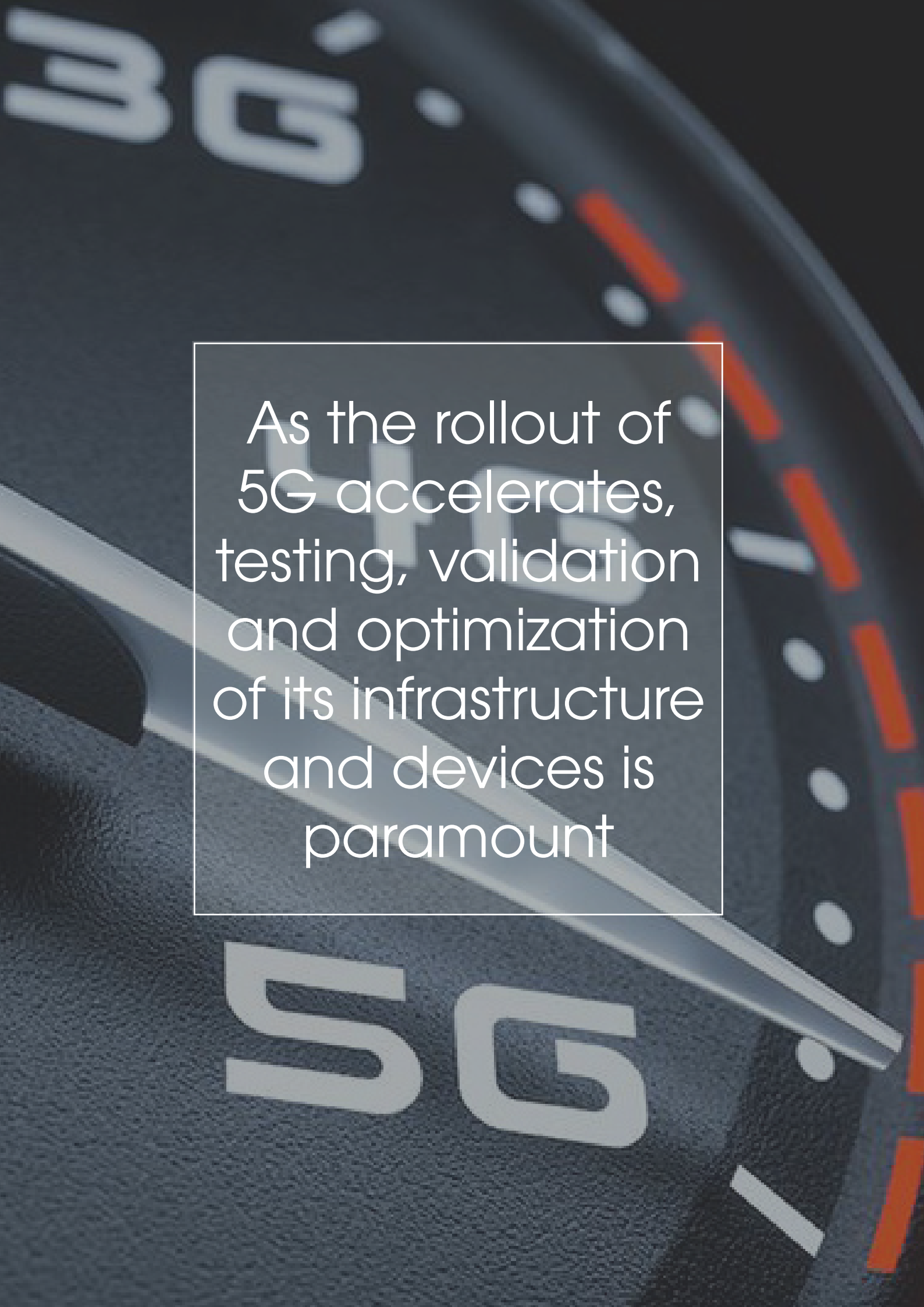


As the rollout of 5G accelerates, testing, validation and optimization of its infrastructure and devices is paramount

5G Testing Survey

With enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive Machine-Type Communications (mMTC) 5G mobile networks will revolutionize communications. The ability to transmit and receive large amounts of data while also connecting millions of devices at once is nothing short of a revolution. Fast, seamless mobile interactions will connect consumers, enhance business operations, and fundamentally alter the mobile broadband landscape.

As the rollout of 5G accelerates, testing, validation and optimization of its infrastructure and devices is paramount. According to a recent report from Global Industry Analysts entitled "Global OTA Testing Industry", the Over the Air (OTA) testing market for 5G is poised to hit almost US$1.4 billion within the next five years. That growth is due primarily to shifting dynamics and "the changing pulse of the market.

To gain a clearer picture of the testing protocols and challenges associated with 5G networks, we reached out to a panel of experts. Comprised of researchers, analysts, and advisors, our respondents provided us with in-depth and insightful information on the how 5G is tested, and what solutions and new strategies are emerging.

Our 5G Testing panel includes: Adam Hostetter, Director of Sales, Test & Measurement for SAF North America, Kevin Ramdas, Professor of Wireless Telecommunications at Humber College and Director of Training at Telecom-TRAIN.ca Dr. Nikhil Adnani, CTO at ThinkRF and Keysight Technologies representatives: Roger Nichols, Keysight 5G Program Manager, Rolland Zhang, FieldFox Product Manager, and Peter Schweiger, Southern Ontario Telco Account Manager.

PANEL DISCUSSION

What are over-the-air (OTA) test solutions, and why are they important?

Mobile communications performance and functionality are characterized by a foundational set of standardized test cases for both base stations and user equipment (UE). For LTE and previous generations, cabled tests were used to measure performance in virtually all of these test cases. Such is also the case for Frequency Range 1 (FR1) for NR. FR1 includes sub-6GHz frequency bands, some of which are bands traditionally used by previous standards but has been extended to cover potential new spectrum offerings from 410 MHz to 7125 MHz. The other frequency range is FR2 which includes frequency bands from 24.25 GHz to 52.6 GHz. Bands in this millimeter wave range have shorter range but higher available bandwidth than bands in the FR1. With the advent of these higher frequency 5G bands above 24.25 GHz, it is not practical to make cabled or conducted measurements because antennae are integrated with the semiconductor amplifiers and there is no practical spot for an RF connector. As a result, Over the Air (OTA) testing is needed to test performance and functionality.

"3GPP, and other standards bodies (e.g. CTIA), have stipulated that 100% of the FR2 test cases must be performed OTA," explains Roger Nichols, Keysight 5G Program Manager. "Most of this is due to the necessity of complete integration of antennas into radio-systems—there is no place to put a connector for a cable. The RF transmission and receive parameters as well as radio functionality KPIs (Key Performance Indicators) need to be tested over-the-air."

OTA involves taking measurements with no galvanic connection between the test equipment and the device under test (DUT). With OTA testing, these entities are connected to antennas, and measurements are made with a true "wireless" link between the equipment and DUT. These OTA measurements can be accomplished in any number of ways, from outdoor ranges to using chambers to contain the electromagnetic fields and prevent external signals from interfering with the analysis.

"Not only is OTA test the only standardized way to qualify the FR2 air interface performance of 5G devices and base stations," adds Rolland Zhang, Keysight FieldFox Product Manager, "it will also help RF designers, system engineers, and network optimization engineers to optimize designs, tweak site locations, adjust antenna orientation and tilts to meet system parameter settings as well as to achieve targeted performance and capacity at reasonable engineering cost."

OTA testing includes verification of beamforming and MIMO—both implemented through electrically steerable antenna arrays. Beamforming implementations involve multi-element antenna arrays. Steering the beam requires tight control of the phase of the signal entering each element. Access to the radio and the internal signal paths is limited.

"The larger the array of antenna elements, the tighter the beams that can be produced," explains Kevin Ramdas, Professor of Wireless Telecommunications at Humber College in Toronto and Director of Training at TelecomTRAIN.ca. "Currently, we are moving to a set of phase-matched cables to connect radios to the antennas. However, as we increase our frequencies, especially the FR2 frequencies, there will need to be direct, manufactured control of the interconnections between the radios and antenna elements. This means that the radio and antenna will have to be part of the same physical unit."

5G radio channel performance will also be heavily dependent upon control of the MIMO link. For MIMO to work correctly, the multiple streams from the transmit antennas to receive antennas require a low level of correlation. The level of variation in the air interface plays a fundamental role in the performance of the link, pushing our testing methodology further toward OTA testing.

"The MIMO link performance will highly depend on how the UE internally processes the MIMO conditions of the radio link," says Ramdas. "The UE will, in a way, send a recipe to the gNb to tell the gNb how best to precode the MIMO streams of data to decrease the level of correlation between the MIMO streams."

What frequency spectrum will 5G technology use? What will be the frequency spectrum in Canada?

"Two frequency ranges are used for 5G NR (5G New Radio), FR1 and FR2. FR1 (Frequency Range 1) refers to spectrum from 410MHz to 7.125 GHz, and FR2 (Frequency Range 2) refers to spectrum from 24.25 GHz to 52.6GHz. In Canada, 5G is also being launched at 600MHz, along with the eventual inclusion of 3.5GHz bands. Industry Canada is actively working to reallocate frequencies in 1.5,1.6,3.5,26,28,39 and 65GHz bands, with some of that spectrum to be auctioned in 2021," explains Zhang.

As of mid-March 2020, 3GPP has defined forty-five (45) bands in FR1 and four (4) bands in FR2 These band definitions are designed and set to integrate national frequency spectrum policy decisions from around the globe with state-of-the-art radio development and testing technology.

The Canada spectrum situation for spectrum that is new to mobile wireless is as follows (from "GSA Spectrum for Terrestrial 5G Networks: Licensing Developments Worldwide" updated August 2019). Figure 1.

"Performance is defined, specific, and tested depending upon the frequency and the duplex method," says Nichols.

Many operators will have to make a transition over time to 5G in their existing spectrum. Since this is now dedicated to LTE, as UEs come on the market with 5G capability, the best way to utilize the new technology is a gradual transition. This is enabled by a standardized approach to allowing NR in the same channel as LTE with Dyanamic Spectrum Sharing. "Dynamic Spectrum Sharing (DSS) will allow coexistence of 5G sharing existing LTE bands as well," adds Peter Schweiger, Southern Ontario Telco Account Manager, Keysight. "Spectrum Outlook 2018 to 2022 includes more relevant details related to this rollout."

Figure 1.

Frequency Range	Status	Comments
614-698MHz	Auction Complete	Technology-Neutral: Some operators will use this for NR
3540-3650 MHz	Auction/Licensing Planned or Complete	Considered "C-band" as part of ITU definition. TDD only.
3650-4200MHz	Taking consultation from national stakeholders.	No immediate plans for license and auction but doing consultation to take appropriate next steps for policy.
26.5GHz-28.4GHz	Auction/Licensing Planned or Complete	
25.25GHz-26.5GHz	Under consideration	
Other FR2 Bands	Likely to be made available late 2021	Includes 37-40GHz and 64-71GHZ (this latter already added as unlicensed in the USA)

What are the challenges that test instrument companies face while delivering solutions to the 5G ecosystem?

5G systems operate in mm-wave frequencies up to 470 GHz. Historically, a vast majority of commercial wireless networks have operated at frequencies no higher than 3 GHz. This has been the case since the first generation of wireless technologies were introduced.

"The Wireless Industry has We have a limited amount of experience in the areas of real-world performance of mmWave-wave wireless systems and this necessitates over-the-air experiments and trials," says Dr. Nikhil Adnani - CTO - ThinkRF. "Legacy field test equipment only operates up to 3 or 6 GHz. At the very least such equipment needs to be frequency extended to address the mm-wave bands – 40 GHz being the most necessary. For deeper testing of 5G demodulation, the bandwidth of such equipment needs to be extended to 100 MHz."

In the context of field testing 5G solutions, testing can involve both static beamforming and dynamic beamforming. Static beamforming uses multiple beams produced by one antenna array, and the UE moves from one narrow beam to another. Dynamic beamforming operates though the coordination of both transmit and receive antennas beam following the user's changes in physical location and in orientation of the UE.

"Dynamic beamforming requires test equipment manufacturers to re-examine how testing is done," says Ramdas. "That makes it the more costly of the two test options, especially dynamic beamforming might require a more distributed test probes (possibly built into the UEs) where test data from the probes are aggregated to analyze 5G system performance."

"While the low and mid-band spectrum (3-7.125GHz) propagation characteristics for cellular are well known, mmWave is a whole new beast," adds Adam Hostetter, SAF North America. "For carriers to deliver on, and monetize the promised data rates of 5G, extensive testing of the signal quality of mmWave deployments will be essential."

That's because, according to Hostetter, early in the 5G development cycle, the established T&M players developed sophisticated OTA test solutions for highly controlled environments, such as anechoic chambers. While there will undoubtedly be a need to perform throughput and QoS testing, characterizing and optimizing the physical layer will be prioritized. As a result, low-cost, ultra-compact, and easy to use solutions for field teams performing these measurements will be needed.

"As 5G is rolled out at mmWave, SAF believes there will be significant demand for an extensive walk and drive testing in the real world," explains Hostetter.

Discussion Panel Expert: Keysight

Keysight Technologies is a leading provider of RF test and measurement equipment. From parametric test of semiconductor wafers to functional and production test of PCBs to the final test of computer systems, Keysight products help engineers achieve the best performance possible. Keysight can also help designers of high-speed digital devices achieve cutting-edge performance while verifying compliance and interoperability with industry standards.

KEYSIGHT TECHNOLOGIES

What technology developments are needed for testing millimetre-wave 5G?

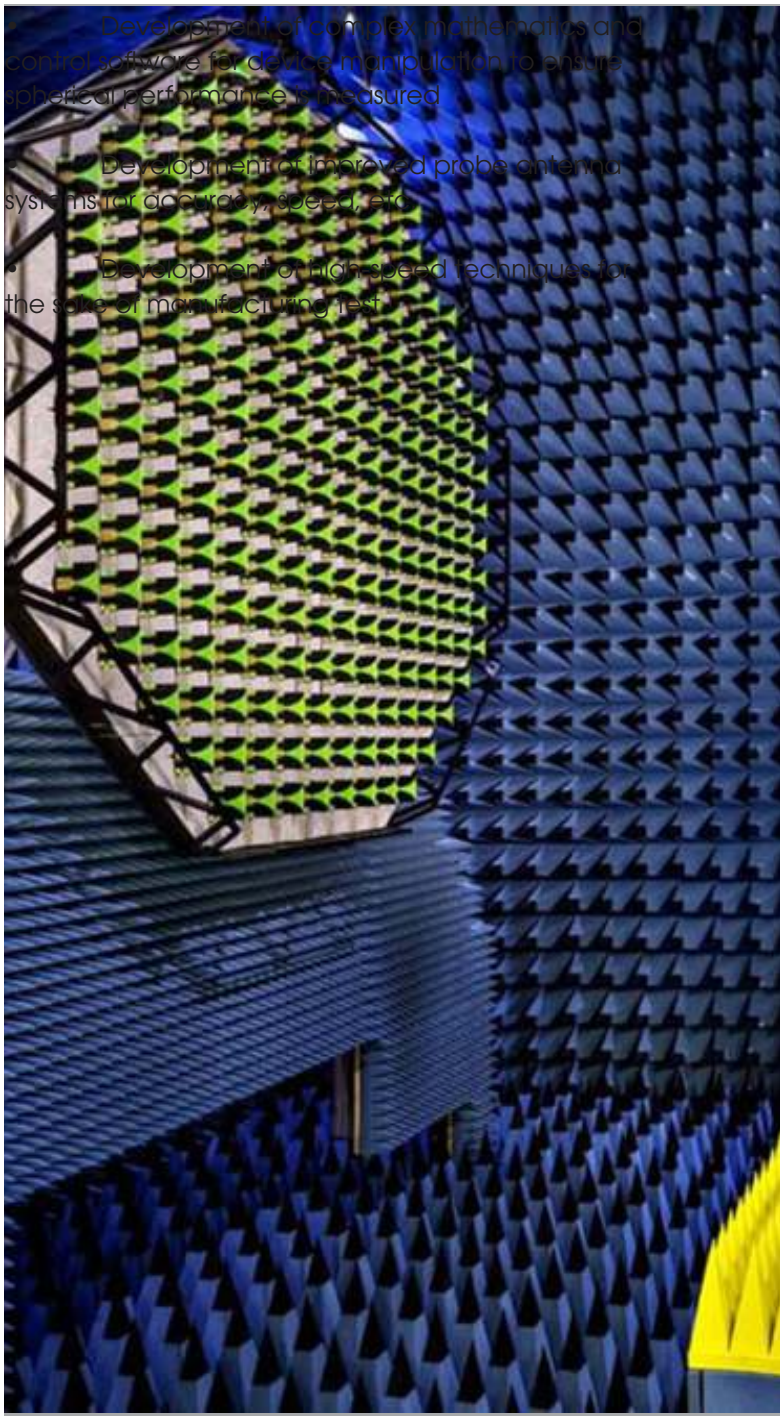
The test solutions available for wireless development and deployment workflow are designed to take into account many of the testing challenges that must be overcome. That is why many test solutions include component modeling and design, circuit modeling and design, mmWave circuit, and system testing for both UE's and base stations, as well as mmWave measurements once systems are deployed in the field. Of course, the constant change in testing protocols triggered by new products, standards, and test cases are developed can be challenging, especially when those changes occur monthly rather than quarterly or annually.

As Nichols elaborates, Devices (UE's) and Base Stations have added new challenges, including some of the following examples:

Antenna technologies: most mmWave antennas require gain (and thus directivity) and be electrically steerable. Hence measurements need to be made on these systems which include measuring the semiconductors that make up these active antennas and also making antenna performance measurements in OTA situations. Most of this is done in anechoic chambers and the challenges include making accurate measurements with reduced dynamic range, spherical measurements with multi-dimensional positioners, and ensuring everything is calibrated and well-understood by customers.

UE tests: the FR2 test cases mean that everything is done in an anechoic chamber—these can be protocol and functional tests, they can be parametric tests, and they can be a combination of the two (Radio Resource Management for example). The challenges abound but mostly are related to accuracy, repeatability, dynamic range, and test time. Spherical/3D performance of these systems is crucial, and these measurements are complex and take a long time. The commercial communications industry is not used to these challenges and it is up to us to simplify the process, make it economical, and ensure that the results are indicative of actual performance in a live system. We have spent significant engineering time on these measurements and include:

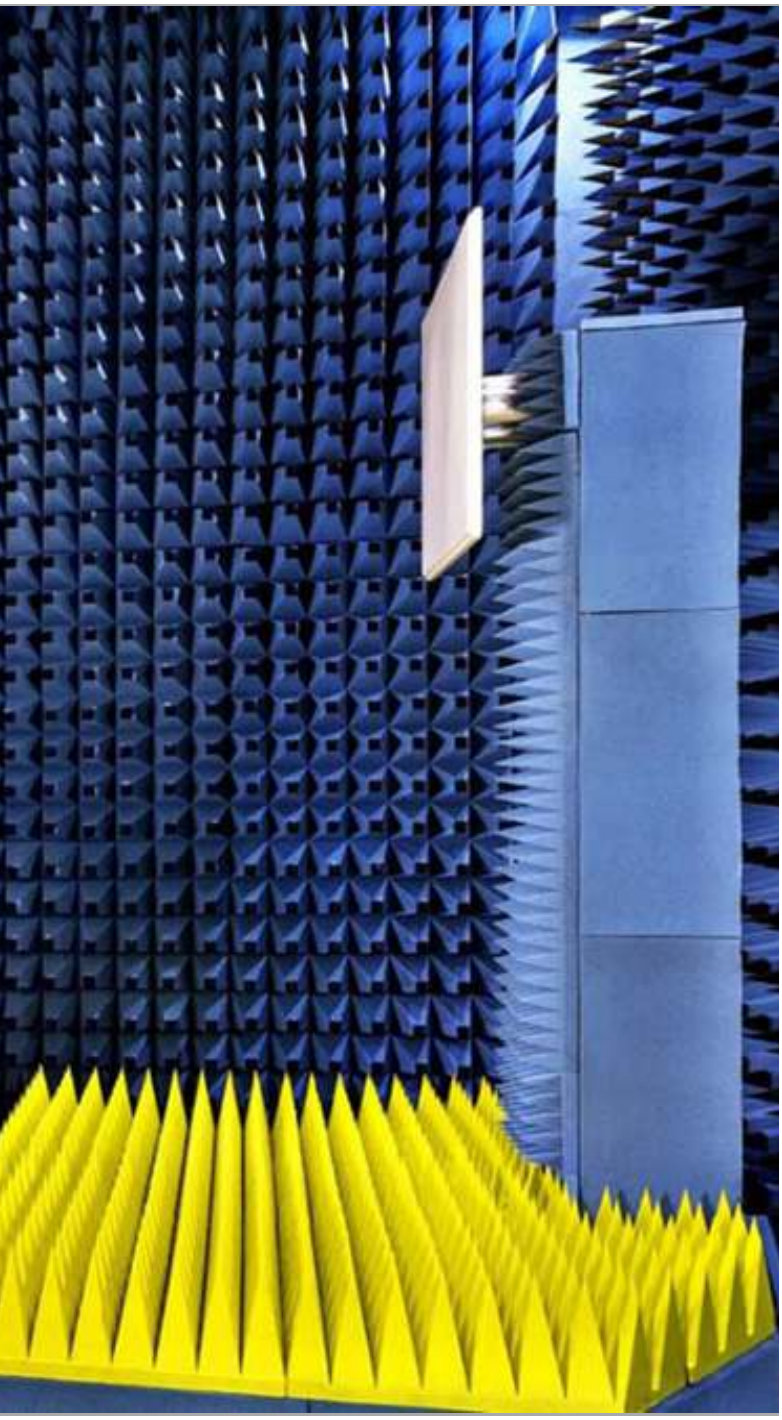
• Development of affordable compact antenna test ranges (CATR) for better dynamic range and managing larger DUT sizes



• Development of complex mathematics and control software for device manipulation to ensure spherical performance is measured

• Development of improved probe antenna systems for accuracy, speed, etc.

• Development of high-speed techniques for the sake of manufacturing test



When it comes to In-field Network testing, millimeter wave presents unique challenges compared to conventional workflow embedded with RF engineering teams. Steerable phased-array antennas are prevalent in the state of the art. For in-system field testing, there are different approaches to the antennas we use on our measurement equipment. An omni antenna may work for CW path loss model tuning in a controlled environment because it measures all energy from all directions. But power levels are such that these antennas are not very practical for mmwave. A fixed horn antenna is a popular choice because they cover reasonable frequency ranges and are easy to use and inexpensive. For example, a WR28 gain horn antenna covering 26 to 40 GHz is suitable for most of 5G mmWave frequency bands. It also has a narrower beamwidth, not precisely like a mobile device, but the designer could interpolate the data to match with any device measurement. The drawback, according to Nichols, is that the designer must manually align antenna direction for each measurement sample and perform a complex walkaround test. This type of analysis is not possible for any drive-test or automated test processes.

"The preferred solution is to use a phased array antenna with the FieldFox spectrum analyzer or channel scanner mode," concludes Zhang. "If connected with a transmitter or signal generator, it can emulate gNB beams to provide precise and realistic operation scenarios. This phased array antenna is very powerful tool and versions exist for the different FR2 bands."

"For customers seeking a complete millimetre-wave 5G testing solution, end-to-end performance guarantees and support are important," adds Schweiger. "Because mmWave testing is much tougher than sub 6GHz testing, and the need to provide the entire solution including chambers, test equipment, calibration routines and application engineers backed by experts ratified by 3GPP standards should be a priority."

Discussion Panel Expert: ThinkRF

ThinkRF is the leader in software-defined spectrum analyzers that monitor, detect and analyze complex waveforms in today's rapidly evolving wireless landscape. Built on patented technology and quality by design principles, the ThinkRF solution offers greater versatility, better performance and additional capabilities for 5G, signals intelligence (SIGINT), spectrum monitoring, technical surveillance countermeasures (TSCM) and test and measurement applications.

thinkRF
monitor. detect. analyze

Why do mmWave channel measurement campaigns continue to be a focus for the entire industry?

The channel measurement work for the favored NR bands started about eight years ago in academia and in commercial research teams in the wireless industry. The measurements include an assessment of many parameters: Path Loss, Power Delay Profiles, number of reflected paths to be expected depending upon environment, Line-of-Sight and Non-Line-of-Sight (reflected) characteristics, Polarization Impact, and Scattering and Diffraction. For a full understanding of the channel, these measurements have to be made in multiple types of channels, both indoor and outdoor. Various environments (urban, rural, roads, trains, stadium, office, etc.) have to be considered under both static and dynamic conditions.

"The measurement campaigns take several weeks to plan multiple weeks to execute and months of post-processing to analyze the results and build channel models," explains Nichols. "They also require a variety of test approaches, all of which are complex, expensive, and generate large resulting data-sets. The industry is still learning how to make all of these measurements and refine our initial models to reflect what happens in the real world."

One of the promises of 5G technology is fast download speeds. Using mmWave frequencies provides the bandwidth needed to deliver that promise. But mmWave measurements are new to the commercial wireless handset ecosystem from chipset providers all the way to service providers and they require Over the Air Measurements which is also new in this ecosystem's labs.

"The ecosystem is eager for good partners with experience with these measurements," advises Schweiger.

"The Wireless Industry has very limited experience in how mm-wave communication systems that are to deliver large amounts of data will perform in the real world," cautions Dr. Adnani. "How will they perform with the added complexity of mobility and under a variety of propagation conditions in an urban landscape? To answer these questions, channel measurement campaigns are a necessity."

How is Massive MIMO technology being considered as one of technologies for inclusion in the 5G specifications?

At its most basic, Massive MIMO involves increasing the number of base station antennas, and associated independent transceiver chains for each antenna element, to provide improved coverage (spatial diversity) and capacity (reuse time/frequency resource blocks in the same cell). One big benefit of Massive MIMO is to resolve the large difference in link-budget demand between uplink and downlink in the mid-band frequency ranges. Because of practicalities of antenna design and radio systems, the uplink budget is required to be from 15-19dB more demanding than that of the downlink.

According to Nichols, one way to address a large part of this discrepancy is with massive MIMO. Most entities implementing systems in these bands expect to use this technology (or are already doing so) to ensure appropriate uplink performance.

"There is early research for massive MIMO at FR2 in only one universities of which I am aware, so that technology will take time to mature," says Nichols. "For FR1, however, Massive MIMO is seen as a necessary technology especially for the increasing demands of capacity and for link-budget management in the mid-band spectrum (2.5-4.9GHz)."

While massive MIMO does not have to be unique to 5G, the large arrays of antennas combined with formable signal processing, allows better beamforming, spatial reuse of spectrum, and multiple streams—all of which are required to realize the 5G vision.

The result, according to Schweiger, is "higher data rates, more efficient spectrum use, and higher subscriber density. All things 5G is also trying to achieve."

Discussion Panel Expert: TelecomTRAIN

Telecomtrain are national leaders in providing hands-on training courses to help your technical and business employees succeed in implementing communication systems. They design a custom learning solution that revolve around your requirements, or you can select from their pre-designed courses.

Telecomtrain's training delivers a strong practical approach using the latest industry equipment.

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5G ready

F-OFDM vs. FBMC ? Which one is a better match in 5G frequency range and why?

"F-OFDM and FBMC are only two examples of many alternate modulation approaches for 5G that were proposed in early 5G applied research. The intent of most of these is to reduce the out-of-band spectral "splatter" of OFDM-type modulations to either insert other modulations inside of an OFDM channel, or to reduce the guard-bands required between adjacent channels. To date, none of these have been adopted by 3GPP for NR.

The primary reason is that while these approaches yield excellent performance gains in simulation, those gains are neutralized in practical applications. The primary drivers are the state of the art of phase noise in transmitter local oscillators and non-linearities in real-world power amplifiers," explains Nichols.

"The combination of these two non-ideal facets render all of these novel ideas to be equivalent of OFDM given today's semiconductor and radio system technology," adds Zhang.

"OFDM will continue to be used with 5G networks with more flexible subcarrier spacings to take advantage of bandwidths and frequencies," adds Schweiger.

How will new use cases for 5G, like autonomous driving and IoT, affect how we test mobile networks?

As we look forward to additional 5G use cases, such as autonomous driving, critical infrastructure, and even applications such as remote surgery, fail-proof networks are going to be essential. Currently, if downloading via a 5G networks takes longer than the promised length of time – 30 seconds vs. 10 seconds, for example – most consumers may not notice the difference, but as use-case demands increase, speed will become a priority.

"In these future use cases, such as autonomous driving and critical infrastructure, fast, reliable, ultra-low latency communication is going to be a matter of life and death," says Hostetter. "While these applications are likely 5-10 years away, we believe there will be a requirement for extensive physical layer testing to ensure the RF coverage is solid."

"In addition, throughput and QoS testing at the network and cell edge are going to be critical to ensure 99.999% or better reliability for these critical networks. Lastly, the test routines will need to be continuous and proactive," adds Hostetter.

Schweiger agrees. "Different applications will need different frequencies (IOT mostly the lowest, Autonomous driving will likely be sub 6 GHz using C-V2x) requiring test equipment at different frequency ranges," he says. "Different applications also have different key performance indicators (KPI's). IoT sensors working ten years off a button cell will need to test battery drain and signal to noise ratio, where remote control will want to test latency and packet error rates (reliability) requiring different test cases and equipment."

Business and governments that use mobile wireless for services in which safety, finances, and fundamental business continuity are at stake will pushing demands of a different sort. Mission-critical use of wireless will prioritize performance related to reliability, latency, and security. As a result, businesses selling mission-critical services will be required to verify their performance in ways that are not fully specified and standardized today (e.g. there are multiple definitions for latency, reliability, and security and not significant standards set—especially for end-to-end performance).

"The change of mobile wireless to be used for industries beyond typical smartphone access will have a significant long-term impact on how we test networks," adds Nichols. "While the demands of today's users are significant and testing and optimizing are a large part of what we work on, the approach to new industries will change this picture."

How will crowdsourcing play a role in testing 5G networks?

It remains to be seen how crowdsourcing will impact testing of 5G networks. Peter Schweiger points to test automation platforms like OpenTap as one avenue that could be explored.

"Companies and individuals can contribute test code based on Standard Commands for programmable instruments (SCPI) in an open, scalable platform and build a library for useful 5G device tests," Schweiger says.

Roger Nichols believes crowdsourcing of information about the network has the advantage of reducing the need for implementing dedicated monitoring transducers and routing their data to the proper analytics engines, but he sees some limitations

"Crowdsourcing information provides only information from 'where the crowds are' and is limited to what the devices and base stations can derive from their normal functionality," he explains, "Such information also has to be 1) tested for validity and reliability; 2) protected from a privacy and security standpoint; 3) efficiently processed by analytics and perhaps even AI engines in the network."

"All of these latter steps are far more complex and expensive than the industry hype would suggest. But we do see this as one necessary part of understanding and optimizing system performance—much like the crowdsourced information of today's most popular mapping systems. It will take dedicated development and computing resources to be put to use for the overall improvement of the networks," he concludes.

Discussion Panel Expert: SAF Tehnika

SAF Tehnika is a designer, producer and distributor of digital Microwave Data transmission equipment. SAF Tehnika products provide wireless backhaul solutions for digital voice and data transmission to mobile and fixed network operators, data service providers, governments and private companies. SAF sells microwave point-to-point radios for licensed and license free frequency bands as well as unique spectrum analyzer Spectrum Compact. SAF Tehnika also provides customized microwave solutions for various applications, such as Broadcasting and Low latency networks.

Who is the governing body for 5G standards globally? Are the variations in the standard in Canada versus other countries/regions such as the USA or Europe?

The 3rd Generation Partnership Project (3GPP) unites seven telecommunications standard development organizations and provides a stable environment to produce the Reports and Specifications that define 3GPP technologies. Created to establish 3G networks initially, they have successfully continued their work to help provide 5G standards being used today.

In Canada the ministry for Innovation Science and Economic Development (ISED) controls and governs the use of the electromagnetic spectrum in Canada.

As Nichols explains, "5G NR is the first mobile wireless standard that has no concurrent competitor from a similar industry consortium, so it is considered global and universal."

"There are not variations in the standard between countries and regions," he says. "The variations that do drive differences in behavior are driven by national policy differences—most of these are how spectrum is governed, which varies by country despite international work to build some degree of harmonization."

It's clear that when it comes to 5G, business-as-usual is not applicable, and that's even more clear when it comes to testing. Because DUT integration will increase significantly, physical testing of equipment will become ever-more challenging, if not impossible. As a result, OTA testing will become essential.

Many 5G providers are already strategizing and preparing for this shift in testing protocols, and will be well-placed for a smooth transition to OTA testing.

Specifically Keysight Technologies, SAF Tehnika and ThinkRF have designed and brought to the market the following 5G testing solutions available at Gap Wireless.

Keysight FieldFox
SUPER 5G NR Next Generation Microwave Analyzers

Over-the-air (OTA) 5G NR measurements (Option 378) – Supported on N991xB/N993xB models only.

Support for 5G NR FR1 and FR2 over-the-air measurements. The FieldFox B-Series N991xB/N993xB with 100 MHz of bandwidth are perfectly suited to capture and demodulate over-the-air transmissions of 5G NR FR1 and FR2 control channels. Provides key performance indicators including physical cell ID, received power levels and beam index information. Conducted EVM measurement is also included with Option 378.

SAF Spectrum Compact
The world's first handheld microwave spectrum analyzer

0.3 GHz – 3 GHz and 24 GHz – 40 GHz test and measurement solutions are a great fit for 5G network deployment. Thanks to its size, usability and sensitivity, the Spectrum Compact can be used for high precision detection of existing interference on installed paths or available radio channels in microwave, millimeter wave and other frequency ranges. Data logging of all spectrum scans is available with the Spectrum Compact device, and enhanced data processing and analysis are provided by SAF Tehnika PC software for your laptop.

ThinkRF D4000 5G 40 GHz Downconverter/Tuner
Small, powerful and cost-effective downconverter / tuner for the Next Generation RF Environment

Downconverters are one of the most economical and cost-effective methods for increasing the frequency performance of RF signal analysis systems. In the new world of 5G networks, a downconverter can reduce time to market and costs for mobile operators and system integrators.

The ThinkRF series of RF downconverters / tuners are designed for maximum performance and interoperability. The D4000 RF Downconverter / Tuner enables translation of RF signals in the frequency range of 24-40 GHz with up to 500 MHz of real-time bandwidth (RTBW), to capture mm-wave 5G signals.