Testing 5G New Radio Devices

Master the complexities of 5G New Radio and accelerate your 5G designs

KEYSIGHT TECHNOLOGIES

With 5G New Radio (NR) initial standards approved by 3GPP and first chipsets released, the race is on to design and deliver high quality devices that can meet the tough requirements of 5G. 5G NR uses new technologies and provides performance improvements due to flexible numerology, more complex waveforms and channel coding techniques, frequencies that extend into millimeter-wave (mmWave), wider channel bandwidths, and advanced multi-antenna access schemes. This combination of new technologies significantly increases complexity in design and test. This application brochure describes new test methodologies and techniques for testing 5G NR chipsets, components, and devices so you can accelerate your 5G NR designs.

5G NR Test Applications

- Testing 5G NR Data Throughput
- 5G NR OTA Beamforming Functional Test
- OTA Test for mmWave 5G NR Devices and Systems

Testing 5G NR Data Throughput

5G NR will require much faster data rates in order to support enhanced mobile broadband (eMBB) use cases like UHD video streaming, virtual reality (VR), and augmented reality (AR). As mobile operators accelerate their 5G NR deployment plans, chipset and device manufacturers must also accelerate their development activities, including determining how to test 5G NR data throughput most effectively.

The 5G eMBB (enhanced mobile broadband) use case targets data rates of up to 20 Gbps in the downlink (DL) and 10 Gbps in the uplink (UL). 5G NR accomplishes this by utilizing higher-frequency mmWave spectrum, in addition to using sub-6 GHz frequencies. LTE operates at frequencies up to 6 GHz, whereas mmWave operating bands up to 52.6 GHz are already approved in 5G NR Release-15. 5G NR introduces new frame structures and beamforming access procedures that increase design complexity, increasing design difficulty and functional prototype test procedures.

Top challenges testing 5G NR device throughput include:

- Configuring 5G NR frame structures for higher throughput
- Configuring 5G NR devices to make and report measurements for optimal link adaptation
- Optimizing 5G NR beamforming performance at mmWave frequencies

5G NR frame structures. 5G NR introduces flexible numerology that scales the subcarrier spacing. The scalable slot duration allows the subcarrier to be optimized for different types of service levels, balancing throughput, latency, and reliability. Subcarrier spacing is governed by 2^{μ} x 15 kHz subcarrier spacings. 15, 30, and 60 kHz subcarrier spacings are used for the lower frequency bands, and 60, 120, and 240 kHz subcarrier spacings are used for the higher frequency bands. Figure 1 shows that as the frequency increases, slot duration is shorter in time, decreasing the TTI (transmit time interval) and optimizing the subcarrier spacing for the operating frequency band and channel characteristics.

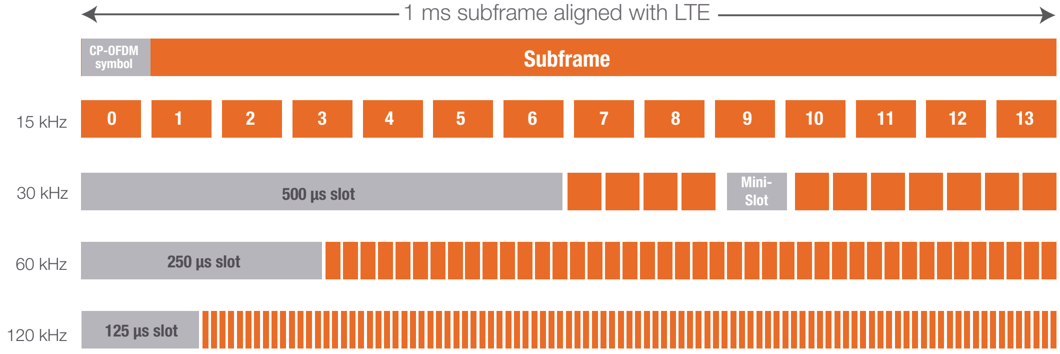

Figure 1. Relationship between subcarrier spacing and slot duration

In TDD (time division duplex) bands, 5G NR also allows dynamic TDD operation where the network can dynamically assign each slot to be DL or UL. This allows more efficient use of the spectrum. By using dynamic TDD, the network can allocate more or fewer resources for DL or UL, depending on the specific traffic requirement of the network, device, and service being provided.

While testing 5G NR device throughput, it is critical to have access into the lower-layer frame structure to configure and test for maximum throughput.

Beamforming performance at mmWave frequencies. Beamforming can be used to overcome propagation and penetration losses at higher frequencies. Beamforming achieves a stronger signal-to-noise ratio (SNR) by using high directive radiation beams that provide additional antenna gain. The following new procedures for beamforming have been defined in the 5G NR specifications:

- Beam acquisition and tracking
- Beam refinement
- Beam feedback
- Beam switching

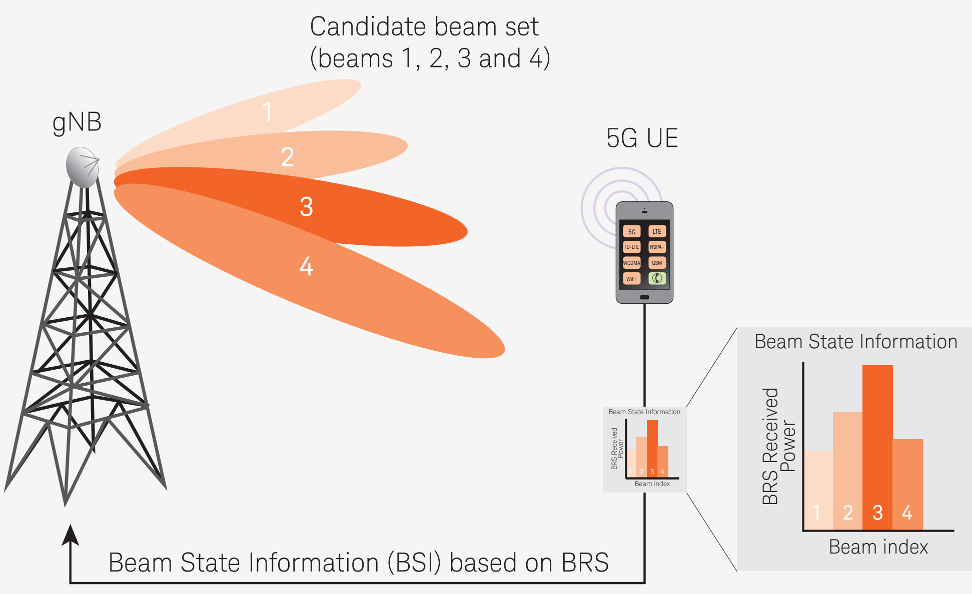

Figure 2. Analyzing 5G beam refinement

Many factors at different layers of the protocol stack impact beamforming performance. Locating bottlenecks and testing different structures is vital for optimizing throughput. In addition, testing beamforming at mmWave frequencies requires over-the-air (OTA) test methods that further complicate the test solution.

5G Throughput Test Solution

Using a network emulator, layer 1 (PHY), layer 2 (MAC/RLC/PDCP), and layer 3 (RRC/NAS) can be simulated to create data throughput tests.[1]

A sample test configuration (figure 3) uses the **Keysight 5G Protocol R&D Toolset** to create the test and configuration script elements. Power levels for synchronization and reference signals, beamforming, and resource blocks used for transmitting and receiving control information and data are specified.

A script is used to evaluate data throughput, and an integrated real-time trace displays the progress of the test including layer 3 protocol messages being sent and received. With the dynamic control points enabled, a test engineer can modify parameters in real time.

The Log Viewer includes a KPI viewer that captures key performance indicators at different layers. This includes throughput graphs at different layers (PHY/MAC/RLC/PDCP and application layer), CQI (channel quality information), MCS (mobile switch center), BLER (block error rate) and ACK/NACKs (acknowledgement/negative acknowledgement) versus time, providing insight into possible bottlenecks in the design. From a signal quality perspective, KPIs like BSI (beam state information) and BRI (beam refinement information) can be verified to ensure that the UE (user equipment) has selected the strongest beam.

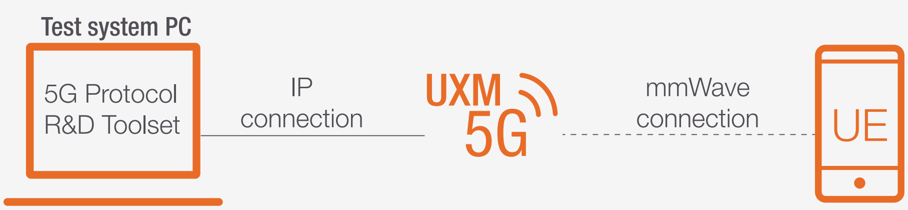

Figure 3. Keysight 5G throughput test setup

Since 5G NR implements new frame structures and beamforming techniques at mmWave frequencies, having a test platform that enables evaluation and tuning at different layers of the protocol stack can be very valuable. Keysight's **5G Protocol R&D Toolset** provides an easy-to-use solution with the ability to monitor and make changes at different layers of the protocol stack, providing insights for rapid optimization of device throughput.

For more information see application note: **Testing 5G Data Throughput**

1 PHY: physical layer, MAC: medium access control, RLC: radio link control, PDCP: packet data convergence control, RRC: radio resource control, NAS: non-access stratum

5G NR OTA Beamforming Functional Test

3GPP 5G NR Release-15 specifies mobile operation up to 52.6 GHz. To overcome higher path loss and multi-path propagation issues at these higher frequencies, beam steering or beamforming will be used. Beam steering is not new and can provide high directivity signals to a desired direction. However, beam steering for mobile communications at mmWave frequencies requires new access techniques that need to be tested and validated. Devices and base stations need to find each other and maintain a quality communication link while the device moves through the network.

5G NR devices operating in the new frequency range 2 (FR2) mmWave operating bands are likely to have their antennas integrated into the chipset and handsets making it difficult to probe for conducted tests. Therefore, over-the-air (OTA) testing is expected to replace traditional conducted test methods that were used in sub-6 GHz designs. OTA testing can also provide a more realistic assessment of beam performance in real-world scenarios.

Top challenges testing mmWave beamforming include:

- Validating mmWave initial access
- Optimizing mmWave beam tracking and switching
- Testing beamforming over-the-air (OTA)

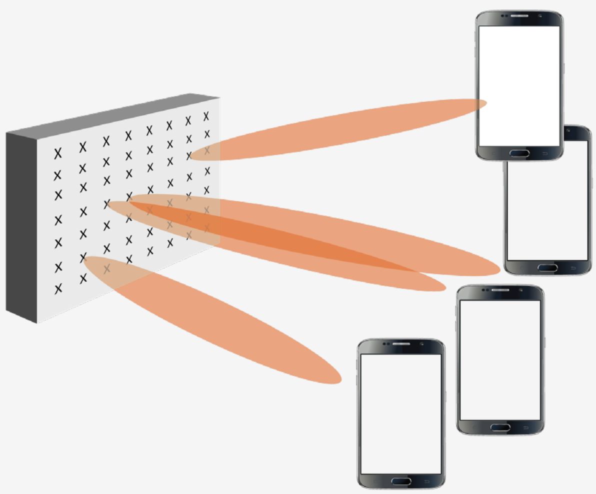

Figure 4. Multi-element antenna arrays steering beams to multiple devices

Conceptually, beam steering is implemented by applying phase and gain adjustments on signals transmitted by an array of antenna elements, thereby providing high gain in specific spatial directions (figure 4).

mmWave initial access. New initial access procedures provide a mechanism by which both the UE and 5G node (gNB) establish suitable beam directions for directional communications. Once the initial acccess procedure is completed, the UE enters a 'connected' state and further beam tracking/refinement is performed using closed loop beam adjustment procedures.

Beam refinement. Using the channel state reporting (CSI) reporting mechanism, the 5G node can track the state of downlink beams with periodic reference signal (CSI-RS) measurements. If the serving beam is sub-optimal, the 5G node can instruct the UE to switch to a different beam.

The highly directional nature of beamformed signals makes it critical to test initial access, beam tracking, and beam switching procedures with beams coming from different angular directions. This requires a real-time OTA test environment.

Solution for testing mmWave OTA beamforming

To support mmWave OTA beamforming measurements, the Keysight UXM 5G wireless test platform can be used with mmWave RF heads and dual polarized horn antennas. The UXM network emulator, together with mmW RF heads, acts as a gNB and supports above-6 GHz transmitter (i.e., downlink) and receiver (i.e., uplink) RF ports. The solution implements the baseband and protocol processing elements to emulate the 5G network entities. This platform enables 5G NR protocol and RF tests. When combined with mmWave RF heads, dual polarized horn antennas, and an anechoic chamber, emulation of simultaneous downlink beams is possible. This setup can be further enhanced, with the addition of positioners to control UE orientation. In this configuration, 5G beamforming with angle of arrival (AoA) test capability in different spatial orientations is possible.

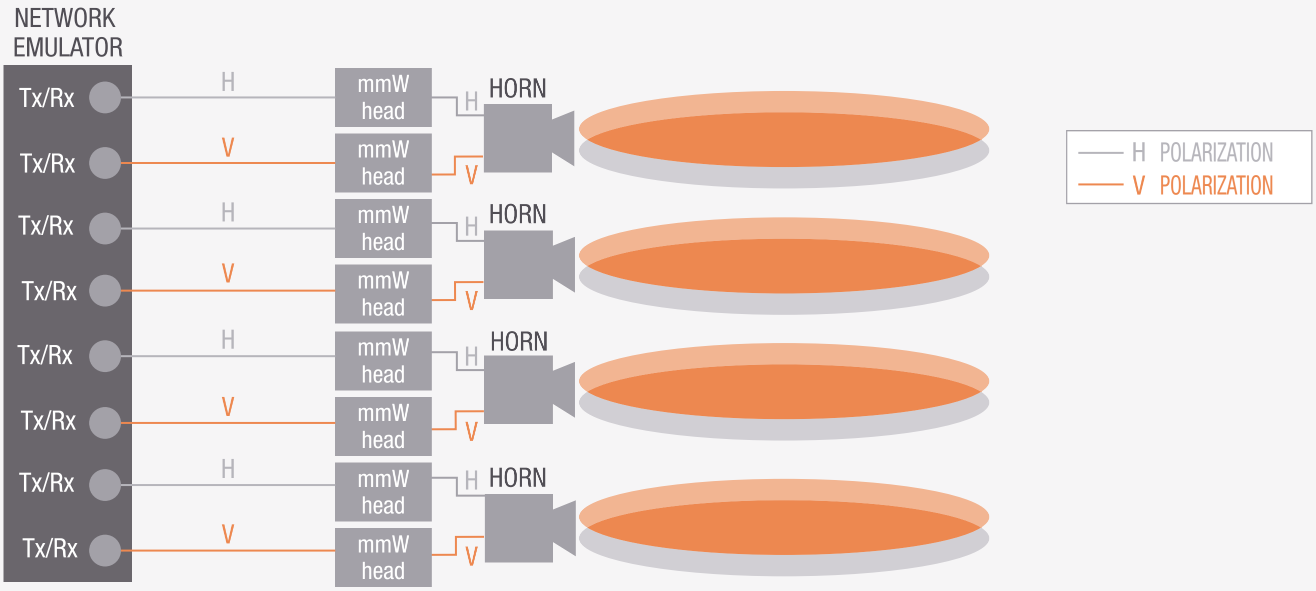

Figure 5. Simulating downlink with multiple angle of arrivals

The **Keysight 5G Protocol R&D Toolset** provides scripted control of 5G NR protocol configuration parameters and procedures such that this OTA test setup can be used to test UE beam power measurements, beam acquisition and tracking, beam switching, and other mobility and protocol test scenarios.

For more information see application note: **OTA Setup for 5G TF Beamforming Functional Tests**

OTA Test for mmWave 5G NR Devices and Systems

mmWave frequencies are important in 5G because they offer more contiguous spectrum and wider bandwidth radio channels. mmWave signals, however, are also subject to signal propagation issues such as increased path loss, delay spread, or even blockage due to chassis or human interference, all of which make it more difficult to establish and maintain a mobile-to-base station wireless communication link. Over-the-air (OTA) testing is needed to test modems that have integrated antennas. OTA tests will be used to visualize, characterize, and validate 5G device beam patterns and performance in a variety of real-world scenarios. OTA testing is one of the most challenging aspects of 5G device development.

Top challenges testing mmWave beamforming include:

- Issues testing mmWave devices in the far-field
- OTA test methodologies still being defined

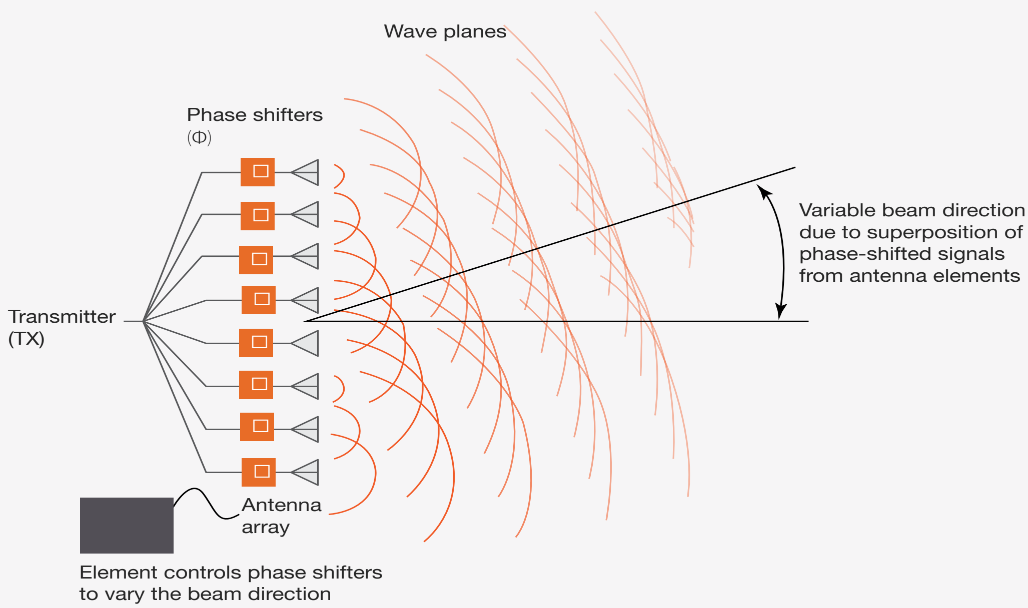

Figure 6. Multi-element antenna array with phase shifters to steer the beam

Phased array antennas that can produce narrow beams with higher antenna gain for overcoming higher path loss at mmWave frequencies, are being integrated into 5G devices with no connectors or probe points for conducted tests. As a result, OTA testing is needed to validate and optimize 5G device performance.

Testing mmWave devices in the far-field. Measurements in the direct far-field are conceptually the simplest and most comprehensive type of OTA measurement system. The device is mounted on a positioner that rotates in azimuth and elevation. As frequency increases and device-radiating antenna size increases, the far-field distance gets longer as well. For example, a 15-cm radiating diameter, operating at 28 GHz, results in a far-field distance of 4.2 meters and a path loss of 73 dB. In this case, a traditional far-field test method results in an excessively large far-field test chamber with path loss that is too great to make accurate and repeatable OTA measurements.

OTA test methodologies. OTA tests are required at different phases of the development cycle, from R&D through conformance tests, and into manufacturing, installation, and maintenance. OTA test solutions must be flexible to handle a wide range of needs. Conformance testing is a critical milestone that all base stations and UEs must pass before being released into the market. 3GPP conformance tests can be grouped into RF, radio resource management (RRM), demodulation, and signaling tests. To date, these tests are less than 50% defined, leaving a big gap in OTA test methods.

Due to the range of test requirements across the design and validation lifecycle, no single test method can fully cover all possible test needs. Understanding the underlying challenges and proposed OTA test methods will be essential to early success with 5G NR device development.

OTA Test Solution

A typical OTA test solution will include an anechoic chamber, different probing techniques, and test equipment to generate and analyze the radiated signals in a spatial setting. The anechoic chamber provides a non-reflective environment with shielding from outside interferences so that radiated signals of known power and direction can be generated and measured in a controlled environment.

OTA test methodology can roughly be determined by the operation frequency, device radiating antenna array dimension, and what tests need to be performed. To date, 3GPP has approved three RF performance OTA test methods for base stations and UEs as shown in table 1.

Direct Far-Field (DFF)	In-Direct Far-Field (IFF)	Near-Field to Far-Field Transformation (NFTF)
A simple, comprehensive approach	Provides a near-field to far-field conversion enabled in a compact antenna test range (CATR)	A compact approach that can be lower cost
Can be very large with greater path loss for mmWave devices	Suitable for testing mmWave devices but not well suited for spatial RRM test	Limited application for transceiver only, no receiver or RF parametric tests yet

Table 1. A comparison of 3GPP approved OTA test methods

The DFF test method is the most capable and covers a broad spectrum of test needs. However, due to the excessive path loss with larger radiating antenna arrays, the DFF method can only be used with devices that have radiating antenna arrays ≤ 5 cm. The IFF test method is a new alternative offering a far-field test environment in a much shorter distance than the DFF method.

It can take a considerable amount of time and rework to investigate and implement an OTA test solution on your own. Consider Keysight as an OTA partner wth experience implementing the different OTA methods that can be used across different phases of the device lifecycle. Keysight's OTA test solutions include chambers, probing, and the test equipment used to address a wide range of RF, demodulation, and functional performance tests requirements from RF to mmWave frequencies.

For more information see white paper: **OTA Test for Millimeter-Wave 5G NR Devices and Systems**

Conclusion

New 5G technologies and performance improvements are driving the need for new test methodologies. As flexible numerology, more complex waveforms and channel coding techniques, frequencies that extend into mmWave, wider channel bandwidths, and advanced multi-antenna access schemes are implemented in 5G devices, designers need to access multiple levels of the protocol stack to sufficiently test throughput and beamforming performance. In addition, the need for OTA test solutions complicates the situation even further.

Keysight partnered early with industry leaders to understand the complexities of 5G and to develop test solutions that span the entire workflow, from simulation and development, to design verification, conformance and acceptance test, and ultimately to manufacturing and deployment.

Our solutions leverage the same measurement techniques throughout the workflow to ensure consistent results, guiding you to the appropriate test solutions specified by chipset vendors and operators, enabling you to leverage measurements and get to market faster.

Learn more at: www.keysight.com

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