OTA MEASUREMENTS OF LTE-ADVANCED DEVICES WITH MULTIPLE CARRIERS AND HIGHER ORDER MIMO

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1 ABSTRACT

This white paper gives an introduction to Over-the-Air (OTA) measurements of LTE-Advanced/Advanced Pro devices supporting multiple MIMO carriers and/or higher order MIMO.

2 INTRODUCTION

LTE has since its first deployment in 2009 continuously been striving for higher data capacity. The higher capacity has been achieved by adding more carriers with carrier aggregation, introducing higher order MIMO and higher order modulation.

We now see devices with 8-10 MIMO streams, either using up to 4 carriers with 2x2 MIMO, two carriers with 4x4 MIMO, or three carriers with a combination of 2x2 and 4x4 MIMO. These devices enable data transfer speeds of up to 1Gbps and the future is expected to bring even more carriers and MIMO streams in various frequency bands.

But this increased capacity comes at a cost of increasing device complexity, and with device complexity also follows an increase in the number of possible test cases. This raises questions such as;

- "Do we need to test all carrier aggregation combinations or is it enough to measure the performance of the individual carriers separately?"
- "Can we test the device conducted or do we need to measure it in an OTA environment?"

This white paper describes a suitable test environment for OTA measurements of LTE-Advanced/Advanced Pro devices and provides insight into the characteristics of this environment, the difference compared with conducted measurements and some vital parameter settings.

3 LTE-ADVANCED AND CARRIER AGGREGATION

LTE-Advanced was originally introduced in 3GPP release 10. It introduced the possibility to simultaneously use multiple carriers to increase the user data rate. The Primary Component Carrier (PCC) is the main carrier that also includes the control plane and the UL. The Secondary Component Carrier(s) (SCC) are the supplementary DL carriers to increase the user data rate. If using more than one SCC they are numbered as SCC1, SCC2 and SCC3 etc. LTE-Advanced Pro was introduced in Release 13 and adds further enhancements to achieve even higher data throughput.

For more information on LTE-Advanced and carrier aggregation see 3GPP web page:

http://www.3gpp.org/technologies/keywords-acronyms

4 MEASUREMENT CHALLENGES

Connecting the wireless device with a coaxial cable directly to the radio communication tester is a straight forward way to enable testing of the radio interface. It can for example be used for protocol testing, set-up of calls etc. The conducted testing does however not include the performance of the antennas or the connection between the antenna and the radio. The radio-to-antenna connection includes matching networks and possibly also switches to select the right antenna for the corresponding frequency. All these parts may introduce problems that remain undetected if measuring conducted. Interference between multiple radios in the device being active at the same time is another aspect not possible to evaluate with a conducted test setup. To test all these aspects as well as the chipset performance in a life-like radio environment we need to move to an OTA test environment and to test the supported carrier aggregation configurations rather than one carrier at a time.

So we need an OTA test setup that is capable of handling multiple carriers and MIMO streams in various frequency bands without becoming too complicated and time consuming to use. It is also an advantage in respect to flexibility if that test setup allows the user to expand the system over time corresponding to a growing need for test capability and more carriers/MIMO streams.

5 R&S CMWflexx

The CMWflexx solution from Rohde & Schwarz is the extension to the very successful Radio Communication Tester CMW500 and has been developed to meet the need for flexible configurations with many FDD/TDD MIMO carriers in various frequency bands up to 6GHz. The CMWflexx solution consist of 2-4 CMW500 and a CMW controller unit (CMWC) enabling MIMO/carrier aggregation configurations with up to 16 individual streams.

Even more carriers/MIMO layers can be simulated in a CMWflexx setup if limited RF flexibility can be accepted for the test setup.

CMWflexx enables signaling OTA measurements. Signaling means that all communication with the test object is done over the air interface. This communication can consist of setting frequency, channel bandwidth, modulation and coding, initiating calls etc., but also includes feedback from the test object about number of received packages, bit error rates, received signal strength information etc.

Figure 1, R&S CMWflexx with 2 x CMW500 & CMWC

5.1 ROUTING

The CMW500 is very flexible when it comes to configuration and internal signal routing. Figure 2 shows three different ways to route a 2CC, 2x2 MIMO signal in the CMW500. The black solid lines show separate paths from signaling units to RF connectors. The red dashed line shows an example where signals from two transceivers are combined on the RF side to a common RF connector. The green dotted lines show an example where two carriers within 80MHz bandwidth are combined on the baseband side and share one transceiver. The examples in this white paper assume a fully equipped CMW500 with 4 transceivers and 2 RF frontend units. This enables the most flexible and straightforward routing where each individual MIMO stream has a separate path from the signaling unit all the way to the OTA system antennas.

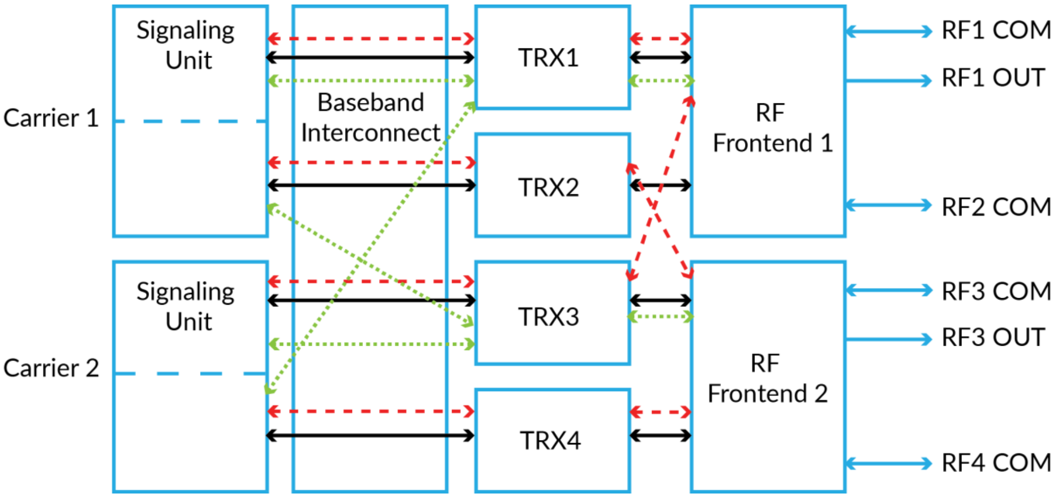

Figure 2, CMW500 signal block diagram and signal routing options

The RFx COM ports can be used for both transmitting (DL) and receiving (UL) while the RFx OUT ports only are used for transmitting (DL). This can be used for splitting the uplink and downlink signal. See more in section 9.3.

6 REVERBERATION CHAMBER OTA ENVIRONMENT

One challenge is to find an OTA environment that is capable of supporting multiple MIMO enabled carriers on different simultaneous frequency bands. One OTA environment that can measure such configurations is a reverberation chamber like RTS65 from Bluetest. The reverberation chamber relies on statistical measurements where hundreds of samples are collected to create a stable average value. It offers some very crucial properties enabling straight forward, accurate and repeatable OTA measurements on modern LTE devices supporting the latest LTE-releases with multiple MIMO carriers.

1. The RF environment, with its reflecting surfaces, provides inherent support for multipath communication (MIMO)
2. It provides very low correlation between carriers and MIMO streams transmitted at the same time
3. The RF channel is inherently Rayleigh faded reducing the need for a separate channel emulator and simplifying the test configuration
4. The measurement provide a full 3D isotropic evaluation of the device
5. It supports large measurement volume only limited by minimum distance to wall (>0.5λ), size of the turntable and chamber door, making it suitable also for large form factor device testing
6. The positioning of the test object is not critical
7. Low complexity - more streams can normally be added just by connecting an additional coaxial cable between the CMWflexx and the reverberation chamber.

The channel model with Rayleigh fading and an exponentially decreasing delay spread is normally referred to as the “NIST-model”. The RMS delay spread is typically tuned to 80ns for LTE measurements by using small amounts of absorbing material applied in strategic locations inside the chamber (Figure 3).

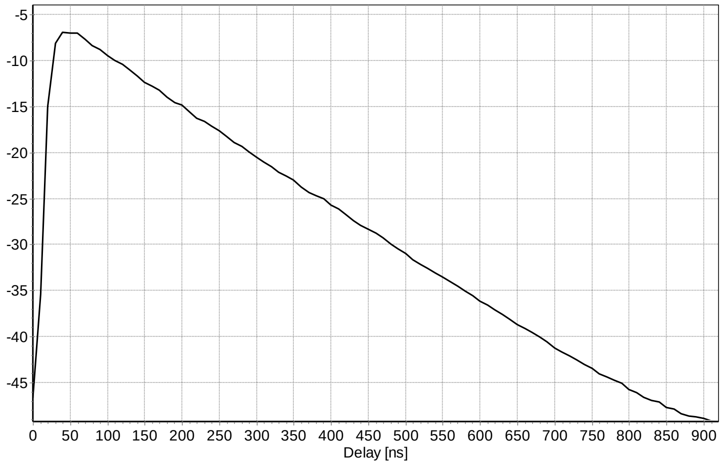

Figure 3, Power delay profile for NIST channel model

This channel model corresponds well to the kind of environment experienced when using the mobile phone in an indoor location such as an office. Some Doppler frequency in the order of a few Hz is present due to the moving mode stirrers and turntable. In addition to the NIST model it is also possible to emulate more complex RF environments with longer and more complex delay spread, higher Doppler frequency and antenna correlation, by adding a channel emulator to the test set-up. Examples of commonly used other channel models are Urban Macro (UMa) and Urban Micro (UMi). This is however not covered in this white paper.

Figure 4, Bluetest RTS65 Reverberation Test System, exterior and interior

The main components of the Bluetest RTS65 and what contributes to creating the Rayleigh faded, isotropic, multipath environment are shown in Figure 4:

1. Shielded chamber with reflective metal walls
2. Mode stirrers (moving reflector plates)
3. Turntable (Ø 0.6 m)
4. Blocking plate removing line-of-sight components
5. Measurement antennas (located behind the blocking plate)
6. Reference antenna (used for system calibration)
7. Device Under Test (DUT)
8. Absorber location markings (for tuning of delay spread)
9. RF-connection panel
10. Measurement server and chamber control panel

The RTS65 outside dimensions are 2.0 m x 2.0 m x 1.4 m (w x h x d) and it is suitable for measuring smaller devices such as phones, tablets and laptops. The RTS95 is a larger version (3.3 m x 2.6 m x 4.4 m) of the RTS65 making it suitable for larger and/or more heavy devices as well as measurements on body worn devices or antennas.

7 CALIBRATION OF THE TEST SYSTEM

One of the advantages with the reverberation chamber combined with the CMWflexx is the very straight forward calibration process that needs to be done before starting measurements of the LTE performance. Any R&S VNA such as the ZND or ZNB can be used for this calibration.

Figure 5 illustrates the complete typical communication path from the CMWflexx to the test object (DUT). The power levels going into the DUT (P_{DLin}) or coming out of the DUT (P_{ULout}) are unknown and difficult to measure directly. The output (P_{DLout}) or input power (P_{ULin}) at the CMWflexx ports are however well known and can be measured.

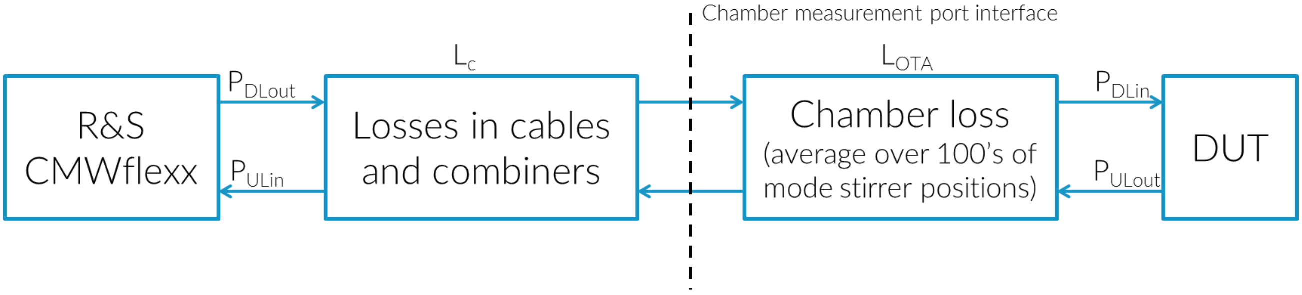

Figure 5, Path loss overview

The power levels at the DUT interface (DUT antennas) can hence be calculated if we know the losses between the CMWflexx and the DUT. These losses consist of two parts:

1. Conductive losses in external cables and combiners (L_c)
2. Chamber losses (consisting of internal cables, antennas and Over-the-Air path loss)(L_{OTA})

So the power level into the DUT receiver, $P_{DLin} = P_{DLout} - L_c - L_{OTA}$ and correspondingly, the DUT transmitter power, $P_{ULout} = P_{ULin} + L_c + L_{OTA}$

L_c is normally static over time and only varies over frequency. L_{OTA} – the chamber loss is however different, as it in addition to frequency variation also varies over time due to the faded environment inside the chamber. This loss is hence the average loss measured over several hundred mode stirrer positions.

L_c and L_{OTA} can be determined by performing the following three steps:

1. Calibration of the VNA itself
2. Chamber loss (L_{OTA}) measurement replacing the DUT with a reference antenna with known performance
3. Cable loss (L_c) measurement (also includes losses in any combiners used for the test setup)

The resulting loss vs frequency files are then used in the system when running all other LTE performance measurements.

8 TYPES OF MEASUREMENTS

There are today three main types of OTA measurements that can be used to characterize the performance of active devices such as LTE phones:

- TIS, Total Isotropic Sensitivity - measures the DUT receiver's ability to provide correctly decoded data at low received signal levels. (3GPP references: TS 34.114 & TS 37.544)

- TRP, Total Radiated Power - measures the transmitted output power radiated from the DUT antenna (3GPP references: TS 34.114 & TS 37.544).
- Data Throughput – measures received data throughput on MAC or IP-layer vs. received power level. Normally measured in the downlink direction to DUT (3GPP reference: TR37.977).

The data throughput measurement is for the more data-centric LTE devices often preferred over TIS measurements as it is a more comprehensive receiver test than TIS, covering more parts of the receiver and the result, especially on the IP-layer, reflects the actual end user experience. A percentage level of maximum throughput is often selected as a reference point when comparing performance between devices or between design solutions, for example 70% of maximum throughput.

Normally it is also possible to reduce the measurement time by measuring throughput instead of TIS. Data throughput on one power level typically takes less than one minute and 5-6 power levels may be enough to assess the device performance for one carrier. The reduction in measurement time becomes even larger when measuring multiple carriers as each additional carrier typically adds only 10-15% to the total measurement time. The focus of this paper is therefore on throughput measurements although the described test configurations can be used for TIS and TRP measurements as well.

9 CONFIGURATION EXAMPLES

This section shows some measurement configuration examples from the basic two carrier, 2x2 MIMO configuration to configurations with four 2x2 carriers and two 4x4 carriers. The most important thing to consider when connecting the communication tester and the reverberation chamber is that each MIMO stream of an individual carrier must be transmitted through its own antenna to maintain separation and individual multipath/fading.

9.1 2 COMPONENT CARRIERS, 2X2 MIMO

Figure 6 shows a typical basic LTE-Advanced OTA configuration with 2 CC, each using 2x2 MIMO. RF1 COM to RF4 COM from the CMW500 are connected to the four measurement antenna ports on the reverberation chamber. This configuration is also capable of measuring 1 CC with 4x4 MIMO as well as 2 CC uplink carrier aggregation. The antenna switch at the connection to the reverberation chamber contributes to the mode stirring of the chamber and ensures channel symmetry between the four connections.

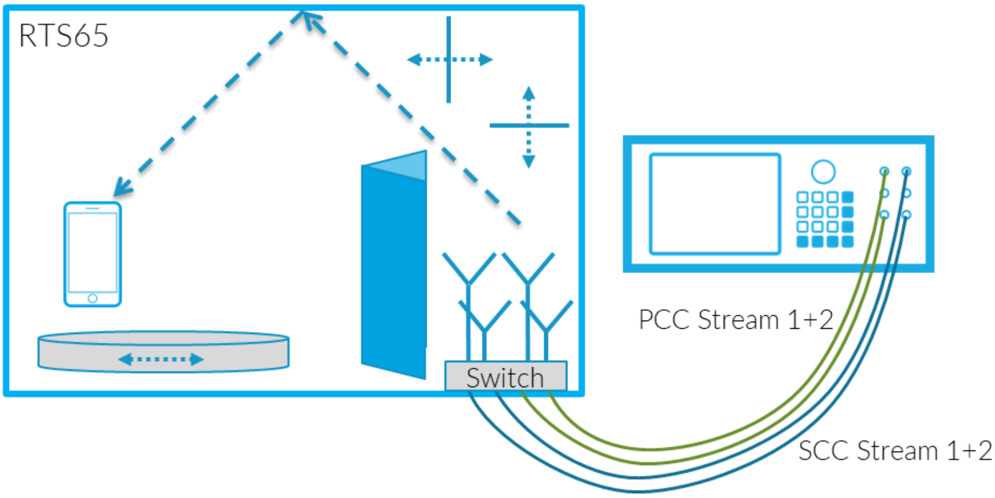

Figure 6, 2 CC, 2x2 MIMO configuration

For 2 CC, 2x2 MIMO it is also possible to combine the two carriers internally in the CMW500 and just use two chamber measurement ports (RF1 COM carrying MIMO stream 1 for PCC+SCC and RF3 COM carrying MIMO stream 2 for PCC+SCC) as shown in Figure 7. The internal combining can as shown in Figure 2 be done either on the baseband side providing that both carriers are located within the transmitter (DL) bandwidth of 80MHz or on the radio side provided that the CMW500 is equipped with four transceivers.

This configuration can be useful for smaller system configurations but limits the flexibility and can for example not be used for 1 CC, 4x4 MIMO as each MIMO stream needs its own separated and uncorrelated path from instrument to chamber antenna. Using one measurement antenna per MIMO stream still offers maximum system flexibility.

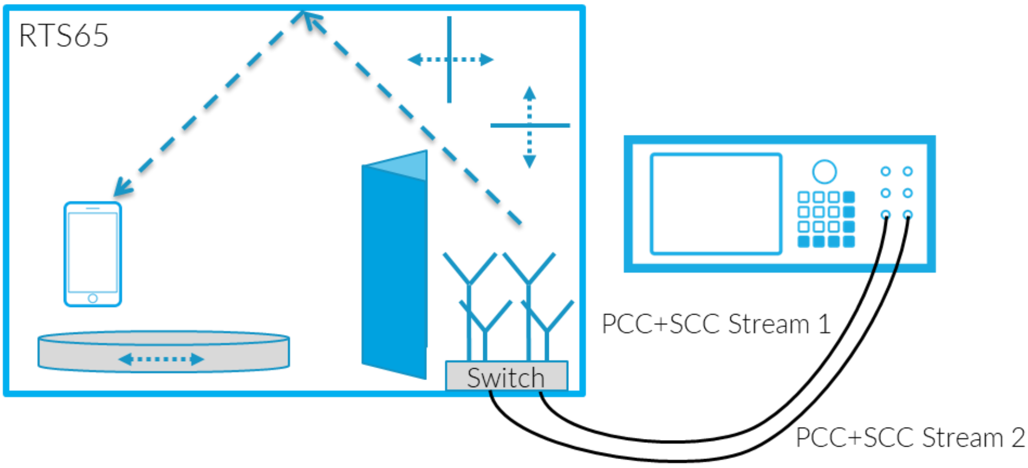

Figure 7, 2 CC, 2x2 MIMO using internal carrier combining

Figure 8 shows two measurements comparing the two configurations shown in Figure 6 and Figure 7. The black curve is with combining of the two carriers (corresponding to Figure 7) and the green curve is without combiners, i.e. four separate transmission antennas (corresponding to Figure 6). Each

MIMO stream will even if the carriers are combined experience independent fading and uncorrelated paths to the UE. MIMO streams belonging to the same carrier shall of course not be combined as they would then be correlated and hence it would not be possible to separate them from each other at the UE receiver.

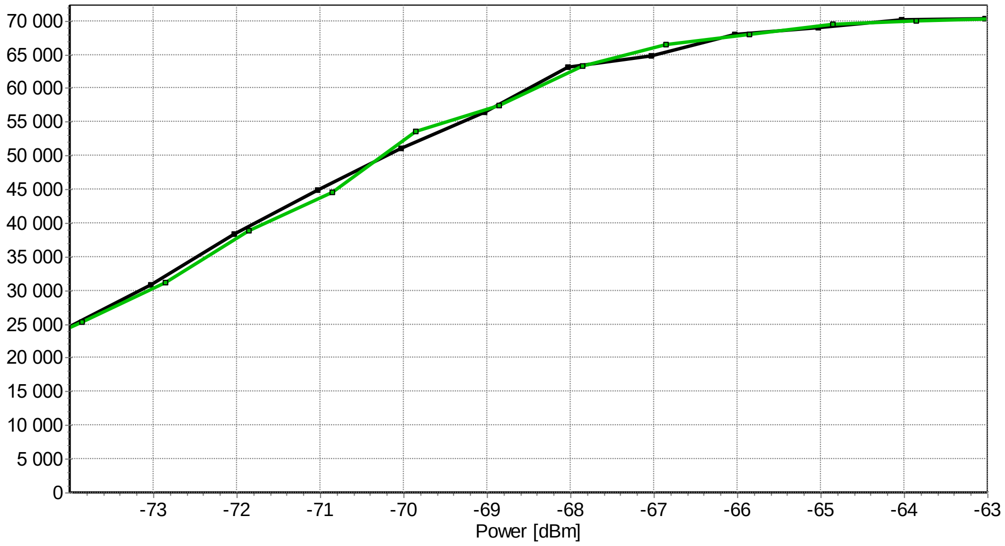

Figure 8, Example results for a commercial handset operating on LTE band 5 (PCC) and band 3 (SCC). With and without combining the carriers before the reverberation chamber

9.2 3 AND 4 CC, 2X2 MIMO AND 2 CC 4X4 MIMO

The next example (Figure 9) is showing a configuration supporting up to 4 CC, 2x2 MIMO or 2 CC, 4x4 MIMO. In this example the CMWflexx solution with 2xCMW500 and a CMWC is used in combination with a reverberation chamber with 8 measurement antenna ports. The most flexible solution is still to maintain separate paths for each carrier and MIMO stream from instrument to chamber measurement antennas.

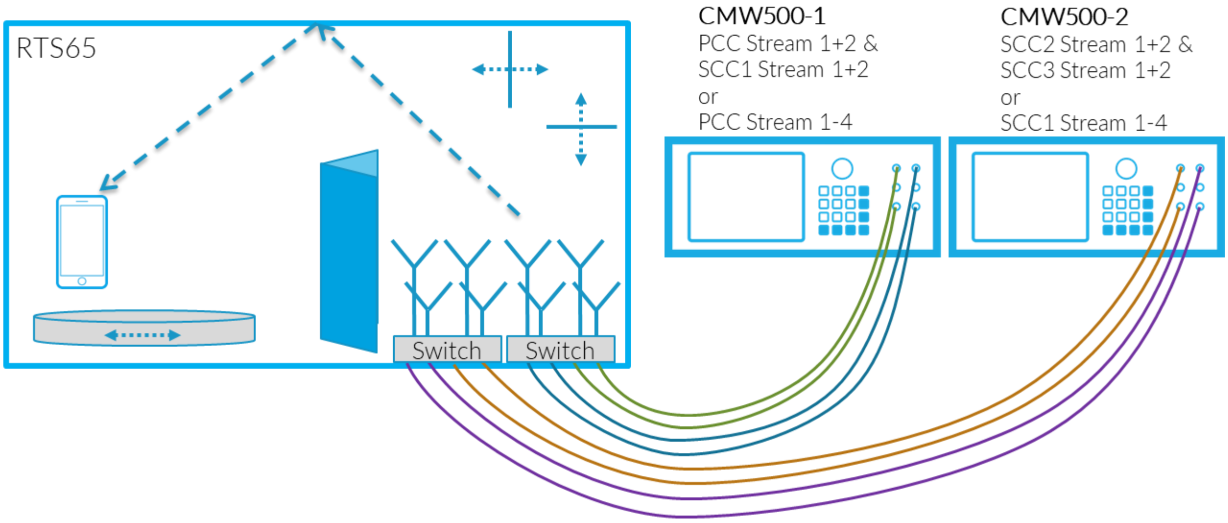

Figure 9, 4 CC, 2x2 MIMO or 2 CC, 4x4 MIMO configuration

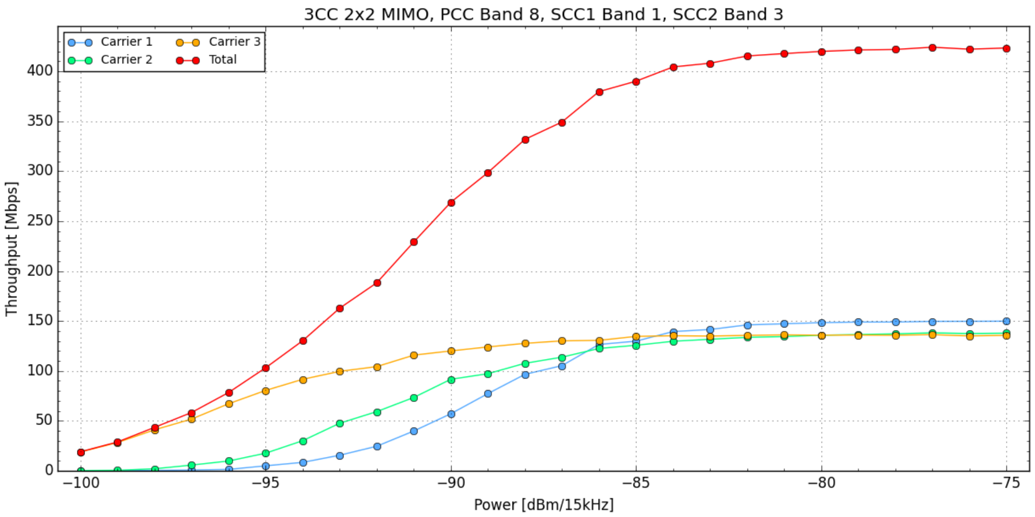

Figure 10, 3 CC 2x2 MIMO measurement example

Finally an example with 10-12 individual MIMO streams (Figure 11). Carrier aggregation configurations providing 10 streams are for example 1 CC 2x2 MIMO + 2 CC 4x4 MIMO or 5 CC 2x2 MIMO, while 12 streams are used for 3 CC 4x4 MIMO. These are configurations that in combination with 256-QAM modulation deliver throughput rates close to, or in excess of 1Gbps. The test setup is in this case using a reverberation chamber with at least 12 antennas (Figure 11 shows connection using Bluetest RTS65 with 16 measurement antennas) and 3 pcs of CMW500 for full flexibility in allocation between carriers and frequency bands.

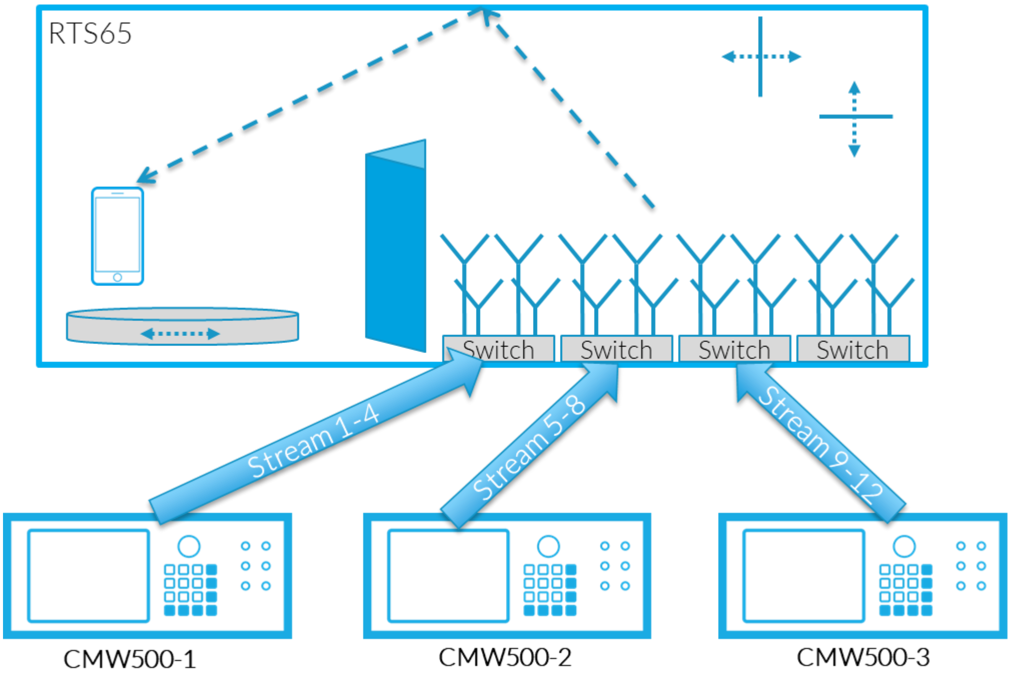

Figure 11, 10-12 stream configuration

9.3 USING A SEPARATE UPLINK ANTENNA

The CMW500 allows for separation of the uplink and downlink signals on different ports (RFx COM and RFx OUT). This can be useful for example when measuring downlink throughput where the output (DL) power levels from the CMW500 can be quite high compared with the (UL) received power from the device, potentially causing interference. The CMW500 receiver port can then use a separate chamber antenna. Typically the reference antenna located on the turntable is used as the uplink antenna. The location of the antenna on the turntable provides line-of-sight to the DUT and in addition to separating the signal from the downlink also reduces the fluctuation of uplink received power making it easier to keep the uplink power within the CMW500 optimum power receiver window. Other examples when it can be beneficial to use a separate uplink antenna are when using a channel emulator or for WLAN measurements.

The separate uplink antenna located on the turntable can of course only be used when measuring downlink UE performance such as TIS or downlink data throughput.

10 SETTINGS

LTE-Advanced/Advanced Pro supports a huge amount of parameter settings, most of them like channel numbers, bandwidth, modulation, allocated resource blocks etc. are the same regardless of conducted or OTA testing. There are however some settings such as uplink and downlink power levels that may require more attention when moving to a faded OTA environment.

10.1 NUMBER OF SAMPLES

Typically 100 measurement samples on each power level are enough to get to an uncertainty of less than 0.5dB (STD). It is possible to improve the uncertainty by increasing the number of samples up to a certain point. More than 1000 samples do normally not yield any improvement. Each sample corresponds to a new mode stirrer position and a new multipath fading environment for the device.

10.2 POWER CONTROL

The power settings, especially for the uplink signal becomes important due to the faded signal with over time varying signal strength. The uplink signal strength should match the CMW500 receiver dynamic range as good as possible with the maximum received uplink power levels being as close as possible, but not exceeding, the point where the CMW500 receiver is saturated. This gives the best margin for the CMW500 receiver to still be able to decode the uplink signal even in deep fading dips. (Figure 12).

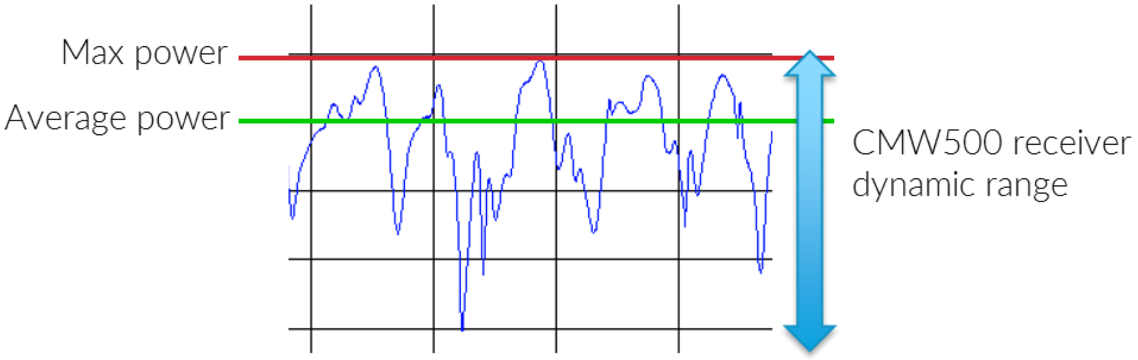

Figure 12, Faded uplink received power vs time

There are a number of uplink power settings that can influence the stability of the connection to the UE, the measurement and the measurement time such as:

- "Automatic UL expected power control" lets the instrument detect the input signal automatically and adjust the expected input power accordingly. This should be the default setting.
- "Power control algorithm" sets the algorithm to be used for power control of the PUSCH.
  - Max power – normally used for TRP measurements
  - Closed loop – normally used for TIS and Throughput measurements
- "Target UE power" specifies the target received UL power level when using Closed loop power control.

It is also possible to adjust power levels manually if needed. The manual mode settings include:

- "Max expected UL power" sets the expected input power to the instrument and depends on the DUT output power
- "User margin" sets the user margin used by the instrument to, together with the expected UL power determine its reference power level.

Note that many of the above parameters also are possible to apply to all carriers or to each individual carrier.

The downlink power is less sensitive but the use of multiple downlink carriers introduce some new parameters such as:

- "Idle cell power" specifies the output power of the instrument when not measuring. If the output power is too low, the DUT might not be able to receive the signal from the instrument.
- Setting the output power relation between the carriers, i.e. shall they all transmit at the same power level or should there be a power offset between the PCC and SCCs.
- A carrier can be selected to be on but not included in the throughput/TIS measurement

10.3 OPTIMIZING FOR MAXIMUM THROUGHPUT

Another typical problem is that the measurement does not yield the expected throughput figures. A good point to start looking for the root cause is to review all the settings related to the throughput and make sure that they enable the device to support the wanted data rate. These settings include:

- Connection type
    - RMC (Typically used for TIS measurements with pre-defined settings according to 3GPP)
    - TTI based (Allows different settings for different sub-frames)
    - User defined (The same settings apply to all sub-frames)
    - Follow mode (Adaptive modulation based on various feedback from the device)
- DL Modulation, for example QPSK, 16-QAM, 64-QAM, 256-QAM
- DL Scheduling parameters such as
    - RB allocation
    - TBS Index
    - Reduced PDCCH
    - UL/DL frame allocation (TDD only)
- Cyclic prefix type

More information about the various settings can be found in the CMW LTE UE Firmware Application User Manual, Ref 6).

It is also important to remember that the fading environment in the reverberation chamber requires more downlink power to reach maximum throughput than needed for a static environment such as a cable. The downlink power for each carrier must be high enough to reach maximum throughput for all multipath/fading conditions including the deepest fading dips, if the average throughput over the entire measurement shall be equal to the maximum possible throughput. This may in practice be difficult to accomplish, especially for the higher order modulations, and for some measurement samples/mode stirrer positions even lead to excessive downlink power levels driving the DUT receiver into saturation.

10.4 OTHER USEFUL SETTINGS

It is recommended to use a robust modulation such as QPSK and a low TBS Index for the uplink when measuring downlink throughput or TIS. This will enhance the robustness of the uplink communication.

“UE report” is normally only used when extracting received power data from the device and hence not needed for TRP or throughput measurements.

11 OTHER TYPES OF TESTING

The ability of R&S CMWflexx together with the Bluetest RTS to handle multiple wireless standards and multiple MIMO streams at the same time opens up for other OTA tests like investigation of inter device interference performance between different radios such as LTE and WLAN being active in one device at the same time. Another example is evaluation of handover performance between different radio standards.

12 THE ROAD TO 5G

The introduction of 5G is expected to bring even more carriers and MIMO streams on even more frequency bands to increase the capacity and data rates even further. The ability of the reverberation chamber to handle multiple signals on multiple frequency bands at the same time makes it well prepared to handle the transition from 4G to 5G. Early 5G devices will in fact rely heavily on 4G for control signaling while 5G is used to increase the data rates. It is also expected that more UE and base station measurements such as spectrum masks and spurious emission will be moved from conducted to the OTA domain due to the increased integration of transceivers and antennas. These measurements can be performed using a Rohde & Schwarz signal analyzer such as the FSV or FSW combined with the Bluetest reverberation chamber.

13 CONCLUSION

LTE-Advanced/Advanced Pro introduces new measurement challenges. These challenges can be handled by the R&S CMWflexx radio communication tester combined with Bluetest's RTS65 reverberation chamber. Test complexity and test times are reduced to allow for the increasing amount of test cases related to the increase in device capability. Together they provide a powerful tool for optimization of device performance and early problem detection ensuring a successful and trouble free market launch of the device.

14 ABBREVIATIONS & ACRONYMS

CC	Component Carrier
DL	Downlink (from base station to device)
DUT	Device Under Test
FDD	Frequency Division Duplexing
MIMO	Multiple In Multiple Out
OTA	Over The Air
PCC	Primary Component Carrier
PDCCH	Physical Downlink Control Channel
RMS	Root Mean Square
RTS	Reverberation Test System
SCC	Secondary Component Carrier
TDD	Time Division Duplexing
TRX	Transceiver
UE	User Equipment
UL	Uplink (from device to base station)

15 REFERENCES

1) 3GPP TS 34.114
2) 3GPP TS 37.544
3) 3GPP TR 37.977
4) R&S White Paper 1MA169_3E, LTE Advanced Technology Introduction
5) R&S CMW500 Wideband Radio Communication Tester User Manual
6) R&S CMW KM-5xx/-KS5xx LTE UE Firmware Application User Manual

16 ADDITIONAL INFORMATION

This white paper was written in cooperation between Bluetest AB and Rohde & Schwarz GmbH.
For more information about Bluetest see: bluetest.se
For more information about Rohde & Schwarz see: rohde-schwarz.com

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