White Paper

5G Impact on Wireless Device Lab Testing

Mobile device test considerations to assure 5G lives up to its promise

Few technologies have arrived with more fanfare and greater promise than 5G. Fifth generation (5G) cellular promises a list of impressive numbers that far exceed today's 4G LTE specifications. The 5G network of the 2020's is slated to deliver us:

- Download peak speeds of up to 20 Gbps, upload peak speeds of 10 Gbps
- 99.999% reliability
- 1 millisecond latency
- Sub-meter level of location accuracy
- Support for up to 1 million devices per square kilometer[1]

These and other capabilities enable a wide range of demanding, mission-critical applications, including autonomous vehicles, smart grids, augmented/virtual reality (AR/VR), and even remote robotic surgery.

But of course, delivering on those promises won't be quick and easy. For operators, infrastructure vendors and device manufacturers, 5G is introducing a brand-new technology that uses more spectrum bands and fundamentally different core and radio network architectures vs. 4G. All of that creates a steep learning curve riddled with complexity and challenges. 5G deployment takes many stages of evolving technology and its ramp will demand agility as the 5G industry standards continue to move forward.

1 *https://www.5gamericas.org/wp-content/uploads/2019/07/3GPP_Rel_14-16_10.22-final_for_upload.pdf*

"There's a lot of pressure on the industry to be able to deliver the 5G experience, especially from the very beginning," says James Kimery, director of marketing at National Instruments, which is collaborating with Spirent on 5G performance testing. Media attention and scrutiny on initial 5G data and application performance will live in the spotlight. Contrary to the belief that consumers are uninterested in 5G services, a recent Ericsson survey found that the idea of 5G appeals to 76 percent of smartphone users globally—and that expectations are high.

Testing at many levels is critical for assuring 5G's bold promises. Not only to assure conformance with industry standards, but to deliver against the great expectations. "With 5G, service providers are dramatically increasing the range of services that they offer and the variety of devices that they support," says Phil Marshall, Tolaga Research co-founder and chief research officer. "Efficient and reliable testing is a linchpin for 5G to succeed. Without this, reliable service and device enablement will be uneconomic and ineffective."

This paper discusses why 5G is inherently more complex than 4G and how that additional complexity has created new test challenges and considerations for operators, device OEMs, test labs and chipset manufacturers. It covers both expected and unexpected test challenges along with insight on a 5G test strategy that meets immediate high-priority needs while laying the foundation to support future requirements.

High Tech, High Expectations

5G uses new, fundamentally different core and radio network architectures to enable a world of futurist high tech applications that simply aren't viable with 4G. And although every new generation of cellular technology generates buzz and anticipation, 5G has taken the hype to a whole different level. While initial 5G networks and devices have only recently made their commercial debut, there are positive signs that the technology is quite capable of living up to the hype.

Take the seemingly far-fetched example of remote robotic surgery over 5G. Recently, doctors in China's Sanya City used 5G to perform a three-hour brain surgery on a patient half a continent away in Beijing.

"The 5G network has solved problems like video lag and remote-control delay experienced under the 4G network, ensuring a nearly real-time operation," one of the surgeons, Ling Zhipei, told China Global Television Network. "You barely feel that the patient is 3,000 kilometers away."[2]

By proving some of the most demanding use cases, these kinds of initial success stories further raise the bar of expectations that the industry must meet in terms of 5G.

"With 5G, the expectations are already very high, so a lot of testing needs to be done upfront," Kimery says. "In fact, more testing will be needed upfront with 5G than was done with 4G, and quite frankly that testing level needs to be a cut above what was available with LTE. I think the operators understand this and the device manufacturers understand it, too. That's why they're willing to invest in test equipment and do this testing at the very beginning: so that their devices and networks will meet those expectations."

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— James Kimery
Director of Marketing, National Instruments

2 *https://news.cgtn.com/news/3d3d774d7945444e33457a6333566d54/index.html*

New Performance Requirements Change Everything

Figure 1. The three 5G usage scenarios.

5G is designed to deliver much more than traditional mobile broadband. New network performance requirements are being driven by multiple applications intertwining across 3 different grades of service:

- **Enhanced Mobile Broadband (eMBB)–**delivering super high-speed data throughput (think gigabytes in a second) that will be required for the likes of AR/VR applications and immersive video experiences. Fixed Wireless Broadband is a sub use case of eMBB being deployed by some operators to provide consumer home internet and video distribution.
- **Massive Machine Type Communications (mMTC)–**supporting a high density (millions upon millions) of devices with long range and low data rates for IoT driven applications such as smart metering, asset tracking and agriculture.
- **Ultra-Reliable and Low Latency Communications (URLLC)–**providing exceedingly responsive connections, extremely low latency with ultra-reliability and availability for applications such as self-driving cars, industrial automation and drone control

5G will deliver quite a bit of improvement vs. 4G and thus requires quite a bit of overhaul to achieve it. How so? By 3 primary ingredients that completely change pretty much everything.

Spectrum, Architecture and New Radio: 5G's Three Technology Ingredients

5G is designed for use in far more spectrum bands, including some residing at frequencies that are new to the cellular industry such as 28 GHz and 39 GHz. 5G introduces a new core network moving to a now essential cloud native design heavily dependent upon virtualization, network-slicing and edge computing technologies. It also gives operators a wider variety of antenna schemes to choose from. These three ingredients are just a few of the new variables that device vendors will have to accommodate in their testing to ensure that they provide a consistently superior user experience - no matter to which 5G network they're connected.

1 New Spectrum

5G requires much higher bandwidth, and as the current bands will not support wider bandwidths, 5G will leverage additional spectrum located in much higher frequencies. As such, frequency bands for 5G are being separated into 2 different ranges.

- **FR1**, with a corresponding frequency range of 410 MHz to 7,125 MHz. This is commonly referred to as the **Sub 6GHz frequency** range.
- **FR2**, with a corresponding frequency range of 24,250 MHz to 52,600 MHz, colloquially known as the **mmWave frequency** range.

While mmWave supports very high data rates, it can suffer from a relatively short transmission range. And while sub 6GHz 5G does not hit the speeds of mmWave (although still faster than 4G), it provides broad coverage. As such, most carriers will optimize a mix of both.

As in previous generations, a "duplexing" scheme must be chosen for carrying both downlink and uplink traffic. **FDD** (Frequency Division Duplexing) employs two sub-bands, one for downlink and one for uplink. In **TDD** (Time Division Duplexing) a single band is shared, switching back and forth between uplink and downlink. FDD consumes more spectrum bandwidth and thereby can offer higher download speeds, whereas TDD is more spectrum efficient.

In addition to caring for new spectrum, the aggregation of these 5G bands to increase data throughput (called **carrier aggregation**) also becomes far more complex vs. today's implementation with LTE-Advanced. Carrier Aggregation (CA) allows operators to combine two or more radio channels into a single aggregated channel that can carry more data. This allows carriers to operate with fragmented bits and pieces of spectrum and combine them to act as if they had contiguous channels. CA comes in many flavors (aggregation within bands, across bands, in TDD and FDD versions, in various channel bandwidths, and numbers of channels). As we've moved into 5G, the sheer number of CA types has skyrocketed from just a handful in 3GPP R10 to many dozens in R16, and now include simultaneous 4G and 5G band combinations.

2 New Network Architecture

To achieve larger numbers of connections and low latency, 5G brings new core architecture concepts and components. One of the biggest changes involves the way that carriers adopt 5G and transition from 4G LTE to 5G in the first place. 5G introduces the new concept of Non-standalone (NSA) mode, in addition to the more conventional standalone (SA) mode.

- **Non-Stand Alone (NSA)** is considered the most convenient approach for getting 5G up and running as quickly as possible. In the 3G-to-4G days, most endpoints supported both but were only attached to either 3G or 4G at any point in time. Devices would grab 4G service when possible, and "fallback" to 3G when they couldn't. Instead, the NSA architecture always anchors the device over 4G LTE radio to the LTE core. The user plane (i.e., the data connection) can be over LTE or the device can use 5G NR when it is available to augment or replace the LTE user plane.

- **Stand Alone (SA)** is the "pure" 5G model, where the operator deploys 5G New Radios on a new 5G core network. This is considered to be the long-term solution and introduces new core network architectures to enable new applications and business cases. Note, however, that for most networks, 4G will still be in play (just like 3G was in the 3G-to-4G days) for fallback when a 5G signal is unavailable.

With NSA and SA modes, the operator's choices seem to be straightforward (Figure 2).

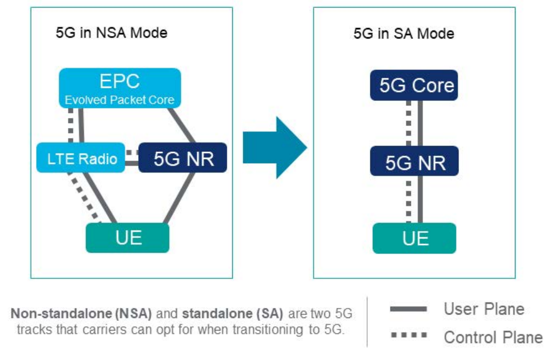

Figure 2. Migration from LTE to 5G taking the NSA to SA path.

However, operators must juggle many existing deployment capacity variations, budget constraints and goals. Recognizing that, 3GPP has created quite a few potential versions (Figure 3), and therefore many different paths that operators will take from today to into their 5G futures. Some operators will move straight to Option 2 (SA). Others will start with Option 3x and move to Option 2 via Option 7. The bottom line is that device vendors and component manufacturers must be able to test their products in both SA and NSA environments, across multiple carrier evolution paths, and with both legacy radios and 5G.

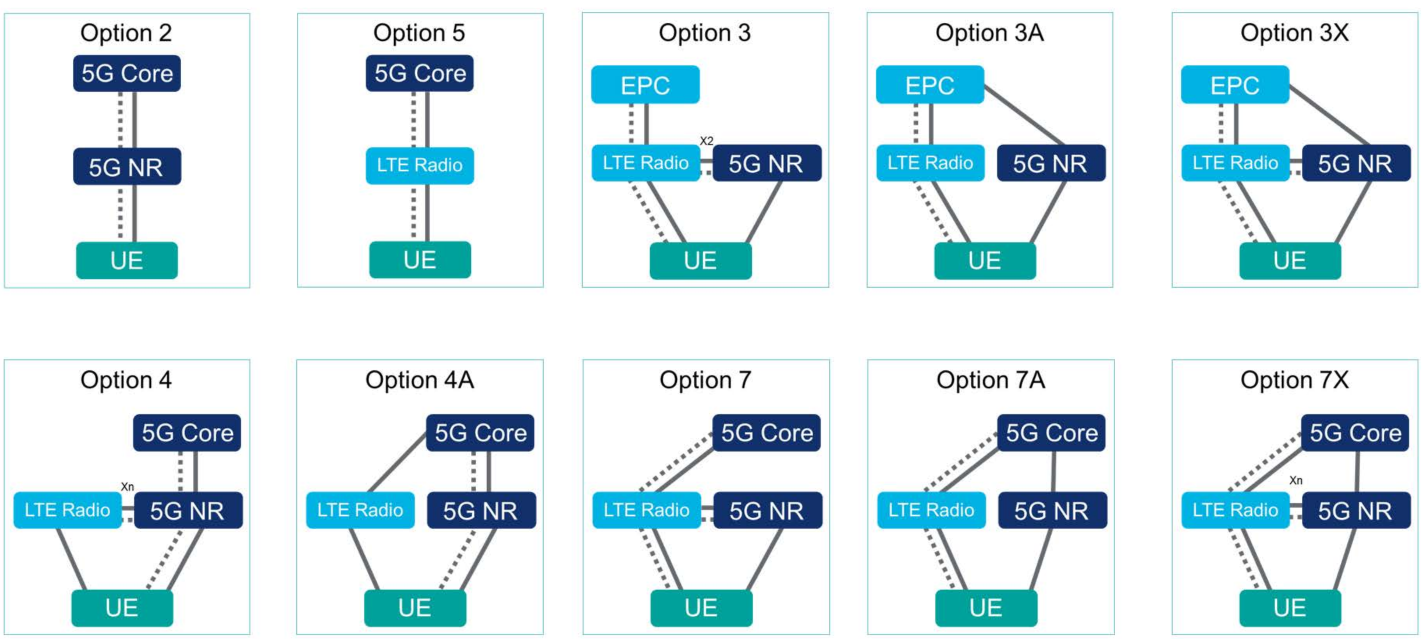

Figure 3. There are many choices of migration models and paths.

3 New Radio

To achieve higher data rates and increased user density, 5G brings improvements in radio technology.

While 5G New Radio (NR) upgrades the modulation (Orthogonal Frequency-Division Multiplexing or OFDM) that is used in LTE, the big difference is around the sophistication of antenna systems. 5G introduces antenna systems with dozens or even hundreds of smaller elements to enable massive MIMO and beamforming. By precisely controlling the phase of the transmitted signal at each element, the base station antenna can create targeted narrow beams.

With the antenna elements arranged in an array (e.g., 8 rows, each with 8 elements), beams can be steered across an area and can be steered vertically. There is some beamforming today in LTE Advanced, but most cell sites are still set up as three sectors (120 degrees each). 5G lets us point a beam at a specific device or group of devices and point a different beam at a second group, thereby reusing a given slice of spectrum over and over in the same cell area that previously would have supported only one group.

NR also introduces a new concept at the Radio Frequency (RF) frame layer known as the mini-slot. Slots are groupings of OFDM symbols used to schedule data transmissions. To meet the new 5G low latency requirements of URLCC, mini-slots allow more flexibility. Mini-slots can start anywhere in a frame and can contain just a few symbols.

Location determination is also advancing in 5G. In 4G systems, satellite-based global navigation systems (GNSS) are augmented by information from the network. To help the handset get a faster fix than GNSS receivers can achieve alone, Assisted GNSS (A-GNSS) provides the device with information about which satellites are currently overhead. Additional technologies [Enhanced Cell ID (eCID) and Observed Time Difference Of Arrival (OTDOA)] provide coarse position information as well, based on power level, delay and triangulation techniques.

5G steps up the positioning game in several ways. Most notably, beamforming provides more granular location in the horizontal plane. Beamforming also introduces, for the first time, z-axis position by identifying which vertical beam a user is occupying. In FR2 deployments, small cells are densely deployed providing improved accuracy outdoors and potentially indoors, as well. Further enhancements are also coming in 3GPP releases 16 and 17 with improvements in Downlink/Uplink-TDOA, Angle of Arrival, Multi-RTT (round trip time), ECID, PPP-RTK (precise point positioning over real-time kinematic networks) and Broadcast AD.

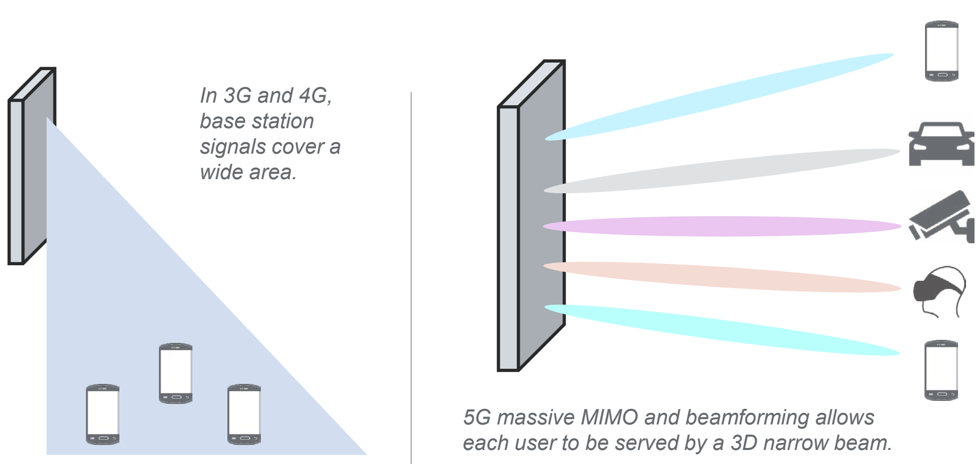

Figure 4. Beamforming allows a given bit of spectrum to be used multiple times within the same cell area.

How 5G Is Changing Device Lab Test

The cellular industry has well-established lab methodologies for device conformance and performance test. Expanded and, in some cases, entirely new test methods are needed to accommodate the new technologies and challenges of 5G.

RF Channel Test

Channel emulation is the method used to replicate the RF propagation effects that occur in the air between a transmitter and a receiver. A channel emulator operates on the downlink and/or uplink RF signals that pass between the base station and the device. It connects between them and modifies those signals to accurately replicate the effects of motion, distance, reflections, and interference.

For 5G, channel emulators must handle mmWave FR2 bands in addition to the more conventional FR1 bands that they have always handled. RF port counts are increasing to handle higher order MIMO. The mathematical modeling is more sophisticated, allowing emulation of MIMO and beamforming antenna arrays. This includes accurate phase manipulation, as well as precise control of the geometry of a signal's angle of departure from and angle of arrival at the antenna.

Conducted mode testing (where antennas are bypassed and cables are used to connect between antenna ports) is still extremely useful in 5G contexts for FR1 bands. Most FR2 mmWave band systems, however, cannot support conducted mode. The antennas are physically too small and/or too plentiful to provide cable connections. For that reason, 5G is employing more over-the-air (OTA) radiated mode test methods that take place in RF isolation chambers.

RF Connection to the Device

Test beds for device functional testing typically consist of a device under test (DUT) and a cellular network emulator. In 4G and prior technologies, the DUT (Device Under Test, sometimes referred to as the User Equipment, or UE) is often connected to the emulation system via cables (conducted mode), bypassing the device antennas. Increasingly though, devices such as consumer smartphones lack the physical ability to connect an RF cable in place of the device's antennas. This is happening as device electronics continue to shrink and as the number of antennas in the device increases due to higher orders of MIMO.

5G greatly exacerbates this issue in the FR2 bands because those mmWave device antennas are smaller and more plentiful. 5G FR2 device test beds, therefore, will always incorporate an over-the-air connection method. As in 4G, a simple version of an OTA RF isolation chamber is used. There is no need for precise RF calibration (as is required in the RF test domain described above), so the UE is simply placed in a shield box that contains the gNodeB antenna for the device to interact with.

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More Protocols, Combinations, and Features

5G brings many new protocols and, as we look at the 3GPP roadmap, there are many more to come. Furthermore, given all the options for operators discussed in the previous section (deployment core architectures, carrier aggregation schemes, spectrum variants, mini-slots, beamforming schemes, and the like), it is clear that any given 5G device will be expected to handle many more field configurations than 4G presented. These changes point toward an increasing number of test cases running on lab device test systems.

Mobility handover performance provides a good example of 5G's increasing protocol and feature complexity. Cell-to-cell handover tests have been around since 1G, but 5G introduces a new concept: beam-to-beam handover. As with everything else, testing must ensure that a device maintains service when moving between two 5G cells, between a 5G site and a 4G site, or when changing frequencies within the same 5G cell.

Calling and Voice Performance Scenarios

When LTE began to appear, voice calls were initially carried on 3G. It took a while for 4G voice (Voice over LTE, or VoLTE) to be supported and to appear in handsets. And even longer for operators to agree to carrier-to-carrier VoLTE interoperability.

5G will adopt a similar path, but with a new twist.

NSA systems will initially deploy with 4G VoLTE calling. The twist is that 4G and 5G radios can be active simultaneously, unlike in early 4G devices (where the device turned off 4G and attached to 3G to make a voice call). Even though the device is using a well-established VoLTE service, the testing now needs to cover scenarios with 5G NR active to ensure there are no unintended interactions.

Later NSA systems will employ VoNR (Voice over NR), which will bring a replay of the VoLTE challenges to align codecs between devices and across carriers.

In SA systems, there are again two options. Early systems will use **EPS (Evolved Packet System) fallback,** in which the 4G radio is switched on, attached, and a VoLTE call is placed. Native VoNR on a SA network is the ultimate path for 5G voice calls.

Each of these scenarios requires validation of call performance (call establishment and sustainment) and audio path performance in both static environments and through handovers.

Location Performance

At the same time as device location technology evolves within 5G (as discussed above), other location technologies are also evolving and are being integrated into cellular devices. Known Wi-Fi locations, for example, can contribute to location accuracy. Beyond the basics of knowing to which Wi-Fi access point (AP) a device is connected, Wi-Fi is introducing Fine Time Measurement (FTM) and triangulation. GNSS is also improving, such as with the introduction of the L5 band in the U.S. Global Positioning System (GPS).

Location test systems are typically based on the test beds used for device functional testing, centered around a cellular network emulation platform. Then they integrate emulations for other essential outdoor and indoor location technologies such as GNSS, OTDOA, Wi-Fi APs (beacons), etc. This allows them to send precisely the correct signals to the DUT that would be seen at any location. The best test systems can then carefully modify those signals to simulate motion of the DUT as it travels down a city street, through a shopping mall, or on a train. The test system is then able to measure key performance indicators (KPIs) such as time-to-first-fix (TTFF) and position accuracy.

Moving forward into 5G, again there are new protocols and features, which bring additional test cases.

There is also an immediate new challenge at the RF layer: GNSS interference due to intermodulation (IM) products. First generation 5G devices are relying on 4G LTE positioning technology for emergency calling and commercial applications. In a 5G handset (unlike with 3G/4G handsets), both 4G and 5G radios will operate simultaneously. RF effects of these radios operating on multiple bands has been shown to cause IM at frequencies that directly overlap with GNSS bands. Since GNSS signals are so weak to begin with (compared to the cellular signals that the device modem is handling), there are cases where GNSS is swamped out, causing the emergency call location function to fail.

Test plans are appearing from both standards bodies and cellular operators to head off the IM issue for dual-mode devices. Testing steps through hundreds of combinations of 5G and 4G bands to ensure that TTFF and position accuracy performance are maintained. Over-the-Air (OTA) testing in an RF isolation chamber is used to ensure that antenna and RF front-end designs can cope with the difference in cellular vs. GNSS signal strength (a GNSS signal, typically at a power level of around -160 dbm, is one 10-billionth of the received power of a typical -60 dbm cellular signal). Standards bodies such as CTIA[3] have 5G versions of mandatory OTA Location compliance testing in place especially designed for LTE+5G+GNSS location services, and these compliance tests are evolving in tandem with the 3GPP 5G evolution.

New 5G devices may also experience latency and processor lag issues that affect location and emergency calling performance. These issues appeared in the 3G to 4G transition era and must be checked to ensure they don't reappear in the 5G transition. Latency can creep in when, for example, a 5G NSA device makes a voice call and the device fails to rapidly enable 4G positioning. Processor lag can show up when devices switch between modes, establish data sessions or juggle background 5G data. Early 5G devices are often brand flagship releases that run on high-end hardware. When that software is ported later on to lower-cost hardware with less processing power, processor lag must be assessed to assure that priorities are properly managed during emergency call scenarios.

For a closer look at 5G and other new location technologies, reference Spirent's corresponding white paper, *The Impact of 5G on Location Technologies*.

Bandwidth Evolution

Signal bandwidths are taking a major leap to accommodate the desired bitrates of 5G. The bandwidth limit in LTE for a single channel has been 20 MHz. Within the conventional sub-6 GHz cellular bands of FR 1, 5G systems will support up to 100 MHz bandwidth. In mmWave, FR2 channels can get

3 https://www.ctia.org/test-plans

even wider, with 3GPP Release 16 specifying up to 400 MHz of single-channel bandwidth in the 3GPP 38.101-2 specification[4]. With carrier aggregation, R16 allows up to just over 2500 MHz aggregate bandwidth.

We are still in the early days of 5G performance. While we won't see some of these extremes for a few years, we already see operators deploying 100 MHz systems and we see gNodeB manufacturers testing systems at 200 MHz.

The implication for test systems goes directly to their lifecycle cost. Supporting these bandwidths and their corresponding bit rates requires test systems to be architected at these rates at every point along the end-to-end chain. Test systems are capital intensive and most organizations plan for (and depreciate on) a system lifetime of greater than five years. Over time, as rates rise from today's levels, it is reasonable to expect some test system components (e.g., the server and client driving and measuring data throughput) will upgrade as needed. However, to avoid a budget-busting mid-cycle fork-lift upgrade, test labs would do well to consider the throughput that their emulation platform can deliver today and over its full lifetime.

Performance Beyond the Standards

Standards-driven conformance tests are vital. By design, though, they drive all vendors to a common denominator. It is in the performance arena where individual solutions display competitive differences.

It's never too early to focus on the customer experience, especially as the 5G timeline accelerates. And while both conformance and performance test domains are important, it is in evaluating performance criteria that assure your customers' true experience.

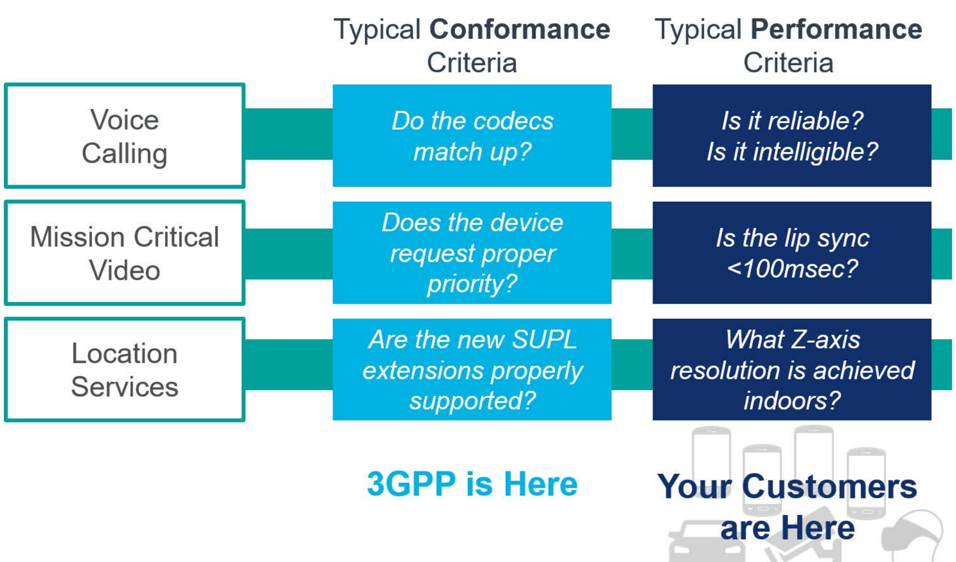


Figure 5. Performance testing aims to create great user experiences.

As 5G unfolds over the 2020's, performance and conformance testing priorities are following a different path than for previous generations. New use cases, the leveraging of 4G for some functions, and the way that consumers behave and adopt 5G will determine what needs testing when. Here in the early years of deployments, we see that 5G testing programs are initially prioritizing **connectivity** (including connections, network adversarial, mobility, and other areas), **location** testing, and new features such as **4G/5G Dual SIM**. **Voice quality** is up next as VoNR becomes available. **Video quality** is important immediately in some use cases (e.g., home broadband) and will continue to evolve throughout for mobile streaming, augmented reality, and new applications. And of course, **data throughput** is an important test area as capacities increase through the 5G lifecycle.

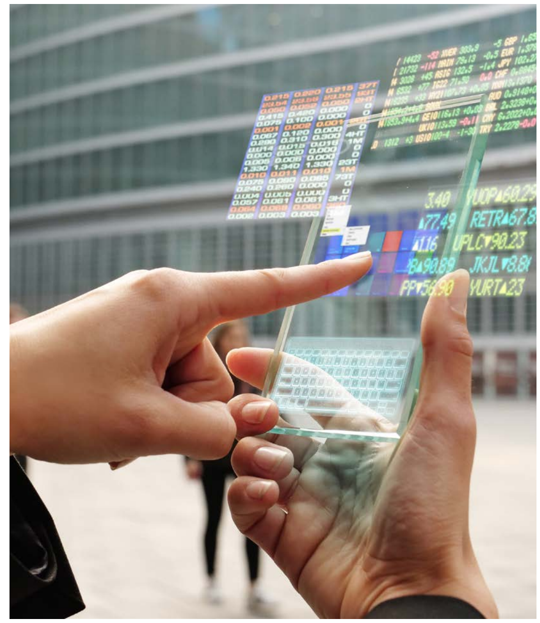
4 https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3284

Assure the Promise of 5G—From Day One and Beyond

4G LTE has served us well for close to 10 years, and over the past decade it has enabled our societal transformation into the always-connected lifestyle that we already take for granted.

5G will again usher in a new generation of advancements that we can only begin to visualize. It uses dozens of additional bands in spectrum with which operators and vendors have no experience. It also introduces options to use different core and radio network architectures. All of these differences enable exciting new applications and market opportunities.

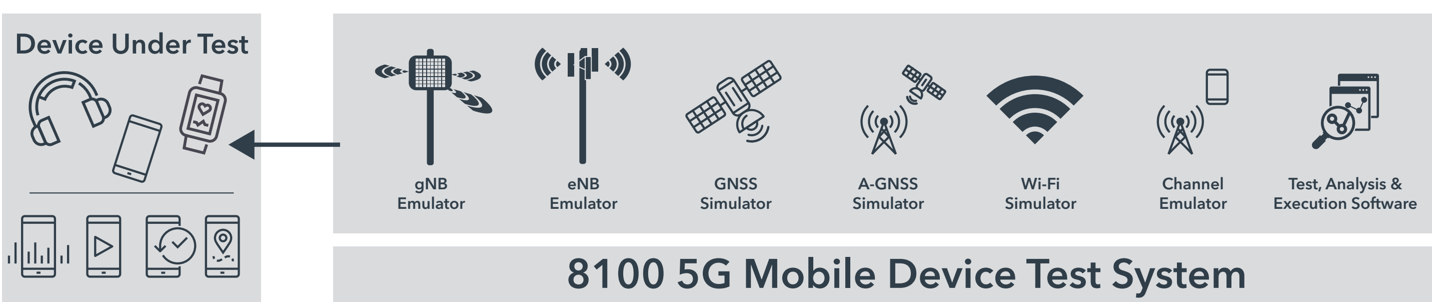
These differences also require operators and vendors to completely rethink their test priorities, processes and retool accordingly. Doing so ensures that they can provide the kind of 5G experiences that their customers and business partners expect.



Simplify the Complexity, Accelerate Time-to-Market and Assure a Great Experience

5G mobile device test solutions must be flexible to quickly adapt to the many changes and challenges ahead, allowing future upgrades while avoiding costly hardware changes as the standards and industry evolve. That's why Spirent, a recognized leader in assuring the performance of devices and network services, is collaborating with National Instruments to adopt NI's flexible software defined radio (SDR) platform in the development of its 5G mobile device performance solution.

The Spirent 8100 mobile test system for 5G devices will allow chipset and device OEMs **to validate the performance** of mobile smartphone and IoT designs in the lab in emulated cellular environments. 8100 provides fully automated and customizable turnkey test libraries **specializing in connectivity and application layer location, video and audio testing.**



The goal, overall, is to:

- **Simplify 5G by reducing the complexity** and economics of testing through innovative test methodologies to help cost effectively validate 5G NR devices.
- **Accelerate 5G innovation and time-to-market to provide performance testing** of smartphone and IoT devices for voice, data, video and location technologies with fully automated, customizable turn-key solutions for R&D, standards-based testing and carrier acceptance.
- **Assuring 5G delivers the perceived real-world user experience promised** through proven test methodologies and industry-leading technologies that validate devices are fit for launch, optimized and benchmark strong against competitors.

Whether a chipset manufacturer, device OEM, test lab or service provider, you promise your customers a superior 5G experience. Spirent is here to simplify the journey, accelerate time to market and assure that success.

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