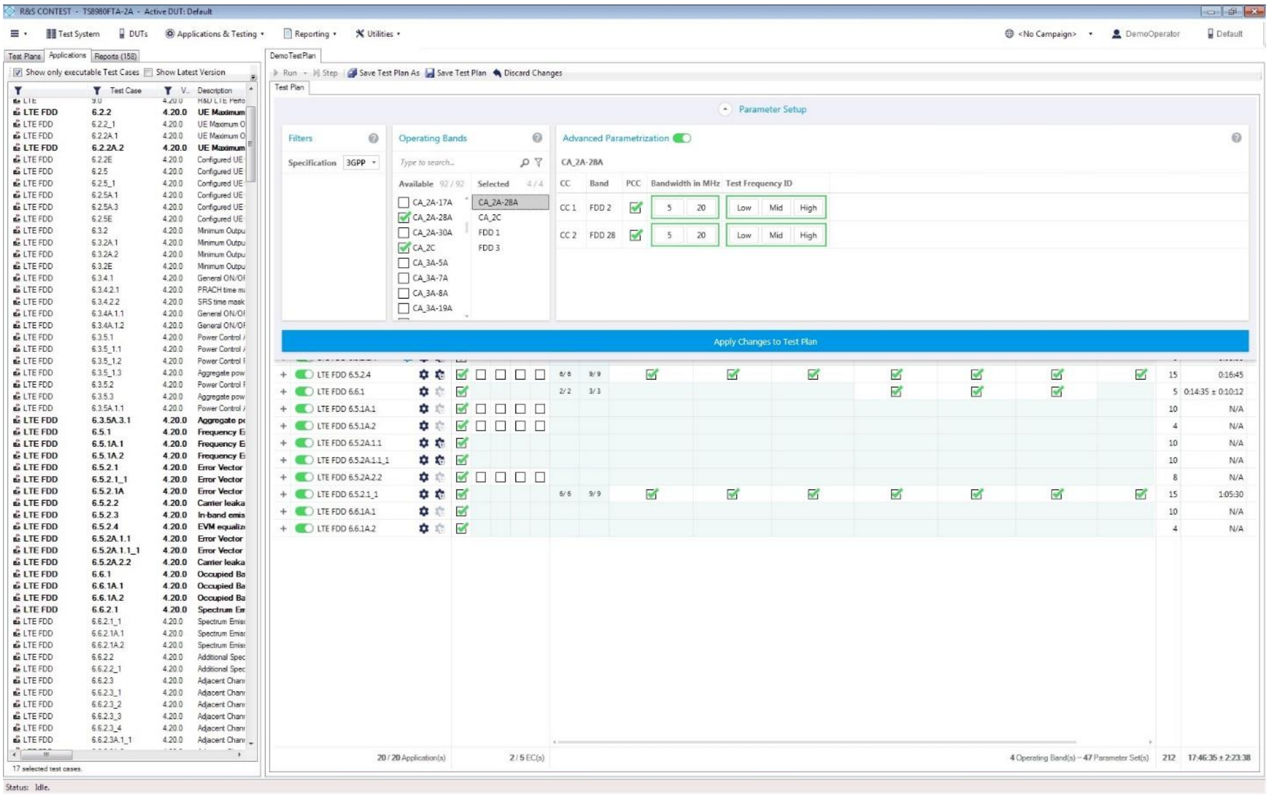


Fig. 3-48: Contest testplan editor

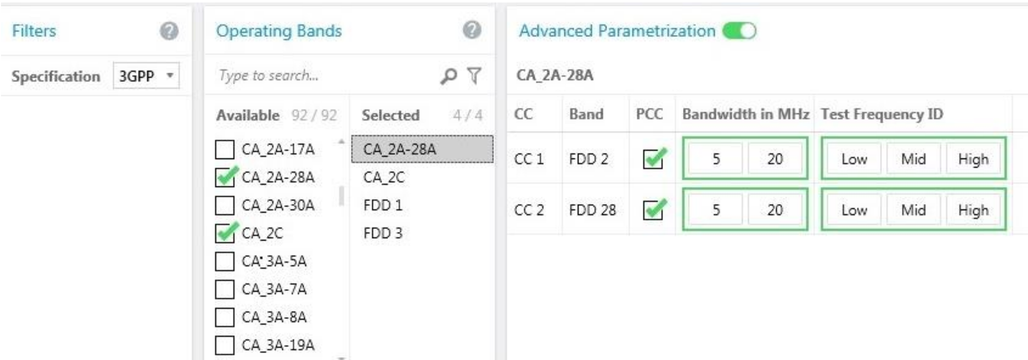


Fig. 3-49: CA band combinations in Contest

Margin Search routines and Performance Evaluation modes allow to evaluate the headroom a DUT has vs certification-level PASS criteria or vs user-specified minimum values.

RF test for LTE and WCDMA may be combined with RRM conformance for LTE / WCDMA.

Test Case Packages

Available validated test case packages for LTE according to Releases 11 and 12 are

- Release 11
  - Further enhanced non CA-based ICIC (feICIC)
  - Improved Minimum Performance Interference Rejection
  - Coordinated Multi-Point Operation (CoMP)
  - E-PDCCH
  - Non-contiguous intra-band carrier aggregation

- Release 12
  - Small cell enhancements (up to 3 CC)
  - 64 QAM UL
  - 256 QAM DL
  - TDD-FDD joint operation in different bands

4 Appendix

4.1 Literature

[1] **Rohde & Schwarz** LTE Release 9 Technology Introducation [White Paper, 1MA191].

[2] **Rohde & Schwarz** LTE Transmission Modes and Beamforming [Application Note, 1MA186]. - 2015.

[3] **Rohde & Schwarz** LTE-Advanced (3GPP Rel.11) [White Paper, 1MA232]. - 2013.

[4] **Rohde & Schwarz** LTE-Advanced (3GPP Rel.12) [White Paper, 1MA252]. - 2014.

[5] **Rohde & Schwarz** Testing LTE Release 9 Features [Application Note, 1MA210].

[6] **Rohde & Schwarz** Testing LTE-Advanced [Application Note, 1MA166]. - 2014.

[7] **Rohde & Schwarz** UMTS Long Term Evolution (LTE) Technology Introduction [White Paper, 1MA111].

4.2 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

4.3 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

  SGS100A vector signal generator

  SGT100A vector signal generator

- Signal and Spectrum Analyzer

  FSW signal and spectrum analyzer

  FSV3000 signal and spectrum analyzer

  FSVA3000 signal and spectrum analyzer

- Radio Communication Tester

  CMW wideband radiocommunication tester

- Test Systems

  TS8980 Conformance test system

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Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

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Rohde & Schwarz GmbH & Co. KG
Mühldorfstraße 15 | D - 81671 Munich
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com