As users of mobile devices demand more bandwidth for their apps, network carriers have begun implementing LTE (Long-Term Evolution) technology into their networks. Part of the LTE infrastructure relies on MIMO (multiple input, multiple output) radio channels, which use several antennas to focus signals and boost performance. Because users of mobile devices are generally on the move, carriers and equipment manufacturers must test their networks and their devices by emulating the signal fading of an actual network’s radio channel.

To test the performance of a cellular handset or chipset, manufacturers can measure BER (bit-error rate), BLER (block-error rate), and FER (frame-error rate) as a function of the signal-to-noise ratio. All of these measurements count the number of errors in a predefined amount of data. High error values mean that the mobile device doesn't adequately mitigate fading effects in the radio channel. Another typical performance measure is the data throughput vs. the signal-to-noise-ratio. This is typically measured in kilobits per second and defines how much data the system is able to correctly transmit in 1 s.
Performance tests require a communications tester and a radio-channel emulator (Figure 1) for the DUT (device under test). A communications tester establishes a link to a cellular device by emulating a base station, but its features include only a small subset of those in a real base station. For a throughput measurement, the communications tester sends a known data pattern to the DUT. With a direct cable connection from the tester to the device, the test setup can achieve its highest possible throughput. A radio-channel emulator, placed between the tester and the DUT, will distort the signal, which causes a decrease in throughput. Figure 2 shows a typical test setup for a device with multiple antennas.

Typically, the main purpose of testing is to verify a product's compliance to a standard. Standard channel models are defined by the 3GPP LTE standard (Ref. 1). The standard also sets performance limits with a given model, ensuring a certain minimum performance for all LTE devices on the market. Most tests against the standard requirements are simply pass/fail measurements, so they do not measure the maximum performance of the device.

Performance testing in the lab provides a fully repeatable environment that allows manufacturers to debug problems in a design. After a design change, the performance can be checked against the same test conditions.

**Beamforming and MIMO testing**

Proper emulation of the radio channel spatial effects is crucial in the development and verification of multi-antenna systems such as LTE. Beamforming is a multi-antenna technique that uses the spatial dimension of the mobile radio channel. By changing the actual antenna radiation pattern electrically, dynamically, and on a per-user basis it improves spectral efficiency of the network. The beamforming technique is applicable to both the transmitting and the receiving side, but due to size...
and antenna spacing constraints, the use of beamformers is practically limited to base stations.

**Figure 3** shows how a base station uses beamforming.

![Figure 3: Beamforming](image)

**Figure 3.** Beamforming applies weights to antenna patterns to direct the transmitter port toward the mobile device. *(Click on the figure to enlarge.)*

Beamforming has been used in radar and optical systems for decades. The basic idea of focusing an antenna beam is simple. Parallel antenna elements in the array are phased so that signals received or sent at a wanted direction experience constructive summing. Therefore, the combined signal power to that particular direction is maximized. This is the traditional form of beamforming, usually referred to as beamsteering.

Beamforming functionality has been an optional feature in telecommunication standards since the mid-1990s, but the lack of computing power forced system designers to select simpler approaches. Requirements for spectral efficiency and higher data throughput, along with improved digital-signal processing power, have made beamforming attractive for cellular systems. In current standards such as LTE and IEEE 802.11ac, beamforming is used adaptively. This means that optimal weights for each antenna stream are calculated based on given optimization criteria. That technique provides the best antenna characteristics against spatial radio propagation and interference conditions at each moment in time.

The test system needs a way to measure the radio channel's performance and adjust the antenna pattern. In TDD (time-division duplex) systems, the downlink-sounding procedure is used to find the weight of each portion of the transmitted signal. The test system simply measures uplink signals and predicts the optimal weights for the downlink. In FDD (frequency-division duplex) systems, user equipment must measure downlink sounding signals and report the results to the base station.

System designers must optimize the channel sounding so that the wideband spatial channel is measured accurately enough and yet efficiently without consuming too much valuable data payload capacity. The mobility of devices makes testing more difficult. Interference and reflections in multipath radio channels are continuously changing as UE (user equipment) and other objects move. The feedback latency of a closed-loop based channel estimation and weighting must be taken account in system implementation. The beam adjustment must be shorter than the changing speed of spatial channel characteristics.

Developing a beamforming system for a stable environment is a fairly simple task, but developing a beamforming system that also works in a real radio environment, which is never constant, is much more challenging. The whole concept of beamforming relies on phased antenna arrays. Therefore, in the beamforming test setup, engineers must work to control and maintain phase accuracy and stability over the whole test system.
Test-system calibration is an essential step in the execution of laboratory tests. Because a beamforming test setup has multiple parallel radio channels, the relative amplitude levels need calibration to achieve balancing. A special element in beamformer testing is the phase calibration in addition to amplitude calibration. A beamforming test environment requires phase accuracy within a few degrees. It's important to compensate for effects from antenna RF cabling as well.

![Figure 4](image.png)

**Figure 4.** In a typical TD-LTE downlink, the connection topology is two times 8x2 and in the uplink, it is two times 1x8. The complete setup must be phase accurate in order to allow uplink channel estimation, user tracking, and interference suppression performance. (Click on the figure to enlarge.)

A typical setup for performing beamforming testing on TD-LTE equipment consists of an eight-antenna base station and two mobile devices, each having two antennas. Because downlink channel estimation is based on uplink measurements, the uplink channel also needs to be emulated. Thus, the full setup (Figure 4) is two times 8x2 setup in the downlink and 1x8’s for uplink (uplink is transmitted with one UE antenna). Thus, the full setup (Figure 4) has two 8x2 connections for the downlink emulation and two 1x8 connections for the uplink emulation (uplink is transmitted with one antenna per UE device).

Perhaps the most important aspect of using a radio-channel emulator and software simulations for lab testing is to select the proper channel model. In performance evaluations, channel models must be realistic, and they must model a known type of environment. It's not meaningful to optimize system performance against a rural model if the target environment is an urban street canyon. Equally, it doesn't make sense to use simple line-of-sight models for systems designed to mitigate urban fading.

Channel models specified for different standards can be categorized in different families by their mathematical form. Channel models always require a tradeoff between complexity and accuracy. Correlation-based models are easy to implement but lack realism, especially for tests involving beamforming. Ray-tracing models, or recorded impulse responses, are the most accurate models, but they are typically location specific and require heavy computational effort. The most promising models, and also the most widely used, are GSCMs (geometry-based stochastic channel models).

Unlike correlation-based models, GSCM models are antenna independent, and a realistic antenna model can be embedded in the channel model. This is important because beamforming antennas have a strong impact on the complete system performance. The channel modeling approach is simple—there is a good selection of models available for different types of environments. Radio-channel models such as SCME (spatial-channel model extension), IMT-Advanced (International Mobile Telecommunications) and WINNER (wireless world initiative new radio) models are based on this approach. The latest TD-LTE beamforming test development in China relies also on this approach.
Figure 5. In (a) user tracking, user equipment (the red dot in the picture) travels back and forth radially around BS (base-station) sector. In (b), adding a second user tests a mobile device's interference suppression by stressing the wireless network. (Click on the figure to enlarge.)

Figure 5 shows two examples of the typical test cases. Beamforming testing with real fading gives the necessary confidence to engineers that a new technology works. Throughput is the key question—does beamforming really deliver the promised data throughput? Testing with proper channel models lets you verify throughput. Technology will be more mature after systematic lab testing, which will result in easier and faster field deployment.

**Testing of 802.11ac access points**

Techniques such as beamforming that are used for testing LTE devices can also be used for testing IEEE 802.11ac WLAN devices. IEEE 802.11ac is the evolution of IEEE 802.11n for very high data-rate-to-end-user devices, offering improved performance. IEEE 802.11ac device performance gain is, however, highly reliant on physical-layer extensions compared to 802.11n systems because 802.11ac has a wider RF bandwidth (up to 160 MHz), more MIMO spatial streams (up to eight), multi-user MIMO, and high order modulation (up to 256 QAM). The extension towards higher data rates is also known as VHT (very high throughput) mode of 802.11ac. WLAN performance expectations are set to a new level with the 802.11ac standard, yet the high volumes of WLAN devices still require vendors
to focus on low manufacturing costs. Therefore, these devices require more effective physical-layer test methods than did older mobile devices.

Verifying MIMO techniques like spatial multiplexing and beamforming that are defined in the 802.11ac standard requires the use of advanced propagation modeling and emulation as well as multichannel fading capability with a mandatory 80-MHz bandwidth. The spatial multiplexing technique uses spatial diversity between separate data streams, and a receiver uses channel estimation to separate the streams and demodulate the data. A receiver's radio-channel transfer characteristics need to be programmable for efficient and controllable testing to verify a device's MIMO performance under different propagation conditions.

IEEE 802.11ac introduces MU-MIMO (multi-user MIMO) to WLAN. Single-user MIMO improves the data throughput to an individual device, whereas MU-MIMO re-uses resources to improve network performance, although the data rate to any individual user is not improved. The IEEE 802.11ac standard defines up to eight MIMO spatial streams and allows simultaneous transmission to up to four users. **Figure 6** depicts example MU-MIMO transmission with four spatial streams and three users.

![Figure 6](image)

**Figure 6.** MU-MIMO transmission scenario with three users shows the paths among antennas. (Click on the figure to enlarge.)

MU-MIMO system design and verification bring on new challenges compared to single-user MIMO systems. Channel conditions between the users are critical for spatially multiplexing multiple users, and accurate CSI (channel state information) is required for proper transmission control and scheduling. Accurate CSI at the transmitter improves the capacity of the system by allowing simultaneous transmission to multiple users in a way that minimizes inter-user interference. In real environments, the channel characteristics between the separate users are not always independent of each other due to the short distance between users and the geometric arrangement of antennas. To verify MU-MIMO systems, carriers and vendors must be able to model and emulate the different propagation scenarios where the users and their movement can be defined on geometrical basis. The use of a radio-channel emulator makes it possible to verify any environmental scenario in order to guarantee the MU-MIMO system performance under non-ideal conditions with several different levels of correlation between the parallel MIMO spatial streams for multiple users.

![Figure 7](image)

**Figure 7.** A MU-MIMO test procedure uses a radio-channel emulator to simulate fading among three users and a base station. (Click on the figure to enlarge.)

The MU-MIMO scenario in Figure 6 can be tested with a multichannel fading emulator. There is a
separate fading channel between each transmitter and receiver when the downlink and uplink topology consist of 4x4 MIMO links with a total of 16 fading channels in both directions. Correlation between the channels is based on the antenna arrangement, channel characteristics and the location of the users and their movement. GSCM models are good for testing MU-MIMO where any kind of propagation scenario can be created and, additionally, where real antenna beam patterns can be included.

The test setup shown in Figure 7 enables manufacturers to design and verify the 802.11ac device spatial multiplexing and beamforming algorithms as well as the critical CSI functionality with a single multichannel-fading emulator unit. An emulator that provides full control of the radio-channel characteristics enables performance testing that allows manufacturers to optimize the air interface performance and to maximize the achievable system throughput before launching products on the market. T&MW

**REFERENCE**

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