Challenges for Effective and Realistic 5G OTA Testing

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The path towards a realistic and cost-effective 5G over-the-air (OTA) testing scenario is not clear yet. With a tremendous pressure on 5G standards development, network deployments and device manufacturing, the realistic answers that a 5G OTA test system should provide are far from being obtained to date. This article identifies some of the challenges ahead with possible solutions.

New Radio (NR) is eagerly expected as the total solution for current wireless communications demands aiming to provide fast throughput and low latency, with a significant improvement in user's quality of service (QoS) and quality of experience (QoE). The primary concern is the need to satisfy the exponential rise in user and traffic capacity in mobile broadband communications. Global mobile traffic will experience a growth from 7,201 petabytes per month in 2016 to around 48,270 petabytes per month in 2021, an astonishing 670 percent growth.[1] NR is also expected to handle an enormous number of devices connected to IP networks, some 3× as high as the global population in 2021, raising up from 2.3 networked devices per capita in 2016 to 3.5 by 2021. To add complexity, a perceived availability of 99.999 percent and ultra-reliability are also envisioned as key features of 5G.

In the race towards satisfying the expected growth, connectivity, availability and reliability, 3GPP and CTIA have emerged as the standardization bodies that will enable adequate OTA testing of the new technologies prior to massive deployment. With the experience of 4G OTA testing standardization history in mind, there are more questions about the capabilities of consensus-driven OTA testing standardization and how it works to solve the real challenges of 5G deployment and operation. With new engineering concepts in 5G like MIMO, beamforming and the generalized use of mmWave frequencies, 5G OTA testing is clearly the challenge of the decade for wireless communications and a key milestone for 5G deployment and operational success.

TABLE 1

3GPP 5G DUT ANTENNA CONFIGURATIONS AND OTA TEST METHODS

DUT Antenna Configuration	Description
1	Maximum one antenna panel with D ≤ 5 cm active at any one time
2	More than one antenna panel D ≤ 5 cm without phase coherency between panels active at any one time
3	Any phase coherent antenna panel of any size (e.g., sparse array)

DUT Antenna Configuration	Direct Far Field (DFF)	Indirect Far Field (IFF)	Near Field to Far Field Transform (NFTF)	Near Field without Transform (NFWOTF)	Reverberation Chamber (RC)
1	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes
3	No	Yes	No	No	No
	Approved in RAN4 [3GPP TR 38.810 v2.0.0]		Approved in RAN4 [3GPP TR 38.810 v2.1.0]	Not Approved in RAN4 [3GPP TR 38.810] yet for variety of reasons	

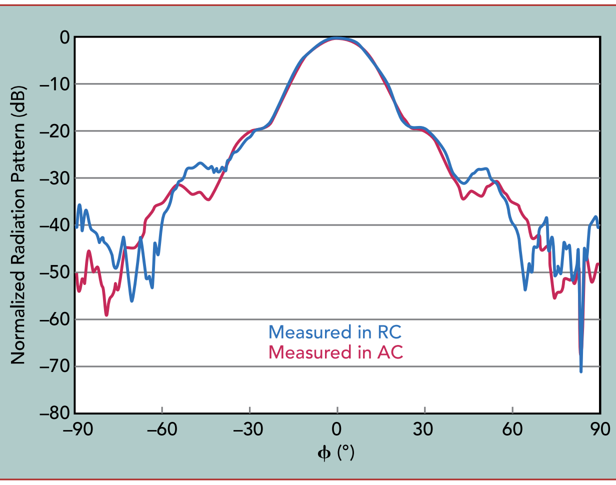


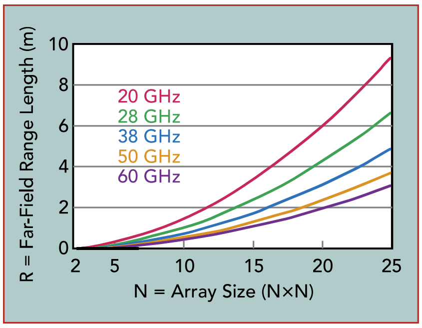
Fig. 1 AUT H-plane radiation pattern measured in RC and in AC (reproduced from Reference 2 with permission).

5G OTA TEST METHODS

Three different 5G device under test (DUT) antenna configurations and several 5G OTA test methods are being discussed within 3GPP TR 38.810, summarized in ***Table 1***. The Reverberation Chamber (RC) method can be very useful for isotropic Key Performance Indicators (KPI), particularly total radiated sensitivity (TIS) or spurious emissions, and recent progress has added the capability of directional measurements by means of either time-reversal or Doppler-discrimination effects,[2] as shown in ***Figure 1***. Non-conventional uses of RCs for 5G OTA measurements are also being explored, in particular for devices designed to function in directional-channel environments[3] and for real-time OTA testing of throughput and latency. RC-based methods have some positive aspects for 5G Non-Standalone (NSA) and Standalone (SA) OTA testing, like considerably-reduced setup cost compared to other solutions for the complex multicarrier requirements. While spatial information may be partially lost in these rich multipath systems, an average 3D isotropic emulation of delay and final throughput performance, which is after all what the user perceives in a reasonable time slot, may very well serve the purpose. Yet, little progress has been made for 5G OTA using isotropic 5G channel model emulation using RCs and with RCs lack of strong support at

3GPP, it is not yet a 5G-standardized test method.

Extending the multiprobe anechoic (MPAC) approach to 5G implies the use of 3D channel models and mmWave operation, which makes it impractical due to the increase in complexity and the fact that too many probes would be needed, with their associated channel emulator ports, and the effect on the already-reduced quiet zone will be large. Although some simplified sectorized MPAC variations have been proposed, the additional need to operate in the far-field makes the use of MPAC for 5G OTA limited, at least at mmWave frequencies.



▲ Fig. 2 Far-field range for an N×N array of λ/2 spaced elements.

▲ Fig. 3 H300 CATR+DFF+SNF 5G OTA Test System by EMITE.

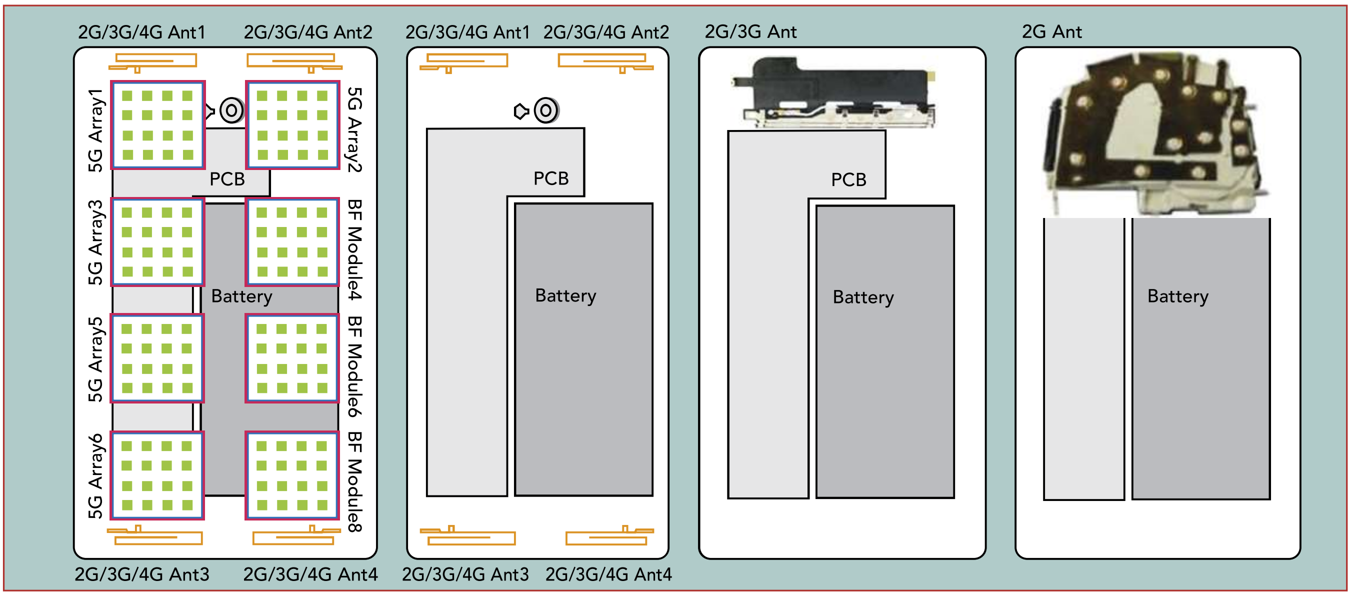
The incorporation of the Radiated Two-Stage (RTS) method into standardized 5G OTA testing is benefiting from an apparent harmonization to the MPAC method using seven 4G LTE FDD devices in single 2×2 single-carrier MIMO OTA mode, but the "Wireless Cable" is not transparent with respect to the DUT antenna characteristics, as these must be measured beforehand for the method to be applicable. In addition, the RTS method cannot yet support the user equipment (UE) beamlock test function (UBF) for 5G UEs which is clearly a limiting factor for standardized OTA testing. On the other hand, the electrical size of DUT is only limited by the size of the test chamber.

The Indirect Far Field (IFF) Compact Antenna Test Range (CATR) method can create a plane-wave field in much less space than a Direct Far Field (DFF) method by means of a reflector, and it seems ideal for 5G mmWave OTA testing, but it has difficulties providing different frequency ranges. With the options on the table, CTIA operators have recently considered the IFF method as essential for consideration during development of the CTIA 5G NSA mmWave OTA Test Plan v1.0,[4] due for release in 2Q 2019.

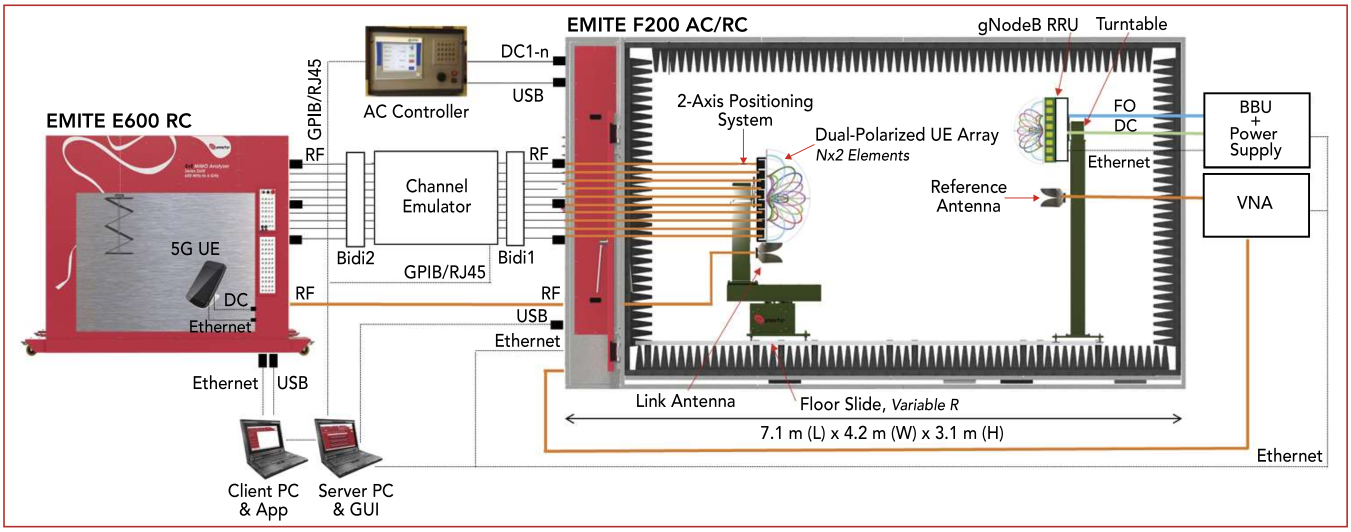
The Near Field to Far Field (NFTF) method relies on using a mathematical transformation to determine the KPIs in the far field from a near-field pattern scan. The NFTF method shows deficits with respect to testing during real-time operation of the device. Initially, Equivalent Isotropic Radiated Power (EIRP) and Total Radiated Power (TRP) have been reported to be measured by NFTF test systems.

The Direct Far Field (DFF) method requires Fraunhofer far-field distances and for mmWave frequencies, it is not practicable due to the space and cost requirements and the large link budget. ***Figure 2*** illustrates how the far-field range for an N×N array of half-wavelength spaced elements increases dramatically as the size of the array increases. The hybridization of DFF for use at 5G sub-6 GHz frequencies, however, it may be quite useful since other methods present drawbacks at low frequencies.

It is clear that there is no single OTA method today capable of providing answers to all the challenges of 5G testing. Several companies and institutions have called for the development of new or hybridized test methods that can provide the required answers to the numerous 5G OTA challenges presented. One good option is the recently-released



▲ Fig. 4 The antenna layout evolution on UEs.



▲ Fig. 5 gNodeB-UE E2E 5G OTA testing vs. range with two cascaded chambers.

CATR+DFF+SNF 5G OTA Test System shown in ***Figure 3***. A specific and optimized reflector design covers both the mmWave region (Frequency Range 2 or FR2) and part of the sub-6 GHz region (Frequency Range 1 or FR1), and a hybrid DFF/SNF tower completes the picture to provide full-range and simultaneous FR1+FR2 OTA testing.

CHALLENGES FOR 5G OTA TESTING

Fully-integrated antenna arrays

In addition to a densely antenna-populated layout, illustrated in ***Figure 4***, and unlike previous generations, 5G UE antenna arrays do not provide access to their RF ports due to small form factor and higher frequencies for some bands. Testing connector-less antenna arrays is an obvious challenge, which forces RF tests and calibrations to be performed OTA in a well-controlled environment. Phase calibration between the chains is typically required in addition to signaling performance tests and power measurements. The fact that coupling may occur and the limitations of the testing enclosure make the coherent calibration of each RF chain not necessarily leading to optimal beams. The up- or down-conversion for operating at mmWave frequencies further complicates the testing equipment.

DUT form factors

Each DUT form factor type has specific requirements and restrictions. Chipset 5G OTA measurements can be defined as the test that provides the chipset RF performance evaluation in the real SA environment.[5] It is good that chipsets are small since the mmWave wavelengths of 5G frequencies are also small, and therefore the issues with large far-field distances are minimized. The problem arises due to the fact that the chipsets usually do not have RF connectors and are also very fragile. Two other chipset-specific challenges for 5G OTA testing are the need to accurately control temperature and humidity cycling within the chamber due to the chipset being sensitive to environmental conditions and the fact that for mass production chipsets may need to be measured in the form of panels. With each panel containing a lot of similar types of chipsets, their accurate and individual 5G OTA testing becomes a very challenging task. Controlling the temperature and the humidity within any OTA test environment is also a challenging task, and only two companies have announced such feature at their test systems to date, R&S and EMITE.

5G OTA UE testing is thought to be, at least initially, compatible with legacy 4G technologies. While it has been proposed that 4G OTA methods should be attempted first for the new 5G devices, it is also clear that 5G OTA testing will further be complicated if we have to also support 4G OTA testing simultaneously.

gNodeB testing, in addition to their associated larger size, also requires phase coherency calibration, which is currently a concern due to the large number of channels. The specific OTA measurements challenges of high directivity beam performance, not only for the gNodeB end but also for the 5G UE end, deserve its own section in this technical feature.

Spatial agility

Spatial intelligence is another key performance aspect of 5G. The 3GPP has defined centered and off-center KPIs for static beams, but the beam dynamics are an inherent part of 5G. Processes such as beam searching, beam matching, beam tracking, beamforming or beam scheduling, among others, become essential when the UE moves dynamically. When the gNodeB incorporates massive MIMO, the spatial non-stationary property, the angular spreads and the 3D spatial properties cannot be ignored. Since the number of probe antennas is large, the channel between different probe antennas has a strong correlation, and removing the impact of the channel correlation across gNodeB antennas and probes remain an issue of concern.

Finally, the addition of multiuser bidirectional channels introduces yet additional challenges to the OTA test. Interestingly enough, the whole 5G gNodeB-UE end-to-end (E2E) set seems to be attracting the most attention, as it is the pair that provides a specific user-performance. Extraordinarily complex cascaded chamber sets are being proposed for this type of testing, aiming at getting accurate and realistic KPI evaluation vs. range when using power-fix connectorless gNodeBs in one end and a moving UE on the other end. In this type of OTA test setup, shown in ***Figure 5***, for NR beam steering, beamforming or baseband beam tracking algorithms performance testing, real-time throughput, latency and mobility tests are being proposed. One chamber captures the 5G signals coming from the gNodeB and redirects them to a channel emulator and an attenuator matrix, which in turn attenuates and re-route the signals to a second chamber, an RC or AC, in which the 5G UE is located. This represents a breakthrough over previous single-chamber OTA test setups, with a lot more complexity, associated required expertise and cost.

Channel modeling

Realistic channel modeling represents yet another key aspect of 5G OTA testing. Several studies have found some extensibility of the existing 3GPP channel models to be somehow applicable at higher frequency bands up to 100 GHz. The measurements indicate that the smaller wavelengths introduce an increased sensitivity of the propagation models to the scale of the environment, which is to be expected, and show some frequency dependence of the path loss as well as increased occurrence of blockage. Furthermore, the penetration loss is highly dependent on the material and increases with increasing frequency of operation. The shadow fading and angular spread parameters are larger and the boundary between line of sight (LOS) and non-line of sight (NLOS) depends not only on antenna heights but also on the local environment. This has simplified some initial proposals, but the main drawback remains on how to model a signal that is divided into several carriers and MIMO paths which can extend from very different frequency bands. It is expected that FR1+FR2 bands will be successfully combined, providing total user throughputs in excess of tenths of Gbps and new channel modeling challenges.

CONCLUSION

5G is expected to bring significant benefits for the wireless communications industry, but it also carries the need for drastic changes in the way of how OTA testing is performed today. Performance metrics and cost-efficient ways to measure 5G equipment in a lab that is close to real world use are urgently required. This will necessarily include testing the main beam, testing in the presence of other radios in same channel and testing the communication performance against interference from different directions, evaluating also the dynamic adaptation performance of both sides—the UE and the gNodeB.

While some progress has been made, consensus-based 3GPP standardization is far from reaching the goal, and is currently limiting the scope of what can be achieved in terms of solving the existing real challenges. Failure to meet the expectations is not realistic at this stage of the process, and developing accurate and realistic OTA test methods is also the responsibility of the scientific community. We still have time, but it is rapidly running out.■

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