WHITE PAPER

Optimize 5G New Radio MIMO Test and Debug

The demand for next-generation wireless communications with better performance, MIMO support, shorter design cycles and greater band-width is driving the need for analysis tools that bridge the gap between signal / spectrum analysis and digital design.

Introduction

Radio technology is evolving from single antenna transmit-receive communication systems to multiple-input multiple-output (MIMO) antenna communication systems. MIMO technology is a wireless communication technique for sending and receiving multiple data signals simultaneously over the same radio channel. MIMO techniques play a prominent role in Wi-Fi communications, as well as in 4G long-term evolution (LTE) networks. Further, 5G New Radio (NR)networks use different technologies to deliver higher data rates to end-users than 4G LTE networks, thanks to massive MIMO which combines both spatial multiplexing MIMO and beamforming.

MIMO for 5G NR is significantly more complex in terms of testing due to the wider bandwidths and millimeter wave (mmWave) frequencies. As engineers move from single antenna (SISO) implementations to MIMO, and then to mMIMO, the complexity will increase. These changes introduce various design and testing challenges that impact peak data rates and make it difficult to troubleshoot and debug hardware performance issues. To tackle these challenges, a comprehensive MIMO analysis, such as error vector magnitude (EVM), radio frequency (RF), and baseband impairments is critical to validate mmWave MIMO system performance in real-world scenarios.

KEYSIGHT TECHNOLOGIES

MIMO 101

To navigate the challenges, you need a basic understanding of the techniques that deliver high-quality, robust signals to and from the 5G device. There are different techniques for implementing MIMO and each offers distinct benefits and compromises.

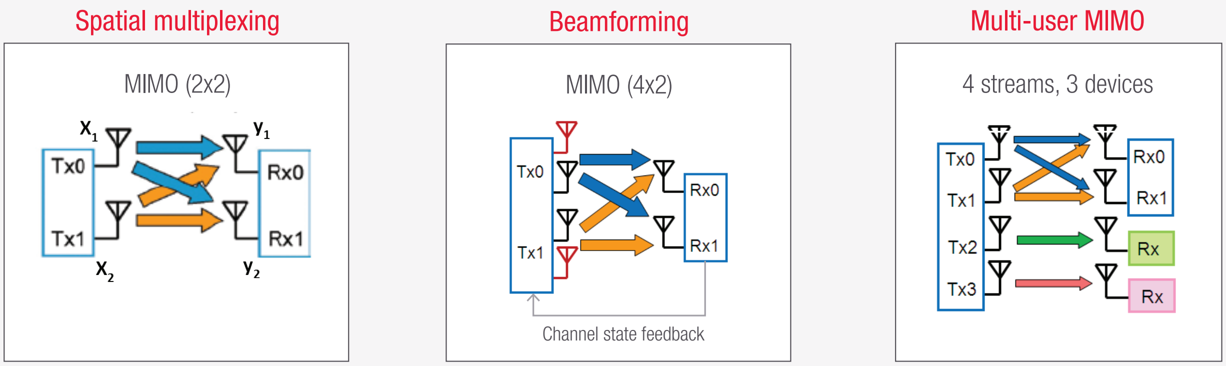

Figure 1. MIMO techniques

- **Spatial multiplexing** represents a multiple-antenna technique that feeds independent data into each antenna, with all antennas transmitting at the same frequency. It then creates multiple channels with independent streams, which improves the efficiency of the frequency channel and leads to higher capacity and data rates.
- **Beamforming** uses multiple antennas to create directional transmissions, increasing gain in exchange for a beam that must accurately point at the receiving antenna. Beamforming is more complex than beam steering as it incorporates channel feedback to manipulate the beam shape and direction in real-time. In Massive MIMO, beamforming is 3D so the beams can appear horizontal and vertical to improve data rates.
- **Multi-user MIMO** is a technique that uses multiple beams that aim at different devices to achieve greater spectral efficiency. Spatial multiplexing and beamforming together make the signal more robust which, in turn, offers better throughput.

5G NR challenges

5G NR standards provide the physical-layer frame structure, new reference signal, and new transmission modes to support 5G enhanced mobile broadband (eMBB) data rates. Designers need to understand 3D beam patterns to ensure that the beams can connect to the base station. To ensure reliability, robust performance, and an optimal user experience, designers need wider channel bandwidths to send more data through the air interface, and spatial multiplexing to enhance channel feedback and improve throughput.

5G NR Release 15 specifies frequency use up to 52.6 GHz with up to 400 MHz bandwidth per carrier, and aggregation of multiple carriers for up to 800 MHz channel bandwidth. However, operating at mmWave frequencies introduces challenges in path loss, blockage, and signal propagation. Beam steering is a key technology that can overcome these issues. And NR specifies new initial access procedures to ensure alignment of the directional transmissions beam steering uses. The main factors for successful beam steering implementation in 5G are validating initial access, beam management, and throughput via the wireless link

Solving 5G NR MIMO challenges

The demand for next-generation wireless communications with better performance, MIMO support, shorter design cycles and greater bandwidth is driving the need for analysis tools that bridge the gap between signal / spectrum analysis and digital design. Engineers need solutions at their disposal that enable them to:

- Generate and analyze 3GPP 5G NR and multi-format waveforms with high fidelity.
- Support a wide range of modulation bandwidths, from 100 MHz to over 5 GHz.
- Minimize signal generation impairments to correct for IQ modulation, phase noise, flatness, and linearity errors.
- Achieve EVM and signal-to-noise ratio better than their device under test (DUT).
- Support a wide range of frequency bands from RF to millimeter-wave.

Keysight's Infiniium UXR-Series oscilloscopes provide the signal integrity, versatility, affordability, and performance necessary to combine signal, spectrum, and digital capabilities in a single instrument.

Keysight's UXR ultra-high-performance real-time oscilloscope enables direct digitization of mmWave wide-bandwidth signals for MIMO testing and debugging. The UXR provides up to four phase-coherent full-bandwidth channels with a maximum instantaneous bandwidth of up to 110 GHz at a sample rate of 256 GSa/s. A 10-bit analog-to-digital converter (ADC) and high sample rate together provide excellent signal fidelity and near-spectrum, analyzer-like dynamic range. These conditions are ideal for in-channel demodulation measurements such as EVM for MIMO applications.

Quick and accurate MIMO measurements

Keeping pace with developments in the MIMO applications space depends on advanced measurement solutions that enable you to quickly validate your research and increase your success rate with innovative technologies. Such solutions need to deliver exceptional measurement quality, as well as a deeper understanding of measurement challenges and transformative insights.

Figure 2 shows a 44 GHz 5G test bed configuration with the UXR that enables 4x4 MIMO analysis and phase-coherent measurements of a device under test (DUT). For example, with DUTs such as phased array antenna systems, evaluating the performance between individual antenna elements with real-world modulated signals is critical to revealing true device performance and characteristics.

Figure 2. Keysight's 5G test bed

These are the instruments that will help you create the configuration:

- UXR1104A Infiniium UXR-Series oscilloscope: 110 GHz, 4 channels
- 89601B PathWave vector signal analyzer (VSA) software
- M9384B VXG microwave signal generator

Using this configuration, 5G development engineers can leverage key benefits like exceptional in-band performance (EVM), wide bandwidth, low phase noise, and speed to address their 5G NR for MIMO challenges.

Achieve 5G NR EVM performance at wider bandwidths

Numeric error vector magnitude (EVM) is a key indicator of a signal's modulation quality because it provides an overall indication of waveform distortion.

5G NR specifies a cyclic prefix orthogonal frequency division multiplexing (CP-OFDM), which is a multi-carrier modulation scheme. An EVM measurement reflects any variation in a circuit's phase, amplitude, or noise that appears in wideband signals.

With the expected use of higher-order modulation schemes in 5G, up to 256 quadrature amplitude modulation (QAM) initially, and then up to 1024 QAM, components and devices require a better EVM result as the modulation density increases.

Table 1. EVM requirements for different 5G modulation schemes per 3GPP TS 38.101-1

Modulation scheme for PDSCH	Required EVM
Quadrature Phase Shift Keying (QPSK)	17.5%
16 QAM	12.5%
64 QAM	8%
256 QAM	3.5%

A test solution needs to have the capability to evaluate the constellation diagram and measure the EVM that 5G components and devices require. You will also need the flexibility to make spectrum measurements and scale to higher frequencies and bandwidths.

Keysight's Infiniium UXR-Series enables 5G NR EVM measurements with performance equal to or better than a spectrum analyzer in FR2 bands, making it a cornerstone of Keysight's 5G testbed. The UXR provides flexibility and scalability in addressing a multitude of frequency bands, extreme frequency bandwidths, and multiple channels to address demanding emerging mmWave test challenges It supports all 5G NR frequency bands:

- FR1 (450 MHz to 6000 MHz)
- FR2 (24250 MHz to 52600 MHz)
- component carriers (CC), bandwidth >400 MHz
- display data channel (DDC) support for multi-component carriers aggregation up to 2 GHz bandwidth

Low phase noise at high frequencies

Low phase noise is essential for making accurate mmWave measurements. MIMO measurements require distributing a low-phase-noise clock to multiple channels without degradation. The length and wide bandwidth of 5G NR mmWave signals demands a measurement with both excellent close-in phase noise and high-offset phase noise. Broadband noise increases with bandwidth by 10 x log (bandwidth increase). Phase noise increases with center frequency (CF) by 20 x log (CF increase). Consequently, moving a 5G carrier from 3 to 39 GHz will increase phase noise by more than 22 dB if the frequency reference does not improve.

Consider the instruments in your MIMO test setup carefully to address this challenge. Keysight's test setup uses the new UXR oscilloscope which has the low noise, wide bandwidth, multiple channels, and flat frequency response to measure 5G NR MIMO mmWave signals. The UXR also features a clean 8 GHz clock (-130 dBc / Hz at 100 kHz offset) and distributes it to all four channels. The clock multiplies up to 128 GHz for the samplers to collect data at 256 GSa/s. The fixed multiplication chain enables the use of proprietary Keysight amplifiers and filters to eliminate nearly all phase noise beyond the 20 x log (CF increase).

Fixed multiplication maintains tight coherency between channels. When making multiple channel measurements over single channel measurements the jitter is < 10 fs rms. For example, if you run a 39 GHz carrier into two channels of a UXR and measure it with 1 GHz instantaneous bandwidth, it will show < 1/2 degree root mean square (RMS) of jitter between the channels that appears in Figure 3.

This performance makes the UXR an excellent choice for mmWave EVM measurements and enables stellar phase noise measurements. Multiple channels and cross-correlation remove the noise contribution of the channels. In essence, the channels will generate very low-noise and very wide (many gigahertz) offset phase noise measurements.

Figure 3. Keysight UXR phase noise measurements

The importance of speed

Using an oscilloscope is not usually your first choice for making EVM measurements on 5G NR signals. This is due to the slow processing speed and high sample rates that you need for these measurements. Oversampling results in a more accurate and lower EVM result, but increases the EVM demodulation processing time. The UXR-Series oscilloscope supports digital down-conversion (DDC) that enables faster processing and longer time-capture. This technique enables you to down-sample a RF signal's high frequency content before storing it in the oscilloscope's memory.

The oscilloscope first applies a bandpass filter to a frequency span that prevents out-of-band noise from aliasing into the passband region during the down-sampling process. Half-band decimators perform frequency shifting and decimation of the data. Smaller frequency spans enable you to apply more decimation. This results in lower output sample rates and less data storage than would be the case when capturing the full sample rate data record. The smaller data size also requires less data transfer and post-processing time. The UXR oscilloscope supports a series of discrete frequency spans, ranging from 40 MHz to 2.16 GHz. The VSA software can calculate measurements such as EVM several orders of magnitude faster than it could on a full sample rate data record. Figure 4 shows a long capture time and rapid processing.

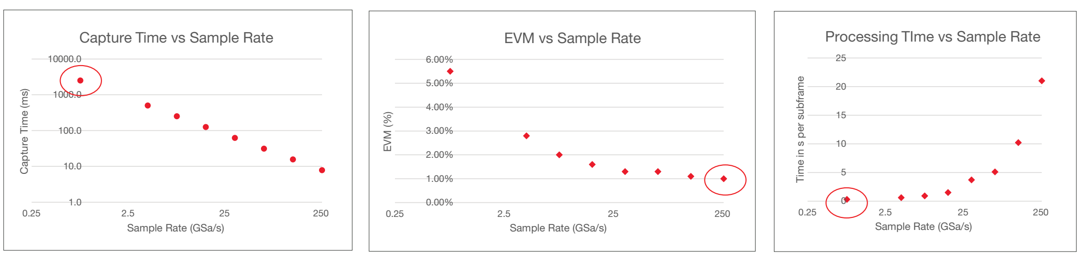

Figure 4. Speed versus performance in 5GNR EVM

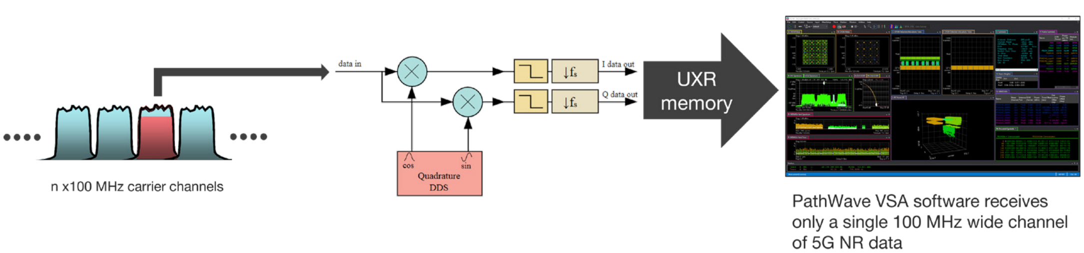

Figure 5. The digital down conversion (DDC) captures only a single channel decimated into memory, which accelerates measurements and shows an efficient use of oscilloscope memory

Choosing the right tools

In 5G, "massive" is an important word whether you are discussing performance expectations or the implementation of MIMO schemes. Delivering on all fronts depends on the evolution of existing technologies, and revolution in new technologies. This idea applies equally to 5G and the hardware and software tools engineers need in order to develop the next-generation wireless ecosystem. Keysight provides 5G solutions that help designers validate their designs in real-world test scenarios to get high-performance products to market quickly.

Learn More

Infiniium UXR-Series Oscilloscopes

5G R&D Test Bed

5G Waveform Generation & Analysis Testbed, Reference Solution

Learn more at: www.keysight.com

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