Bringing the Real World into the Lab for 4G Wireless Testing

Failure to test base-station or mobile device receivers under realistic conditions can add significant risk in terms of support costs, churn, and operational costs.

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Figure 1. Faded multi-path environment at a single instance in time (left) and over time (right).

Wireless receiver testing can be a frustrating undertaking due to the breadth of the technologies and the depth of technical detail involved. Conformance tests are mandatory, but are not meant to quantify or predict realistic mobile operation. Live-network field-testing is realistic, but it is neither controllable nor repeatable. However, “real-world” testing can be performed in the lab under controlled, repeatable conditions through the use of test equipment that is available in most wireless design labs.

Conformance test cases are written and agreed upon by standards bodies made up of operators and manufacturers. They are meant to ensure interoperability, not to provide data that can help in design verification testing (DVT), debugging, network resource optimization or enhancing the competitive nature of product offerings. In fact, since many of the participants are themselves in competition, truly effective receiver test techniques are closely-guarded secrets. This article describes in detail some of the mobile device testing methods used by the world’s most successful operators, base-station manufacturers, and mobile device developers. The key to realistic testing is the ability to create and re-create dynamic RF scenarios. Given the growing complexity of RF techniques, this relies on the usage of both types of fading generation traditionally available in the lab.

Testing with a Realistic RF Link

The radio link presents the biggest challenge in testing mobiles. It is both the foundation of wireless technology and the area with the most sophisticated new techniques. To squeeze higher data rates from available spectra, operators and manufacturers have developed complex advanced multi-antenna methods that add uncertainty and an elevated level of complexity to testing.

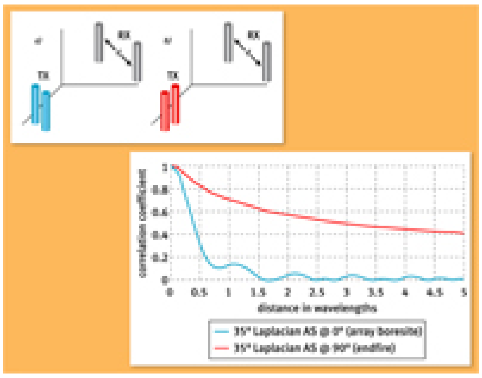

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Figure 2. Correlation coefficients for broadside vs. endfire orientations.

These multi-antenna methods introduce a new level of risk; but this risk can be mitigated by performing DVT and debugging under realistic radio conditions. Otherwise, the deployed device can perform poorly, resulting in increased support costs and customer churn. It can also require disproportionate shares of network resources, causing an increase in operational expenses. In an extreme case, lack of appropriate testing can lead to a failed product or service launch.

Field testing is the simplest approach to realistic testing. It can record what happens at a specific time and place, but it cannot produce the statistically meaningful data sets needed serious evaluation. A better approach is to bring the real world into the lab by identifying real-world RF characteristics and re-creating them with usage cases of RF channel emulators. This strategy leads to a realistic, controllable, and repeatable test plan that can be implemented at a feasible cost point.

Understanding the 4G Radio Environment

Diversity, Multi-Input, Multi-Output (MIMO) and Correlation

When transmitters or receivers use multiple antenna elements to create multiple RF paths, there is a quantifiable correlation between paths. A perfectly high inter-path correlation (correlation coefficient = 1) means that environmental RF impairments affect all paths identically. In this case, transmitting identical signals from multiple elements will not add gain (assuming that total TX power is equivalent to a single-element transmitter).

However, inter-path correlation is never perfect, so adding a redundant path adds gain. Intuitively, when one path is severely impaired the other may still be viable. This apparent gain, or diversity gain, can be transmit diversity (multiple TX antenna elements) or receive diversity (multiple RX elements). If both the transmitter and the receiver use multiple antennas, the system can be called a MIMO system, but the term is usually reserved for the specific cases described later in this article.

Spatial Channel Multiplexing

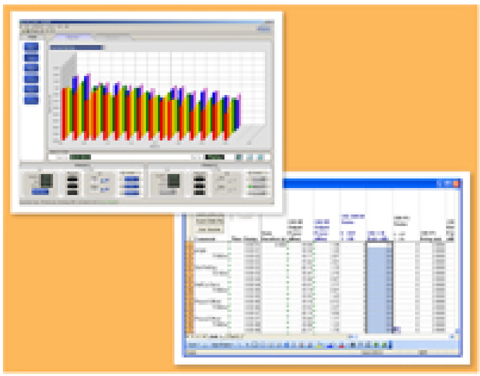

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Figure 3. Coarse-time (~ 10 ms) parameter control can be used with a real-time engine to create virtual drive testing.

In a common MIMO technique called spatial multiplexing, radio paths are distinguished on the basis of spatial characteristics. Paths can be distinguished in the spatial domain, adding system capacity without requiring additional resources in the time or frequency domains. In reality, spatial correlation is always less than one, and spatial multiplexing adds gain.

In the spatial domain, throughput becomes a function of the physical orientation of the antenna, and in how those orientations change relative to each other. Testing must include some way to dynamically adjust the models that define these relationships. In addition, some systems dynamically switch between techniques. If testing does not include these dynamic scenarios it is incomplete at best, and often misleading.

Testing in a Dynamic Environment

At one level, emulated multi-path fading itself is “dynamic”. The emulator uses well-known mathematical distributions to generate the effects of multiple paths and add them to the wireless channel thousands of times per second. This is not “dynamic testing”. It is merely a baseline requirement and represents the environment changing over time for a receiver in a static position.

Standard fading models used in testing are based on these statistical distributions. They are targeted to specific environments (i.e. rural vs. urban) and usage cases (i.e. Doppler effects based on pedestrian or vehicular speeds). This is still not dynamic testing because the average power over time remains constant and path delays don’t change. As complex as fading modeling is, truly dynamic channel emulation goes far beyond this baseline definition.

While dynamic testing is intuitively important, it becomes even more important and complex with the addition of modern advanced antenna techniques. Implications of mobility & a dynamic environment on MIMO Movement affects a considerable change on a MIMO system. System capacity is a function of the ability of the antenna to differentiate paths, based on relative antenna positions and the effects of the radio environment.

Figure 2. shows the effects of a change in the position of the mobile. Because the system can discern spatial paths changes in real time, all the time, it is sometimes the rate of change that causes issues; not just the parametric ranges. It is clearly

important to test the system as it changes, not just at the corner cases or as a set of iterative tests.

As another example, a system may adjust a connection from spatial multiplexing to Space-Time Coding (STC), a combination of diversity and code-domain gains, and down to TX Diversity within a couple of seconds. The engineer must be confident that the system can adjust in real time. In order to fully test MIMO systems, a channel emulator must dynamically alter the RF environment so that it mimics these dynamic conditions.

Fading Engines: Two Approaches

A wireless channel emulator can employ one of two types of fading engines: a real-time engine or a data-playback engine. In the former, standard RF fading models are driven by a pseudo-random fading engine; the longer the test runs, the better the fit with the statistical model. This is useful and is in fact the basis for most standards-based tests but does not include true dynamic control of the RF environment.

In contrast, a data-playback engine loads a buffer with a sample-by-sample representation of the RF environment. Data can come from a channel sounder or synthesized in software. The common question is, “Which method is better?”

More on the Real-time Fading Engine

Given the current and near-future requirements for receiver testing, both approaches are necessary in an efficient DVT or testing lab. While the real-time engine does not create dynamic scenarios, it is possible to dynamically adjust high-level parameters (e.g. average per-path power levels, delay parameters, choice of statistical fading model per path, etc.) while the real-time engine generates fading. “Dynamic” control involves controlling coarse-time parameters over discrete time intervals while the real-time fading engine adjusts momentary power (per the fading model) at a much higher rate.

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click to enlarge

Figure 4. Specific fading scenarios can be re-created with a fine-time (~ 200 us) fading data playback engine (Spirent's Fading Lab is pictured).

This approach can be used to replicate drive-testing where fine-time fading information is unavailable. A cellular scanner recording environmental RF parameters during a drive test around a city can capture power levels received from different transmitters (for handover testing) and gross delay parameters, but not fine-time fading. By marrying scanner data with standard fading models, a repeatable drive test can be performed in the lab.

For example, the “Virtual Drive Test” feature available on select solutions, such as the Spirent SR5500 Wireless Channel Emulator, allows the user to create drive-test scenarios using common spreadsheet software. By copying equations, hours of automated “drive testing” can be set up within a couple of minutes. Or, if all the necessary data can be captured via scanner it can also be converted and used in the lab.

More on a Fading-Playback Engine

Sometimes the best test is a contrived scenario synthesized by the engineer. For example, suppose that a receiver design characteristic leads an engineer to suspect a potentially problematic RF scenario based on a single parameter. This effect can be too rare to capture or can only be captured when other significant effects are in play. In these cases, the engineer must disaggregate the known effect from other causes.

The answer is to synthesize the RF environment. This can be done by using a fading-playback engine that allows the engineer to create the environment from a math package (such as MATLAB®), from ray-tracing software (like 3DRT) or from many other sources.

A fading-playback engine can also be used with channel-sounder data. Unlike a scanner, a channel sounder samples quickly enough to capture fine-time fading characteristics. In this case, the engine will reconstruct a sample-accurate real-world environment, but does not use standard fading models. In this case, all the fading is captured by the system.

Spirent’s Fading Lab for the SR5500 is one example of a fading data playback engine. The SR5500 is a dual-engine solution, so it can perform both fading data playback and real-time fading under dynamic control.

Conclusion

With the introduction of 4G technologies and multiple-antenna techniques, dynamic testing becomes an increasingly critical part of the testing process. Failure to test base-station or mobile device receivers under realistic conditions can add significant risk in terms of support costs, churn, and operational costs. Conformance testing based on standard models cannot exercise the dynamic nature of receivers, and field-testing, while essential, is not repeatable.

RF channel emulators can be used for dynamic testing, but different aspects of testing require different fading engines. Based on the type and quality of available field information and the goals of the process, emulation might require a real-time fading engine (with the ability to dynamically control channel parameters) or a sample-accurate fading-data playback engine. Ideally, an emulator with both fading engines will be available so that all applicable requirements can be met.
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