Part 2: Techniques to Mitigate 5G Product Development Risk

De-Risking 5G Product Development

Component, device, and network equipment manufacturers are racing to be first to introduce new 5G products. Service providers will rapidly deploy this equipment in new networks. These telecom ecosystem members are all exposed to risks inherent with introducing new technology at a rapid pace. Mitigating these risks requires careful selection of tools and technology partners.

Part 1 of this white paper series explores the challenges facing developers of 5G chipsets, devices, network equipment, and carrier networks. Part 2 covers design, test, and optimization techniques that reduce the risks inherent in 5G product and system development.
Rapid Introduction of New Technology is Risky

5G communication technologies highlighted in this paper will dramatically improve the cellular subscriber’s quality of experience and deliver new network functionality, enabling new business models and potentially increasing service provider revenue streams. However, introducing any new technology on a rapid schedule increases risk, and the 3GPP 5G New Radio (NR) standards have been accelerated by a full year based on demand from the 5G ecosystem and cellular subscribers.

The primary risks associated with deploying 5G technology relate to tight schedules for product development. Components, chipsets, devices, and networks rushed to market may fail to meet performance targets, leading companies to choose between disappointing their customers or re-designing their product and missing a market window. Devices and networks may not properly work together, unacceptable emissions may occur outside band limits, or other technical issues may force a recall that harms brand reputation. Legal liability may arise if devices fail to perform as advertised or if service level agreements are unable to be fulfilled.

Mitigating these risks requires an exceptional focus on design validation and conformance testing. 5G designs need to be right the first time. Effective test and measurement tools and technology partners with broad telecom industry experience are critical to reducing unexpected surprises, and to developing products that meet design goals without time-consuming redesigns.

New 5G Technologies Require New Design and Test Tools

5G new radio (NR) increases data transfer speeds, lowers latency, increases reliability, and offers more flexible network configurations. New technology is needed to enable these capabilities:

- **Wide frequency band radios** in user equipment (e.g., smartphones) and base station equipment enable higher data-rate wireless transmissions replacement. Validating and optimizing the physical layer requires comprehensive broadband signal generation and analysis capabilities.

- **Chipset and radio protocol signaling** enable the network to manage complex radio functions, like beamforming and high-priority transmissions intervals.

- **Massive MIMO radios and antenna systems** improve throughput, reliability, and cell site coverage by increasing the spectral efficiency of transmissions.
• **Millimeter-wave (mmWave) beamforming** focuses antennas to create directive signals that overcome large channel losses, unlocking vast bandwidths at higher frequencies.

• **Fronthaul and backhaul optical interconnects** are increasing in speed and using new modulation formats to deliver higher data-rates to base stations.

• **Context-aware transport protocols** create intelligent traffic routing that sends high-priority packets to multi-access edge computing resources that are near the user.

• **Virtualized network architecture** and network slicing techniques allows service providers to offer different levels of performance to different classes of users.

Each of these new technologies must be designed with new software, evaluated with new measurements, and validated with new tests. Solutions to design and build 4G LTE products will not be sufficient for new 5G products. New tools are needed that span the product lifecycle; from design and prototyping to manufacturing and deployment.

**Wide Frequency Band Radios**

5G radios and radio components must be designed and validated to handle higher frequency bands, and as much as 2 GHz of bandwidth. These broader bandwidths create modulated signal quality challenges that are harder to solve. Imperfections that are minor in a 4G LTE 2.5 GHz band with 20 MHz of modulation bandwidth could make a 39 GHz transmission of a 1.2 GHz-wide signal incomprehensible.

IQ impairments, phase noise, linear compression (AM-to-AM), non-linear compression (AM-to-PM), and frequency errors can cause distortion in the modulated signal. Each of these problems are magnified when considered over wider 5G bandwidths. Coexistence of new 5G waveforms with previous generation 4G LTE, narrowband IoT (NB-IoT), or Cat-M waveforms also requires new tests.

System-level simulation tools are necessary to design the optimal radio architecture to address these potential problems. To improve first-pass design accuracy and reduce the risk of re-design, use a toolset that can parameterize system blocks and simulate performance variations due to temperature, component variability, and manufacturing tolerances.
Automated conformance test capability will reduce the attended test time needed to characterize all use case scenarios associated with:

- New 5G frequency bands
- More aggregation of signals occupying different bands
- Potential coexistence problems

A complete characterization reduces the chances of surprises during conformance testing.

**Chipset and Radio Protocol Signaling**

5G radios have vastly different capabilities than previous generation radios, including operating in mmWave frequency bands and directing radio transmissions in certain directions. The new physical layer functionality within the radios is controlled with new layer 2 and 3 air interface protocols. The protocol interface and the radio physical layer behavior requires validation to ensure correct functionality. Radio resource management (RRM) testing includes validating the protocol responses to commands (to determine if the radio appropriately replies when instructed to change behavior) and validating the physical layer performance (to determine if the radio changes behavior when instructed).

Device behavior varies as a function of cellular connectivity, user equipment (UE) mobility, interference from other UE devices, and the physical characteristics of the environment. Testing signaling performance requires channel and network emulation – with a comprehensive suite of RF and RRM measurements – that can simulate and vary these different behavior-modifying parameters in a repeatable lab environment. For devices that operate at mmWave frequencies, conductive testing may not be possible, making an over-the-air (OTA) test chamber a probable requirement. Automated test case management and a high degree of test case parameterization will ensure maximum analysis of the many different use cases now possible with 5G.
Massive MIMO Radios and Antenna Systems

Massive MIMO is a sub-6 GHz technology that improves transmission throughput and cell-site coverage by transmitting many unique streams of data from multiple antennas at the same time. This is an extension of existing 4G MIMO techniques that adds many more antennas. A massive MIMO base station antenna has 64 or more dual-polarized transmit and receive antenna elements.

Massive MIMO antenna systems are very complex, requiring design and validation to address multi-channel amplitude- and phase-coherence, amplifier AM-to-PM distortion, and basic signal integrity. These system characteristics are complicated by the large numbers of antenna array elements, which represent a cross-coupling measurement challenge. Evaluating the performance of the entire array is best made with multiple simultaneous measurements to account for the mutual antenna element coupling.

AM-to-PM distortion is a particularly important problem for MIMO systems. It can be caused by antenna element powers varying by 20-30 dB across an array, changing the transmitter path length relative to the receiver path length, and breaking the antenna reciprocity assumption. Reciprocity is a cornerstone of the MIMO technique due to the importance of channel state information that is calculated by the base station analyzing pilot tones sent by various UE. Antennas without reciprocity would incorrectly precode transmissions designed for each UE, leading to vastly degraded performance. System design tools that evaluate AM-to-PM distortion should be used with multi-channel measurement tools for design validation to address this potential problem.

Technology Collaboration
China Mobile Communications Group (CMCC) has extended an existing partnership with Keysight to use SystemVue system-level simulation to assist in the development of the 3GPP standard.
Millimeter-Wave Beamforming

mmWave frequency bands have much higher path loss than sub-6 GHz bands that are used in current 4G LTE cellular standards. Base stations and devices using mmWave bands will have integrated multi-element antenna arrays that generate highly-directive and high-gain signals necessary to overcome the path loss, which at 28 GHz is more than 150 times greater than losses at conventional 3G and 4G 2.5 GHz frequency bands.

The beamforming aspect of mmWave communications makes testing these products extremely challenging. For example, designers must consider:

- Using three-dimensional channel models to determine base station transmission behavior
- Development of algorithms to search for UEs and track their movement
- Validation of the radio’s ability to correctly steer energy in a particular direction
- Confirmation of the base station’s beamforming repeatability in a manufacturing environment
- Measurement of radiated signals over-the-air (OTA), versus the 4G LTE norm of measuring signals conductively using a coaxial cable

Testing mmWave systems requires OTA measurements made within anechoic test chambers in conjunction with hardware and software tools that emulate the air channel and either the network or the UE, depending on the device under test. Accurate characterization requires multi-probe calibration that accounts for phase, amplitude, and timing errors. Problems with calibration will lead to inaccurate results and potentially impact the beamforming algorithms developed by designers, leading to costly re-designs.
Fronthaul and Backhaul Optical Interconnects

As transfer rates to wireless users increase, so must the optical wireline connections that deliver data to and from individual cell towers, regional offices, and throughout the mobile core network. The fronthaul link from a radio unit on a cell tower to the baseband unit in a regional office is moving from 10 gigabit Ethernet (GbE) to 25 GbE. Backhaul links connecting regional offices to data centers and the internet are transitioning to 100 GbE and 400 GbE interfaces.

These higher-speed optical links transmit digital bitstreams that demonstrate analog-like signal degradation. PAM-4 and 16-QAM modulation formats are used to minimize clocking rates to 28 or 56 Gbaud while increasing data transfer to improve throughput. Other techniques are also used to increase the data-carrying capacity of individual fibers, like dense wavelength division multiplexing (DWDM).

Wireline infrastructure tests must use these new modulation formats, multiplexing techniques, and lengths and types of fiber that are characteristic of actual field deployments (i.e., realistic channel emulation that matches impairments). Lab testing with short fiber pigtails will not accurately represent real-world conditions, which may lead to unacceptably high bit error rates during field deployments.

Context-aware Transport Protocols

Some new 5G applications are extremely latency sensitive, like augmented reality (AR) and virtual reality (VR), which require motion-to-photon response times on the order of 15 milliseconds. Latency is the sum of roundtrip transport time, which is dependent on the physical proximity of compute servers and server processing time. Latency-sensitive applications cannot use centralized servers due to long transport times (e.g., San Francisco to Seattle and back takes 21 milliseconds). 5G networks use context- or application-aware traffic routing to send latency-sensitive traffic to multi-access edge computing (MEC) servers, which are physically close to the edge of the network, while sending less time-sensitive data to centralized servers.

The radio access network (RAN) and the 5G next generation core (NGC) requires functionality and load testing to validate that new transport protocols can correctly route different types of traffic to different destinations. To emulate repeatable and realistic conditions in a lab environment, traffic generation should be based on the modeled behavior of many individual subscribers using popular applications like YouTube, Facebook, Instagram, Snapchat, and others. This type of traffic may expose scaling and load balancing issues that would not be seen with payloads built with pseudo-random number generators.

Technology Demonstration

The 2018 Interop Tokyo tradeshow awarded “Best of Show” honors to Keysight’s AresONE-400GE test system in the Management, Monitoring, and Testing category.

The system demonstrated 3.2 Tb/s aggregated Ethernet traffic generation.

Technology Award

Telecom Asia’s 2017 Readers’ Choice & Innovation Award was given to Keysight’s IxLoad Xair2 platform that enables end-to-end cellular network test.
Virtualized Network Architecture

Virtual next generation core (NGC) network functions, like the new 5G user plane function (UPF), must be thoroughly tested before deployment. Testing involves isolating the virtual function from the rest of the network by connecting it to simulated neighboring network functions and service-based interfaces, and then stimulating the isolated function with network traffic.

Load testing on isolated components and the broad NGC must accommodate different types of user traffic. Ideal traffic generation is based on a simulation of individual subscribers and their mixed traffic requests: VoIP, data traffic, and streaming video. Traffic monitoring and visualization tools measure network performance under extreme conditions, and can help network equipment manufacturers and service providers mitigate risk by testing the network under realistic conditions before the network is live and in production.

Effective Design and Test Tools Mitigate Risk

Here are three recommendations to mitigate 5G schedule- and technology-related product development risk:

1. Use high-performance 5G-ready design and test solutions that can test the specific requirements highlighted in this paper. Addressing the toughest technical problems minimizes the risk of performance problems and potential product redesigns.

2. Choose tools that perform data sharing throughout the product development workflow to accelerate product development timelines while minimizing problems caused by miscommunication between different groups.

3. Leverage the experience of others and consider using integrated advisor services from a trusted partner to uncover issues before they cause problems or delay product development.

Technology Demonstration

DatangMobile and China Mobile demonstrated a 5G base station paired with Keysight’s 5G user equipment emulation solution at the 2018 Mobile World Congress tradeshow.
High-Performance 5G-Ready Design and Test Solutions

The primary challenges faced when developing new leading-edge technology are design and test related. Design software must encompass the functional capabilities of the latest technology. For example, 5G system-level simulation software must be able to model the latest Release-15 protocol signaling schemes and RF behavior for beam acquisition and tracking.

To reduce schedule risk, focus on aspects of the design tools that improve first-pass success, including features that decrease development time and improve simulation accuracy. Look for tools with prebuilt, highly-parameterized radio models, complete end-to-end performance simulation, and the ability to integrate real component measurements into system simulations. Ensure the capabilities of your design toolset will be regularly updated to account for new feature releases, so your future assignments won’t be delayed by a gap in your simulation capability.

To accurately characterize hardware, test solutions must have performance much greater than that of the device under test. This means if the acceptable error vector magnitude (EVM) of a transceiver processing a 5G waveform is approximately 2.5%, and the measurement uncertainty is on the order of 0.1%, the signal generator and signal analyzer used to measure the performance of the transceiver both need to have EVM performance less than 2%. For future-proofing purposes, either select equipment with the best performance or ensure there is an upgrade path to improved performance.

Data Sharing Throughout Product Development Workflow

The second challenge faced during the development of new technology products is the number of different internal organizations that are involved in the process. Each group’s efforts generally reside in separate information silos, and there is typically little information sharing between teams responsible for various product lifecycle stages.

Hardware product development starts with system level simulation, where a design exists in virtual form, and different architectures are evaluated to understand the system-level sensitivity to individual component performance. Once the system simulation is complete, physical prototypes are built and characterized, and design validation and testing follows.

This three-step design/build/test process is often repeated several times before volume manufacturing begins. Further design/build/test is typically employed after the initial product launch for cost reduction and performance optimization purposes. Software development accompanies the life cycle stages for hardware development, and can span one, two, or more stages.
Figure 1. Sharing test software, specifications, and results across lifecycle phases can vastly improve productivity by reducing costly and time-consuming duplicate work.

Information isn’t easily transferred from one lifecycle phase to another because testing is performed differently, data are in different formats, and specifications are inconsistent. This means there’s a lot of repeated work, resulting in slower time-to-market and higher project costs. To reduce development times and minimize the risk of miscommunications causing project delays, look for design and test solutions that share data throughout the development cycle.

**Integrated Advisor Services from a Trusted Partner**

There are many test and measurement (T&M) solutions available today that address the technical challenges associated with developing 5G technology. However, deploying 5G is further complicated by the evolving industry standards, the changing regulatory environment, and uncertainty about which communication techniques will be widely adopted and deployed by service providers.

T&M solution providers offer industry-wide experience and insights that companies operating in one part of the telecom ecosystem may not have. For example, a T&M solution provider who works with chipset and component designers as well as network equipment manufacturers can advise companies working on developing devices. The solution provider has experience with the parts that integrate into the device and with the networks with which the device communicates.
Mitigate 5G Product Development Risks

5G unlocks exciting new radio and network capabilities, but the complexity of 5G technology and the accelerated release of 5G standards represent significant risks for companies developing new products. These risks are primarily schedule-based, caused by performance problems that require time-consuming redesigns, but also include brand-damaging recalls and legal liability from unfulfilled service level agreements.

Mitigating these risks requires effective design and test tools, new tests and techniques to address the complexities of 5G technologies, and experienced technology partners who can accelerate your innovations.

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