Follow the leaders on technology, tools, and techniques

Understanding and Testing the 5G Ecosystem

Wireless communication continues to move forward with the development of 5G technology well underway. 5G brings with it unprecedented challenges that require thinking in new ways to meet the aggressive performance goals. Staying current with 5G is critical for deploying this emerging technology. Strong industry partners engage in all stages of development, starting with early research, contributing to standards development, developing technology and ultimately deploying networks. Validation and testing throughout the development stages ensure that in the end 5G delivers on its promises.

Three major use cases drive the requirements for 5G:

1. **Enhanced Mobile Broadband (eMBB).** This is classic mobile broadband, an evolution of today's 4G technology including streaming video, video conferencing, and basic broadband connectivity but at much faster speeds. 5G will also enable fixed wireless access (FWA) to provide last mile broadband connections.

2. **Massive Machine Type Communications (mMTC).** Like 4G Internet of Things (IoT) use cases, 5G will support a massive number of devices, with dramatic improvements in power efficiency and extreme node density.

3. **Ultra-Reliable and Low-Latency Communications (URLLC).** Low latency, high reliability, and high bandwidth will support a new set of applications not possible with today's 4G technology, such as virtual and augmented reality, remote real-time surgery (tactile Internet), and autonomous vehicles.

> *"5G rollout is unlikely to be a one-size-fits-all story around the world; different approaches are being considered – or will be considered – by different operators at different stages in the 5G rollout timeline. Current industry indications suggest that most operators across many markets will opt for a non-standalone (NSA) approach in the early stage, which, if not a permanent configuration, could serve as a bridge to eventual standalone (SA) 5G networks."*
>
> The GSM Association (GSMA)

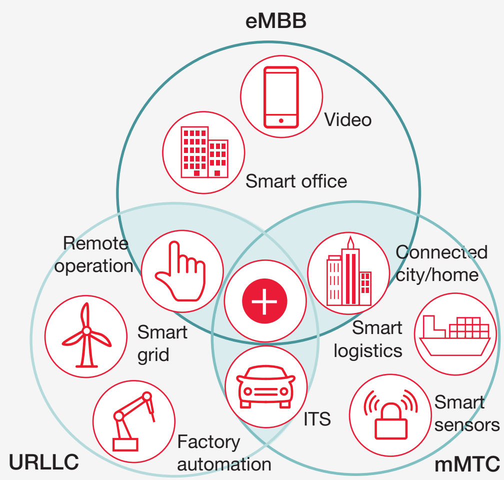


Figure 1: The three major use cases for 5G are overlapped and comprehensive

The goals for 5G are very aggressive, with the use cases spanning very low and very high data rates, low latency, massive machine-to-machine communication, high reliability, and low power operation.

Think about those requirements a bit and you'll see that they are full of contradictions and engineering tradeoffs. However, the 5G specifications handle these conflicting requirements via a new, complex, but highly scalable architecture.

A New Ecosystem: Not Just an Evolution of 4G

5G is not simply an evolution of 4G because the customer requirements drive adoption of major technology shifts. A ***5G Americas whitepaper*** identifies the transformations that make 5G very different:

- Access 10x the spectrum
- Integration of licensed and unlicensed spectrum
- Mass deployment of small cells
- New network architectures (network function virtualization (NFV), edge computing, network slicing)
- Support of IoT (and machine-to-machine communications)

Some network operators are using their initial 5G efforts to deliver fixed wireless access, with both ends of the wireless connection stationary. Initial mobile broadband deployments use the non-standalone (NSA) specification, which depends on the existing 4G long-term evolution (LTE) core network for control and signaling. Later deployments will be independent of LTE and will use the standalone (SA) specification for mobile (and fixed) broadband using the next generation core (NGC) network. Infrastructure that supports the next generation of IoT and low latency/high reliability networks will appear over time.

As the path forward for the wireless industry evolves, you will likely see additional twists and turns as the technology settles out. A recent 5G study by IHS Markit stated that "[5G] standards development and deployment is expected to reach into 2022 and beyond."

The higher data rates of 5G require more spectrum, which is obtained by adding new frequency bands. Most of the new spectrum will be at mmWave frequencies, referred to by Third Generation Partnership Project (3GPP) as frequency range 2 (FR2) covering 24.25 GHz to 52.6 GHz. There will also be new spectrum at lower frequencies in the range 450 MHz to 6 GHz, known as frequency range 1 (FR1). No single region will allocate all this spectrum as these new bands are not globally available.

Frequency range designation	Frequency range	Wavelength (free space)
FR1	450 MHz – 6 GHz	66 cm – 5 cm
FR2	24.25 GHz – 52.6 GHz	1.24 cm – 5.7 mm

You can think of FR1 as an extension of existing LTE spectrum, requiring additional technology development but building incrementally on LTE. The primary FR1 challenge is the move up to 5 GHz with 100 MHz channel bandwidths. FR2 opens a huge swath of spectrum needed for the higher 5G data rates, but the high propagation losses at these frequencies bring much shorter expected operating range. Technology that works at FR2 already exists in other industries (e.g., satellite communications and aerospace/defense), but it is new to mobile wireless where the cost constraints are more severe. From a test perspective, substantial technology and expertise exists in the FR2 region that is being adapted to serve the 5G ecosystem.

5G uses a new scalable air interface based on LTE called New Radio (NR) to support the wide range of use cases. This air interface must work at both the FR1 and FR2 frequency ranges. The frame structures and modulation schemes employed and the associated protocols that travel over the air need to be extremely flexible, which adds complexity to what was used in LTE. In addition, directional antennas will transmit FR2 signals using narrow beam widths to overcome propagation losses, requiring new spatial radio resource management methods to manage mobility and handovers.

Participants Across the 5G Ecosystem

The 5G ecosystem is complex with many organizations contributing vast amounts of technology and expertise to make it work. The simplified map of the ecosystem shown in Figure 2 provides a picture of how the contributors interconnect. The map shows the policy and standards framework overlaid across the entire ecosystem. These are the technical standards developed by 3GPP and other organizations plus spectrum-use policies from the regulatory agencies in each country around the world.

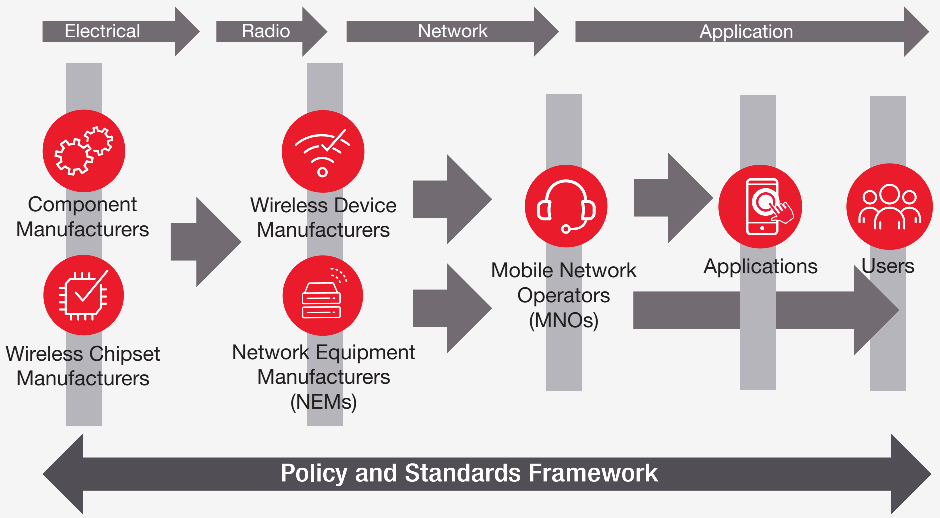


Figure 2: A map of the 5G wireless communications ecosystem

The ecosystem has a general flow of technology from left to right. On the left are the component manufacturers and the wireless chipset manufacturers who provide the building blocks for the wireless device manufacturers and network equipment manufacturers (NEMs). Wireless device manufacturers produce the user equipment (UE), while the network equipment manufacturers produce the equipment to support the network infrastructure (includes wireless and wireline). Mobile network operators (MNOs) combine these devices and network equipment into operational networks to serve the end users. Users make voice calls, send text messages, and run applications over the network.

The general trend is “moving up the stack” as you transition left to right in Figure 2. The figure shows the progression from the physical layer (electrical and radio) to the network and application layers across the top of the figure. One way to think about this is that users tend to focus on the application. They just want it to work, but the application depends on the entire stack functioning properly. The electrical signals need to be right, the radio connection (air interface) must perform correctly, the digital packets need to flow across the network, and the application needs to work, all with speed and responsiveness.

Testing, Testing, Testing

Consider the design and test challenges of this complex ecosystem. Ahead of and in parallel with the standards development, technologists work to prove out the most critical concepts before they are set in stone. As ideas mature, engineering teams build early prototypes and complete some system level testing. Fortunately, the industry has dealt with similar challenges in previous generations of wireless standards (e.g., 3G, 4G).

To manage such a gargantuan task of technology development, the wireless industry uses an established development lifecycle. Figure 3 shows a generic workflow for the design work starting on the left with generous use of simulation while making design decisions and moving through the various stages towards network deployment.

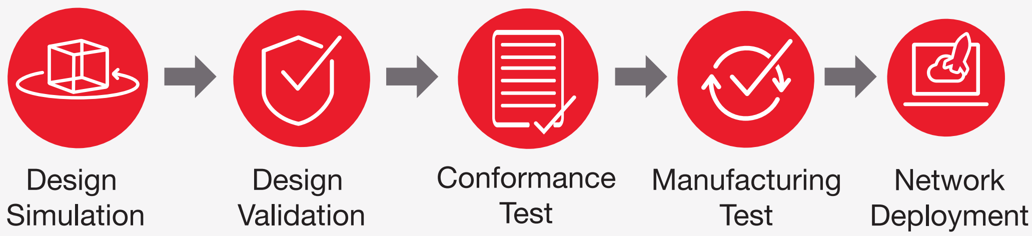


Figure 3: The wireless industry development lifecycle focuses on validation, test, and deployment

Design Simulation. 5G technologists rely heavily on design simulation, doing as much work in the virtual world as possible. It is generally faster to simulate (compared to the time it takes to build real hardware) and easier to change when a design problem surfaces. Engineers simulate designs at different levels of abstraction, from circuit designs to system level simulations. Design and simulation are tightly intertwined, with simulation results determining whether the design meets specification.

Design Validation. Design simulation is never perfect, so eventually engineers build the physical system and test it to see if the design is right, at multiple levels in the system. Validation engineers check out the individual components, chipsets, subassemblies, devices, subsystems and ultimately the entire 5G system.

Conformance Test. Conformance test focuses on standards and regulatory requirements (i.e., does this piece of equipment conform to the relevant specifications?). This includes RF measurements such as occupied bandwidth, receiver performance and intermodulation distortion, and radio resource management (RRM). Conformance test can overlap with design validation with the main difference being that conformance test focuses on checking that the equipment meets the standard or specification.

Manufacturing Test. At this stage the design is proven, so manufacturing test engineers deploy efficient test plans on the manufacturing line to ensure proper operation in the face of material and process variation. Here the priority is to minimize total test cost while maintaining a high level of product quality.

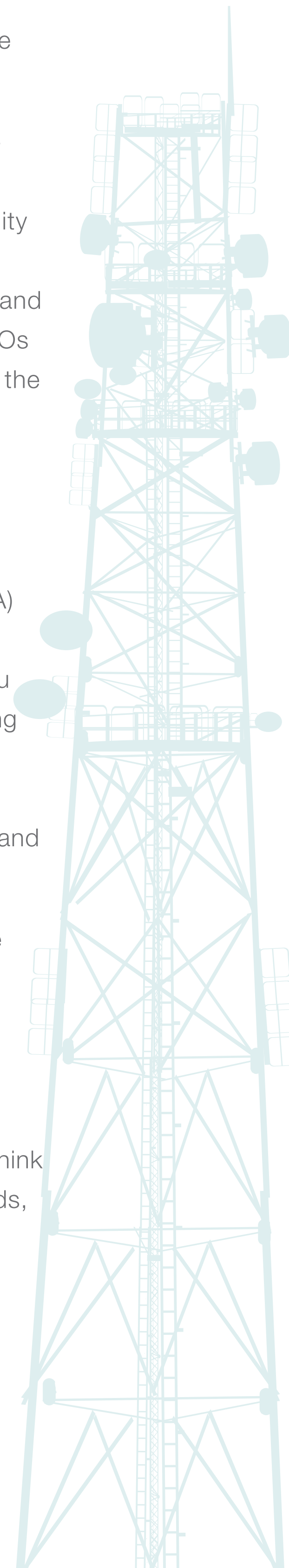
Network Deployment. Before MNOs deploy new technology and equipment on live networks, they perform additional testing (often working closely with NEMs). Pre-deployment lab testing creates a controlled environment for validating the functionality of a system. This subjects equipment to realistic conditions that approximate live networks, measures equipment performance to understand network performance, and validates quality of service under load conditions. After pre-deployment testing, MNOs often launch a field trial to exercise the system in the real world. Finally, they deploy the equipment broadly onto the live network.

The Over-the-Air (OTA) Challenge

5G technology introduces an entirely new challenge in the form of over-the-air (OTA) testing. Radio transmission at FR2 frequencies experience increased path loss and other forms of channel degradation. However, with shorter wavelengths of FR2, you can use multiple antennas to focus the signal, producing antenna gain, and increasing the effective signal power in the desired direction. This beam steering technique compensates for the higher path loss at the expense of a more complex antenna system. The shorter FR2 wavelengths mean these antenna arrays can be very small and may be integrated into components or devices.

This integration of antenna arrays introduces a big problem for the test engineer. The traditional cabled test port disappears, leaving just the antenna array radiating into space.

Accurate connected measurements at FR2 can be a challenge, but decades of measurement science work have made them commonplace. Making accurate OTA measurements is a lot harder, introducing a much larger measurement uncertainty. Think many dB of uncertainty instead of <1 dB for connected measurements. In other words, OTA measurements are going to be less accurate than we have become used to – making everything more difficult.



In addition, steering the antenna can focus the beam towards a particular device or multiple devices. Figure 4 shows a base station with a beam steering antenna focusing its radiated signals on two wireless devices. The base station points the beams in the right direction and tracks the wireless devices when they move. Wireless devices may also have directional antennas that need to be pointed in the right direction, although user devices have lower directivity than base stations. Devices and the base station find each other and maintain the connection through antenna steering algorithms. This means that the signals will be moving around in three dimensions, creating additional test needs and difficulties.

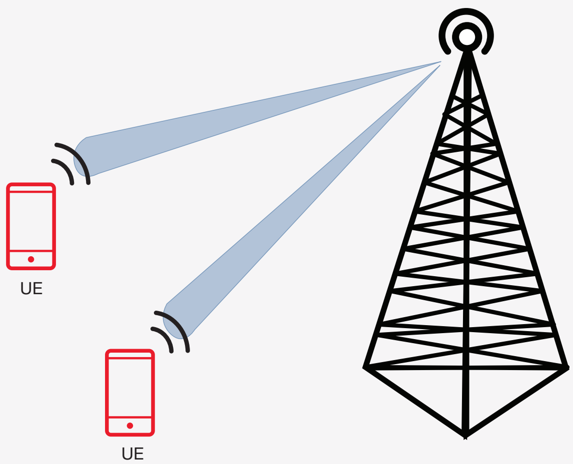


Figure 4: Beam steering from a base station focuses the signal on the wireless devices

Testing Across the Ecosystem

The type of testing required varies widely across the ecosystem shown in Figure 2. Here are some representative examples of the tests used.

Component and chipset manufacturers create the fundamental building blocks for 5G technology. The broad electronics industry uses many of these components (e.g., capacitors, inductors, resistors, batteries), testing them using well-established methods. Other components and wireless chipsets are specific to 5G, and require special test methods. Wireless chipsets are complex devices that manage the air interface and protocol layers, playing a big role in RRM. RRM includes operations such as frequency/channel selection, time-slot coordination, power control, handover between cells, etc.

At RF, the challenge was "how good is my signal?"; at mmWave the new question is "where is my signal?"

Testing 5G: Time to Throw Away the Cables

Wireless device manufacturers use the components and chipsets to create their wireless devices. Most of us think of a wireless device as being a smartphone or tablet (Figure 5). This coincides with the eMBB use model but the mMTC and URLLC use models include a vast number of IoT and automotive devices, which have a wider variety of form factors.

Figure 5: Modern smartphones are highly integrated systems with relatively few parts

With the key functions of a smartphone implemented on complex integrated circuits, a wireless device has relatively few parts. The wireless chipsets are central to the operation of the device but other components play important roles. RF integrated circuits do modulation and signal conditioning for the air interface. Multiple internal and external interfaces route the data between components and to the outside world: DDR, MIPI, USB, Wi-Fi, Bluetooth, and others.

With battery-powered devices, designers must pay careful attention to power consumption. Design engineers assess the power used by each circuit for a particular operating mode of the device, often automatically switching off sections when not in use. Engineers then verify the power consumption on actual hardware under an array of operating conditions.

OTA measurements will play a big role at the device level, especially in the FR2 frequency range. Engineers will use OTA measurements for RF parametric test, protocol test, and antenna system test. Industry experts are developing new methods for making these measurements in the design validation phase. These methods will work for design validation and conformance testing but are likely to be too cumbersome for volume manufacturing. For more information on OTA measurements see *OTA Test for Millimeter-Wave 5G NR Devices and Systems*.

Network equipment manufacturers (NEMs) create the equipment for the infrastructure side, so they need to verify the performance of each piece of equipment, from antennas and radio heads to network switches and routers. The higher data rates associated with 5G and the increased number of devices generate massive amounts of traffic. At the same time, latency through the system must be reduced relative to LTE performance. The network traffic is also diverse in nature, to support the three use cases (eMBB, mMTC and URLLC).

The move to centralized radio access network (C-RAN) is a major shift in architecture that consolidates most of the signal processing for many base stations. Compared to traditional architectures, C-RAN provides significant performance and cost benefits via pooling of resources, enhanced coordination between cells, virtualization, and reduced power consumption.

The core network is also undergoing a major shift towards virtualization of the network via the use of software-defined networks (SDN) and network functions virtualization (NFV). These techniques result in more flexibility and higher scalability, but with new testing required.

NEMs must test a wide range of equipment starting at the air interface and moving through to the core network. They must cover everything from tests associated with base stations (RF parametric, protocol and antenna performance tests) to network equipment tests (throughput, latency, load, and stress tests under a variety of conditions).

Mobile Network Operators (MNOs) need to offer high Quality of Service (QoS) cost-effectively. Ahead of deployment, a verification lab tests new network equipment to ensure that it works under all relevant conditions. The network is put under heavy load to create congestion with varying traffic profiles. It is only under congestion and competition for resources that the QoS key performance indicators can be verified.

To generate enough traffic with real UEs requires a large collection of hardware, so emulation of the UE is a critical tool for this testing. Each emulated UE supports voice, video, and data traffic generation according to the network scenario being tested.

Testing requirements for MNOs include:

- Wireless device acceptance testing
- RF performance and RRM behavior
- QoS in data services (latency, transaction speed, throughput, failed transactions)
- QoS in voice services (packet loss, delay, mean opinion score, jitter)
- QoS in video services (image quality models, subjective video quality)
- Field strength and coverage in the field (conventional drive test)

It's Not Over Until It's Obsolete

As with any major technology development, the rollout across the 5G ecosystem is happening in stages and must coexist with legacy 3G and 4G networks. While it is tempting to look ahead to when everything has settled out, that milestone is beyond the horizon. Three main forces are driving change in the 5G ecosystem and will continue to cause dynamics for many years.

1. **5G standards development**
   The non-standalone version of Release 15 of the NR standard was released in December 2017. The standalone version was released in June 2018, and Release 16 is slated for 2020. Additional standard development will occur after that. Looking back at the LTE standards work, the standard evolved over ten years as the industry translated additional network and customer requirements into technical reality. The broad set of 5G use cases will uncover similar needs that are not fully understood today. For example, all the implications of massive machine communication, which is currently planned for Release 17, are not known.

2. **Development lifecycle**
   Any new technology or functionality must also transition through the development lifecycle within each part of the ecosystem. The design process starts with simulation to prove out the basic technology and circuit design. Then the design moves into a prototype phase where engineers turn on and validate the early hardware. The design

moves into manufacturing and is ultimately deployed in operational systems. OTA testing will be a major challenge as the industry works through adapting OTA test methods in R&D, conformance testing, and especially high-volume manufacturing.

3. **Technology propagation**
   Any new technology or functionality introduced in 5G will start with components and chipsets, and then will be incorporated into devices and network equipment. The MNOs must validate new capability in their verification labs before releasing it into their operational network. From a validation perspective, there is a natural progression from left to right in the ecosystem, which happens for each significant technology change or upgrade. This technology propagation will likely continue. For example, new network requirements or validation techniques needed for safety-related applications (e.g., autonomous vehicles) will emerge.

This pattern of continuous change means that leading test and measurement companies must work closely with standards bodies and industry leaders to stay current with advances in technology. Similarly, all players in the 5G ecosystem are wise to partner with test providers who are engaged with leaders across the ecosystem, not just one portion of it.

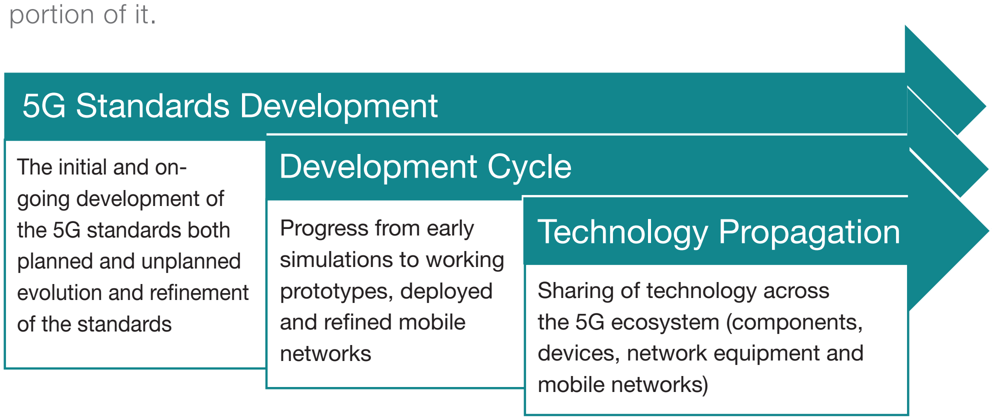


Figure 6: The three drivers of change ensure that the 5G ecosystem will continue to be very dynamic

Follow the Leaders to Stay in Sync

5G is moving ahead rapidly driven by technology investment from major industry players. You will continue to see new developments and deployments as the technology becomes real. These three strategies will help you learn about 5G and stay current as new elements roll out.

- Pay attention to the ecosystem – understand which technologies have been deployed and which are still just emerging ideas. Knowledge will tend to propagate across the ecosystem as early R&D work translates into operational networks.
- Follow the industry leaders, especially those engaged across the ecosystem. Note which organizations set the pace and what tools they use. The industry is still figuring out the various options for qualifying and testing 5G chips, devices and networks. Moving higher in frequency and the need for OTA testing will create challenges for the industry, especially in high-volume manufacturing.
- Work with the design and test experts at Keysight who are helping industry leaders solve their most difficult 5G problems. Keysight engages in all stages of development, starting with early research, moving on to standards development and ultimately deployed networks. Validation and testing throughout the technology development stages is critical for 5G to deliver on its potential.

Learn more at: www.keysight.com

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