
# First Steps in 5G

## Overcoming New Radio Device Design Challenges Series

## Part 3: MIMO and Beamforming

Multiple-input / multiple-output (MIMO), beam steering, and beamforming are the most talked about technologies in 5G. They are essential for delivering the 100x data rates and the 1,000x capacity goals the International Mobile Telecommunications-2020 (IMT-2020) vision specifies.

According to the Ericsson Mobility Report[1] (June 2019), mobile data traffic grew 82% year on year in the first quarter of 2019. The report predicts mobile traffic will rise at a compound annual growth rate of 30% between 2018 and 2024. It forecasts a total of 8.8 billion mobile subscriptions by 2024, including 1.9 billion for 5G enhanced mobile broadband.

**MIMO introduces three key design challenges:**

- 3D antenna beam pattern verification
- Validation of mmWave link integrity
- Device performance optimization under real-world conditions

1. Ericsson Mobility Report. June 2019. Accessed October 11, 2019. https://www.ericsson.com/49d1d9/assets/local/mobility-report/documents/2019/ericsson-mobility-report-june-2019.pdf.

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MIMO is one important approach to improve the capacity and efficiency of a network to meet these demands. These multi-antenna technologies must support multiple frequency bands — from sub-6 GHz to millimeter-wave (mmWave) frequencies — across many scenarios, including massive Internet of Things connections and extreme data throughput. Implementing MIMO on 5G devices brings several design challenges, including 3D antenna beam pattern verification, mmWave link integrity, and optimization of device performance under real-world conditions.

## MIMO Technology Basics

Understanding the challenges requires a basic knowledge of the techniques used to deliver high-quality, robust signals to and from the 5G device. There are different techniques for implementing MIMO, each offering distinct benefits and compromises.

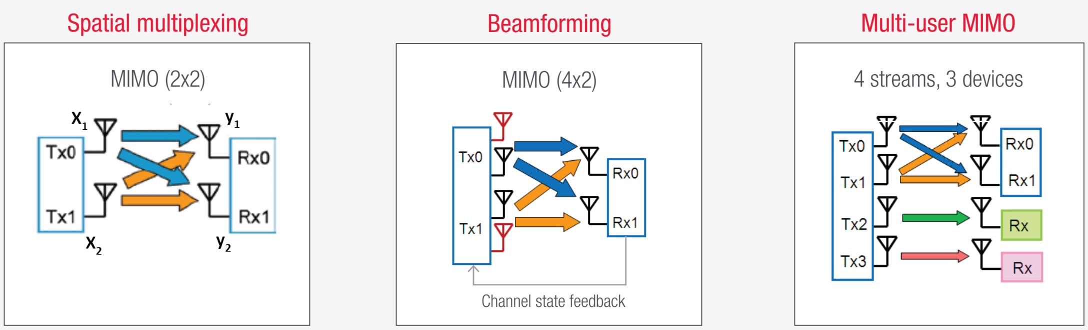


**Figure 1. Spatial multiplexing MIMO configurations**

Spatial diversity helps improve reliability in many forms of radio-frequency (RF) communication. Spatial diversity consists of sending multiple copies of the same signal via multiple antennas. This common technique increases the chances of properly receiving the signal, improving reliability.

Spatial multiplexing is a different multiple-antenna technique that feeds independent data into each antenna, with all antennas transmitting at the same frequency. Spatial multiplexing creates multiple channels with independent streams, which increases the overall data capacity.

Beam steering and beamforming use 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, incorporating channel feedback to manipulate the beam shape and direction in real time. Spatial multiplexing with beamforming increases signal robustness with the added advantage of improved throughput. Multi-user MIMO is a technique that uses multiple beams directed at different devices to achieve greater spectral efficiency.

# MIMO and Beamforming Challenges and Solutions

MIMO and beamforming at mmWave frequencies introduce many challenges for device designers. 5G New Radio (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 must understand the 3D beam patterns and ensure that the beams can connect to the base station and deliver the desired performance, reliability, and user experience. The following techniques are essential to successfully implementing your 5G device design:

1. 3D antenna beam pattern verification
2. mmWave link integrity validation
3. Device performance optimization under real-world conditions

## Beam pattern verification

Beam performance validation requires measurements of 3D antenna beam patterns to verify the right antenna gain, side lobes, and null depth for the full range of 5G frequencies and bandwidths. The location of the side lobes and nulls is important to tune the antenna and maximize the radiated efficiency of the signal.

While design verification of prototypes is crucial, building mmWave prototypes is costly. Modeling an antenna in a simulated system with channel models and base station links provides insights early in the design cycle that reduce prototype and rework costs early. The simulation data becomes an important part of the design process and helps with troubleshooting throughout the development workflow.

Figure 2 shows a link-level simulation with mmWave channel models to help you understand the performance of a simulated antenna. With this approach, it is possible to add different impairments to the simulation to optimize your design before developing hardware prototypes.

Multi-element antenna arrays will be used on mobile devices to implement beam steering or beamforming. Phased array antennas are a practical and low-cost means of dynamically creating and pointing beams in a desired direction, also known as beam steering. An array of smaller antenna elements forms a phased array antenna. By varying the relative phases and amplitudes of the signals applied to the individual elements, the antenna array can steer and shape a beam in a chosen direction. These arrays will be incorporated into RF integrated circuits and will require OTA testing as there are no probe points to make conducted measurements.

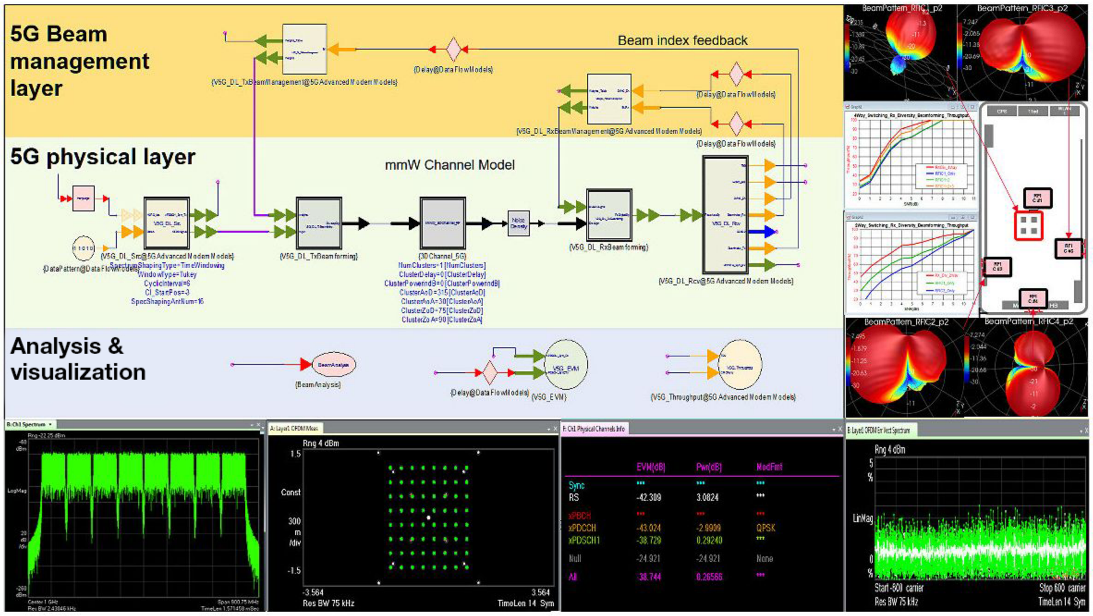


**Figure 2. Electronic system-level tools such as Keysight's SystemVue help designers quickly integrate and validate their designs before moving to hardware**

As mentioned above, once a design moves into hardware, designers must validate that the device produces the correct beam width, null depth, and gain over the required range. It must also meet power output limits. In hardware, this requires over-the-air (OTA) test methods.

**Figure 3. Indirect far-field compact test antenna range for mmWave OTA testing**

## mmWave link integrity


LTE systems use antennas covering large angular areas to cast a wide net for potential users. 5G will use narrow beams to overcome mmWave signal propagation issues, but this makes it more difficult for the user equipment (UE) to find the beams from the base station. Maintaining a quality link is also an issue, especially when the device moves through the network. 5G NR release 15 specifies new procedures for initial access and attach when establishing the wireless link connection. Since neither the device nor the base station knows the other's location, the base station uses beam sweeping to transmit channel information in sync blocks across the spectrum, as shown in Figure 4. The UE determines the strongest match and transmits back to the base station. Once the base station knows the direction of the UE, it establishes a communication link.

Beam acquisition and tracking, beam refinement, beam feedback, and beam switching procedures exist. It takes longer to establish this connection when using mixed numerologies. Designers need to implement, validate, and optimize all these functions, or the user will experience dropped calls or poor performance.

Testing the protocol early in the development cycle ensures that the device can establish and maintain a call. A network emulator with a built-in protocol state machine emulates network signals and tests the resulting device signals to verify and optimize initial access and beam management.

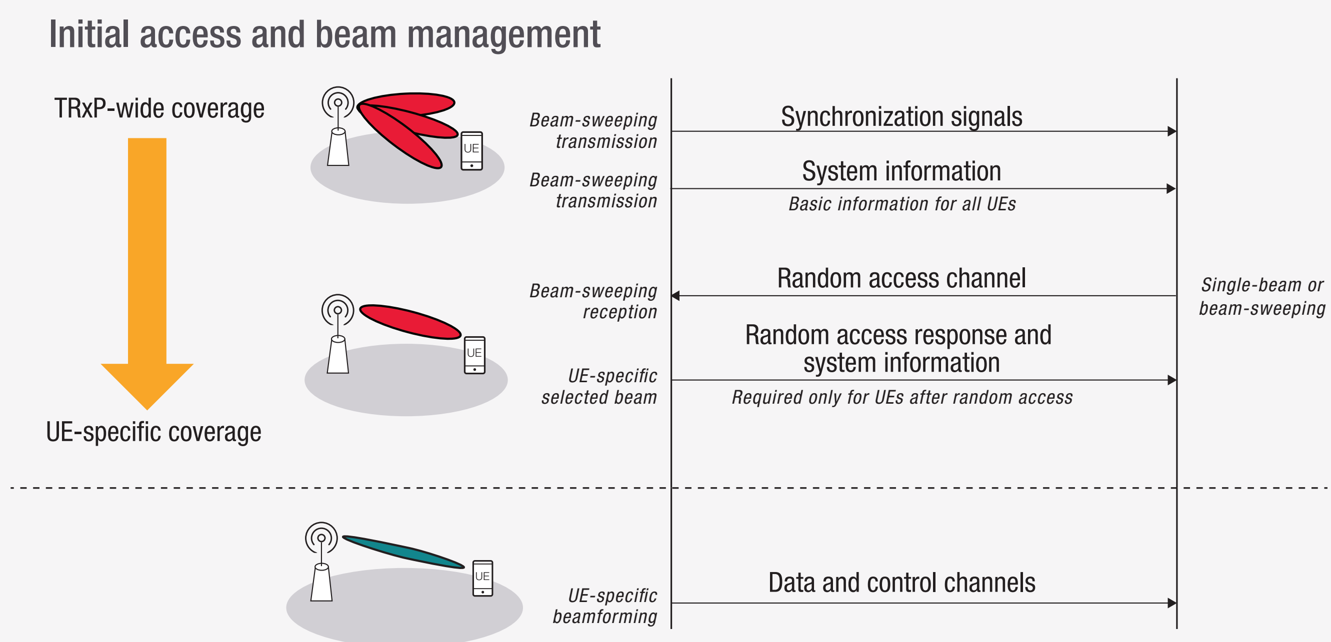


**Figure 4. 5G initial access and beam management**

## Device performance optimization under real-world conditions

Key performance indicators for the wireless communications system include throughput and latency. If the latency — or delay — is too great, then the end-user experience suffers. The different layers of the protocol stack need to work together to deliver the latency and throughput targets of the 5G system. It is important to understand how the device will perform, not only when acquiring a beam, but also when performing handovers, fallback to 4G, and other beam management functions.

One of the most efficient methods for testing end-to-end beam throughput is using a network emulator to send protocol commands to the UE and measuring the UE's response. A network emulator provides the scripts to configure a 5G cell connection, change power levels for synchronization and reference signals, and set beamforming parameters and resource blocks for transmitting and receiving control.

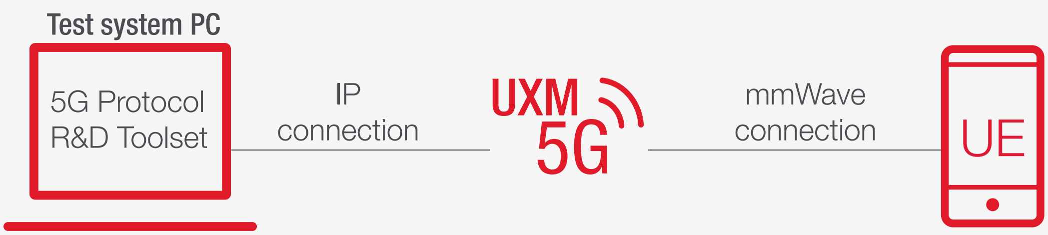


**Figure 5. Test setup with a network emulator**

Most component and device testing requires a controlled environment. However, wireless devices need to operate in environments that have signal propagation issues, including excessive path loss, multipath fading, and delay spread. These real-world impairments impact device performance and require evaluation. Adding a channel emulator to the test setup enables characterization of end-to-end full-stack data throughput while emulating a variety of real-world radio conditions.

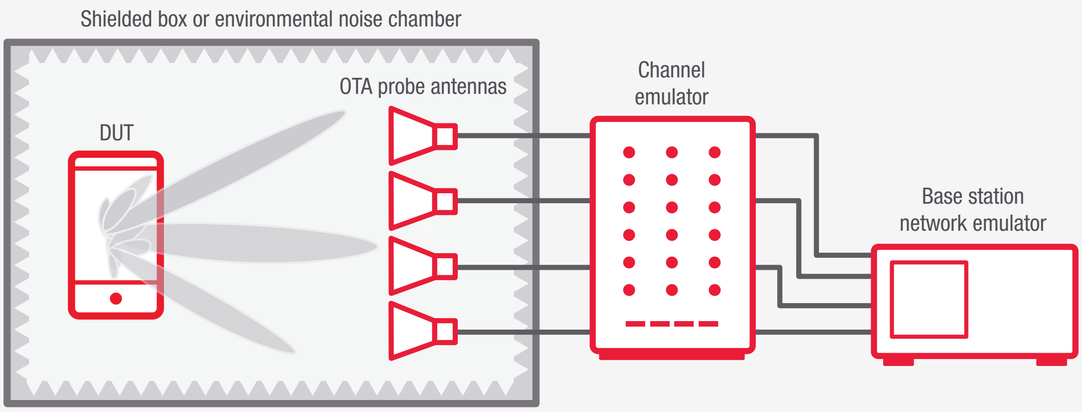


**Figure 6. A channel emulator, such as the Keysight PROPSIM F64, lets you evaluate under real-world conditions**

## Choosing the Right Tools for Evaluating Antenna Beam Patterns

MIMO, beam steering, and beamforming are critical technologies for 5G devices. Implementing multi-element antennas introduces many challenges for device designers. Having the right tools to evaluate antenna beam patterns and ensure that devices can connect to the network and deliver the expected quality of service is essential.

Keysight provides test solutions that validate beam structure and device performance on a simulated network, giving designers a seamless workflow from protocol to RF, resulting in more efficient development — even in an environment of ever-evolving 5G standards. With the addition of channel emulation, designers can validate their designs in real-world test scenarios and get high-performing products to market even quicker.

## Additional Information

See Keysight's 5G Solutions webpage to find out more about 5G NR solutions and view the next installment of the 5G white paper series, which reviews OTA testing challenges.

You can access the different parts of the First Steps in 5G white paper series by clicking on the respective links:

- First Steps in 5G – Part 1: 5G New Radio Standard
- First steps in 5G – Part 2: Millimeter-Wave Spectrum
- First Steps in 5G – Part 3: MIMO and Beamforming
- First Steps in 5G – Part 4: Over-the-Air Test

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