Ensuring product conformance according to 3GPP standards TS36.141 Base Station Conformance Test and TS36.521 UE Conformance Specification Radio Transmission and Reception is critical to any LTE device manufacturer. However, conducting common radio transmit characteristics, such as OFDM, MIMO, and Layers 1/2/3, based on these standards efficiently and accurately can be a challenge. Using designated test instrumentation and implementing certain measurement processes can control the cost of test and help speed time to market.

**OFDM Radio Testing**
Orthogonal Frequency-Division Multiplexing (OFDM) and the use of high order 64QAM modulation require high linearity, phase and amplitude in both TX and RX modules to prevent inter-symbol interference and to enable accurate IQ demodulation. To measure these characteristics, a test solution needs to have a fast and adaptive Error Vector Magnitude (EVM) measurement capability to track and measure the signals during adaptive frequency channel use. Tests can be made on both the “per subcarrier” performance of each individual subcarrier, and then on the “composite” signal where the subcarriers are combined, so the overall performance can be seen.

Subcarriers must have strong phase noise performance to prevent leakage across carriers. The frequency mapping and orthogonal properties of OFDM require the “null” in one carrier be exactly on the peak of the adjacent carrier. Thus, accurate measurement of the phase linearity and amplitude linearity on each subcarrier is important for the proper design of a system.

OFDM transmissions must also be measured “per resource block” to determine if the power levels in each burst are being correctly maintained. Each individual “resource element” has a specific power level to be transmitted, and these power levels should be correctly measured across an entire resource block.

EVM measurements need careful consideration because of two special features. One is the “Cyclic Prefix” (CP), which is a short transmission burst at the start of each symbol. This is actually a repeat of the end of the symbol, and creates a “settling time” to allow for delay spread in the transmission path due to multipath effects. If a measurement begins too soon in the symbol
period, a signal from the previous symbol (inter-symbol interference, or ISI) will corrupt the measurement.

The second point is that the symbol transmission has a “ramp” at the start and end to ensure that there is no strong power burst. The symbol period measured must be restricted to ensure measurements are not made during these ramp periods. The technique to address both these issues is to use a “sliding FFT,” where the period of the symbol that is measured can be adjusted in time to give the best EVM value.

The effect of the ramp can be seen in the measurements below. The waveform on the left has no ramp, so there is a sharp switch on/off between each symbol. This causes a large “spectrum due to switching” emission that is seen as broadening of the output spectrum beyond the desired system bandwidth; in this case 5 MHz. The waveform on the right has ramping enabled, so there is a much less severe switch on/off between symbols. This has the clear effect of reducing spectrum emissions. This type of ramping – also called spectrum shaping – is required to ensure that the transmitter output stays within the allocated frequency band and does not interfere with any adjacent frequencies.

MIMO Testing
In a multiple-input and multiple-output (MIMO) system, the coupling from antenna to air characteristics must be fully understood. The data rate and performance of MIMO links depend on how much the multiple RF antennas are coupled to each other. Accurate calibration of antenna paths, factory calibration and then field installation calibration is required to implement a successful MIMO system.
The base station transmit antenna array may use specialized phased array techniques, such as a Butler Matrix, for accurate control of the phase/timing in each antenna path. This requires accurate characterization of the RF path in terms of electrical path length, coupling and reflections from both ends. This data is then fed into the MIMO adaptation algorithms to enable features, such as beam steering. A Vector Network Analyzer is normally used for complete characterization of the antenna paths.

In MIMO testing, both the baseband processing section and the RF generation/alignment should be measured. Functional and performance tests should be made on both. In addition, it is useful to conduct a “negative test” by intentionally using incorrect signals to ensure they are correctly handled or rejected.

It is necessary to calculate the characteristics of the RF path from each TX antenna to each RX antenna in a MIMO system. To achieve this, the system must accurately measure the RF path characteristics in real time. These algorithms are built into the design of the particular MIMO system, but they all require accurate phase and amplitude measurements of a “pre-amble” or “pilot tone” of a known signal. For testing environments, this provides two challenges:

1. **Accuracy of the received signal measurements.** The test system must be calibrated to separate the measurement system uncertainty from the MIMO system accuracy and uncertainty. This way, the exact characteristics of the MIMO system are measured, with minimum influence from the test system. To achieve this, a test environment must generate reference signals against which the measurements are made. The measurement method needs to be confirmed by adjusting the quality of the reference and checking that the measured result matches the change made.

2. **RF coupling.** For test environments used in performance measurement, algorithm tuning, Integration and Verification (I&V), and production quality, the RF coupling between antennas must be defined, repeatable and characterized if absolute performance figures are to be measured. This requires the use of suitable fading and multipath test equipment with proper signal generation to create the different coupling between antennas. This is achieved using static signals (e.g. signal generator-based references) for initial testing, baseband fading simulators to verify correct operation at the algorithm level, and RF fading simulators for end-to-end system level testing.

The MIMO coding of data blocks is based on Space-Time Block coding, where the actual data coding is based on both the space (i.e. which antenna) and time (when it is transmitted). The diversity gains of MIMO are based on the multiplicity of both space and time for each block of
data sent. Therefore, both the time alignment of each antenna and the spatial alignment of the paths between the antennas must be measured.

MIMO analysis requires extensive test and evaluation of the signal processing and MIMO coding algorithms used. A “step by step” approach is employed in which the individual processing and feedback steps in the MIMO algorithms can be isolated and measured. These tests need to be conducted in a controlled environment where the parts of the MIMO algorithms are verified by comparing them against reference conditions. Verification requires that known conditions be created – both with the RF coupling from transmitter to receiver, as well as the measurements and feedback reports being made between transmitter and receiver.

Testing at a pure baseband level is necessary to check algorithms, as is testing at RF air interface. In addition, precise control of the baseband processes and RF coupling is required. Typically, this is achieved by using fading simulators and system simulators. The fading simulator will provide a controlled air interface coupling, and the system simulator will provide a controlled baseband environment (e.g. a controlled UE to test a base station, or a controlled base station to test a UE).

When the fading function is included in the MIMO test, the fading of each path must be fully described, followed by the correlation between each RF path. In the case of 2x2 MIMO, there are 4 paths, referred to as h11, h12, h21, and h22. In an ideal environment for MIMO, there is no correlation between the different RF paths, so the processing algorithms can fully separate the signals from each path to achieve the full data rate increase.

In the “real world,” there is a non-zero correlation between the different paths, as they have some similar shared routes from transmitter to receiver. For each of these scenarios, a correlation matrix mathematically describes how the different RF paths are related. Then, the algorithms must be tested, verified, and optimized to give the best possible data rate throughputs in each of the different types of RF environment that may be experienced.

**L1/L2/L3 Testing**

Layer 1 (L1) contains the algorithms and procedures associated with reporting and measurements that drive the power control, adaptive modulation, and coding, as well as MIMO processing capabilities. From a test point of view, measurements are made at the receiver and transmitted back to the corresponding element that uses the measurement. This process also verifies that the transmitter is correctly reacting to the measurement reports and adjusting parameters accordingly.
Two typical L1 tests (Power versus Resource Block) are shown below. The first shows the individual power transmitted in each resource block for a single time period (sub-frame). This evaluates how the power is distributed across all available resource blocks, and whether the available resources have been set to the correct power level for the receiver, based on reports and L1 Power Control algorithms. The second shows the variation in time of each Resource Block. Each Resource Block is measured over each time period (sub-frame), and power level is shown by the color of the Resource Block.

Layers 2 and 3 (L2 and L3) testing concentrates on the signaling and message flows between different network elements in the sys and received (e.g. UE and Base Station). The purpose of testing these layers is to ensure that the proper system signaling and higher layer data is properly transmitted.

Tests are normally made using a system simulator to generate and receive the messages to/from the entity being tested. In addition, the simulator normally has a Layer 1 implementation to communicate to the target entity across the proper physical layer. Optionally, Layer 1 may be omitted and a "virtual Layer 1" used to link the Layer 2 and Layer 3 elements of the simulator to the protocol stack.

The system simulator is usually one of the following, depending on the object being tested:

- Network Simulator, for UE test
• UE Simulator, for eNodeB test

These simulators have a comparable architecture, using L1 hardware for PHY layer connection, and then a control environment (usually PC hosted) for L2, L3 and logging/analysis.

**UE Loop Back Test Modes**

It is often required to configure special loop back test modes, where data received by a device is automatically transmitted by the device back to the simulator. This enables the data rates, data integrity and connectivity to be verified.

A large number of MAC and RLC, and nearly all Data Radio Bearer (ORB) LTE tests require the loop back test mode in the UE. Without this, ORB testing will have only limited test coverage and L2 testing will have insufficient test coverage for complete device testing. Because this is not the normal operational mode of the device, the test loop back modes are only activated during certain tests.

**Conclusion**

In an LTE environment, the handover, fading and mobility can introduce significant delay and variation in data rates, causing many problems in the transmission and reception of data. Using network simulators and traffic impairment simulators that create a controlled and repeatable test environment allow the designer to measure the characteristics to be tested to isolate these effects and evaluate their impact on the user experience. The end result is higher quality products being rolled out to the market in a timely fashion.

*About the author: Carl Anderson is Business Development Manager for Anritsu Company. Carl holds a BSEE degree from Drexel University, MSEE degree from the California Institute of Technology, and MBS degree from Rutgers University. He is a member of IEEE.*