Testing the 5G New Radio

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Abstract

To meet the ever increasing need for wireless communication bandwidth, the proposed 5G new radio access technology will utilize techniques such as beamforming and massive MIMO which have not seen widespread adoption in any previous wireless technology. It will also attempt to use millimeter wave frequencies for mobile communication at a scale never seen in previous defense and satellite applications. These decisions will have a drastic impact on the test methods used to validate the operation and performance of new radio designs, requiring radiated test techniques to replace tests that are traditionally performed. This paper will touch on various issues the industry must address, and the current work in 3GPP to develop the basis for these test techniques before the radio design has even been completed.

Introduction

With the Long Term Evolution of the 3GPP standard, otherwise known as LTE, approaching ten years of age, 3GPP has set its sight on, if not its complete replacement, at least a very serious augmentation to the wireless networks of today. While the original 2008 3GPP Release 8 of LTE didn't officially meet the ITU criteria for 4G, the eventual release of LTE Advanced in the 2011 Release 10 did finally meet the goal of 100 Mbps mobile data. Regardless, from the beginning LTE altered the landscape of wireless data consumption, with streaming video becoming a central component of mobile data usage. Now, as we look forward to a massively connected future with applications like autonomous vehicles, virtual and augmented reality, and a proliferation of "Internet of Things" wirelessly connected sensors and other devices, the ITU has set its sights on an aggressive requirement for 5G, which, like its predecessor will likely be met with plenty of marketing hype before we finally see the targeted specifications met by emerging technology. While we're already seeing specifications such as LTE Category M1 and NB-IoT making strides to address the low power, low data rate requirements of IoT sensors, the low latency, high density, 1 Gbps or higher upper end targets of 5G will require significant changes to the network architecture and hardware in order to accomplish that task.

While the architectural changes on the backend of the network are well outside the scope of this paper, it's important to note that the high user density requirements for 5G generally necessitate the use of small cells. By reducing the range of each cell site and increasing the network density, the number of users that may be served with the same RF bandwidth increases. While concepts like massive MIMO hold the promise of further increasing user density and data throughput in current wireless 1bands through increased spectral efficiency and re-use, the principal effort in 3GPP is currently centered around the 5G New Radio (NR) which will take advantage of the much larger swaths of bandwidth being made available in the millimeter wave (mmWave) region of the spectrum. In either case, the proposed technologies will make heavy use of beamforming at the base station to selectively cover individual users using less power. At mmWave frequencies, the user equipment (UE) will also need to have at least some level of beamforming capability to help address the path loss considerations at these frequencies. While the goal of 5G NR is to define a ubiquitous radio access technology that can be used in any application, whether licensed, un-licensed, or shared spectrum, the dynamic channel sounding mechanisms required for features like massive MIMO to work require that the functionality be restricted to time division duplex (TDD) bands that use the same frequency for uplink and downlink. This, and the growing physical size of beamforming antenna panels as frequency decreases will limit this aspect of 5G NR to ~2.3 GHz and above.

While sub-6 GHz frequencies are commonly evaluated for over-the-air (OTA) performance of cellular and Wi-Fi radios, the addition of active phased arrays for beamforming drastically alters

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the requirements for OTA testing. Not only does the adaptive antenna system functionality have an impact on the traditional antenna pattern measurement based OTA test process, but basic radio conformance tests that are traditionally performed with conducted connections to the radio will now require an OTA testing solution, since direct access to the conducted radio signals is impractical if not impossible, and the actual user experience is a function of the aggregate performance of the beamformer and not the individual components. In the sub-6 GHz bands, UE antenna design will actually not be significantly impacted by 5G, simply because there's no room to add antenna arrays. Those enhancements will occur at the base station to provide greater downlink capacity. However, in the mmWave regions, handsets and other UEs are expected to have multiple small arrays to provide a nominal amount of gain and beamforming capability in various directions about the device. Thus, the role of OTA testing in these devices will become forefront to the entire implementation, conformance, and production testing of 5G UEs.

3GPP TR 38.810

Recognizing the need for new OTA test methods to address the needs of the 5G NR, 3GPP commissioned a work item (WI) [1] to develop Technical Report TR 38.810 [2] on "Study on test methods for New Radio." The test methods are targeted for the specified mmWave bands above 6 GHz, and while the initial concentration will be on mobile handsets, tablets, and fixed wireless access terminals for home and business internet, the goal is to cover everything from body worn devices to automobile mounted radios. In addition to all of the traditional RF parameters, tests are needed to cover radio resource management (RRM) and modulation/demodulation related requirements.

Black Box vs. White Box and Range Length

A common concern of any antenna pattern measurement or OTA test is the requirements for range length, but at mmWave, this becomes an even bigger concern due to the path losses associated both with the range length itself and the cabling used to feed the measurement antennas in the system. The good news is that even for antenna arrays with hundreds of elements, the wavelength at these frequencies is so short that the Fraunhofer far field region requirement is met within a meter or so of the antenna. The typical mobile handset will have arrays with a much smaller number of elements, with common R&D designs today having 1×4 to 2×4 element arrays. As long as the antenna has a minimal interaction with the rest of the platform (likely for these directional antenna designs) and is placed in the center of the test volume, the range length can easily be kept short and still give adequate measurement results. This is the so-called "white box" approach, since it requires knowledge of the internal structure of a device under test (DUT) and the ability to offset the DUT position to center the antenna being tested in the center of the test volume.

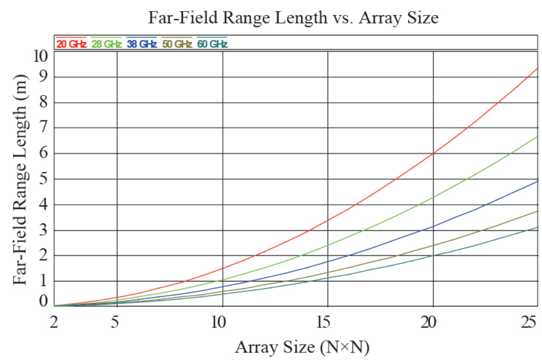

Figure 1 Far-field range length as a function of the number of half-wavelength separated elements on a side of a square N×N array

The alternative then is the "black box" approach, where you assume the antenna could be anywhere within the DUT and there is no prior knowledge of the design used to alter the test setup. This is of course the safer approach since it does not require any proprietary information and there's no opportunity to "cheat" the test by providing misleading information. It's also more practical from a laboratory test setup perspective, since it is likely that UEs will use multiple arrays distributed around the DUT to cover different sectors and address varying usage scenarios where hands or other objects may block one or more antennas. By adopting a black box approach where no assumption is made regarding the antenna location, each antenna array may be tested without the need to alter the test setup, assuming full spherical coverage is available from the antenna positioning system. Otherwise, only specific bulk orientation changes are needed. Of course the downside to black box testing is that now it's the geometry of the device packaging that determines the required far-field condition to ensure that the same radiated power is measured regardless of where the antenna elements are positioned. Figure 2 illustrates the mmWave range length requirements for devices with up to a one meter diameter. While handsets may still be able to be tested at reasonably short range lengths, at least until you bring in a phantom head and hand, anything much bigger than that starts to require excessively long range lengths. By the time you reach the size of a relatively small television, the required test range length starts to exceed the expected communication link distances for typical indoor small cell configurations. The range length requirement for a far-field quiet zone that covers an entire car would exceed the expected outdoor range lengths for mobile mmWave communication!

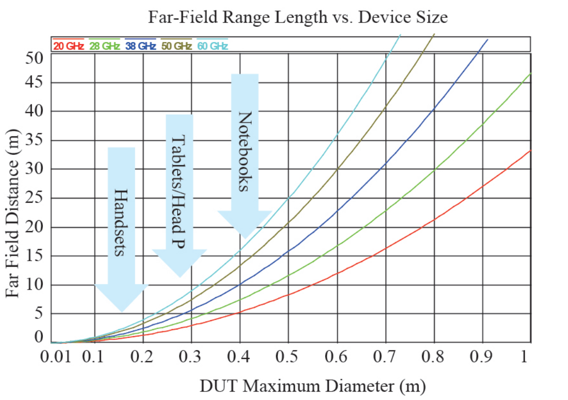

Figure 2 Far-field range length as a function of maximum dimension of a device

It's important to note here that since most of the quantities of interest center around the performance of the signal in the main beam of the array, traditional integral results like TRP and TIS that are not as influenced by range length don't really help out in this case. Instead, it is critical that the phase and magnitude relationships of each component of the main beam from each element of the phased array be very near that which would be seen by the radio at the other end of the link. Otherwise the metrics determined by the measurement may not reflect the expected result. On the other hand, at the long range lengths required to reach far-field distances, the performance of the RF test equipment would become a limiting factor, preventing accurate measurement of device side metrics like EVM, which are well below the maximum signal being generated by the DUT.

While a definitive answer to these problems has not been reached, the current decision in the 3GPP WI is to proceed with a black box approach [3-4]. Several methods to address the range length issues have been proposed, including the use of a compact antenna test range (CATR) or a large dielectric lens to focus the energy and obtain a far-field result at much shorter distances. Near-to-far-field conversion is not a viable alternative for these active signals for a number of reasons, but the most compelling reason is simply test time. Since the only quantity of interest for most of the tests is in the center of the main lobe of the beam, the amount of additional high resolution data necessary to meet the Nyquist requirements of NF2FF conversion would make testing excessively long. Even if this could be accepted for device qualification testing, it would not be viable for applications such as production line testing. Add to that the question of how active signal quantities like EVM would propagate through the NF2FF equations (or the exorbitant amount of modulated data necessary to calculate it brute force) and the inability to determine basic quantities like receiver sensitivity through NF2FF means, and it becomes quite apparent that such effort is likely to be a dead end.

Test Interface

In traditional OTA testing, effort has been made to avoid putting a device into a test mode in order to perform a radiated test. The goal is to determine how the device would perform on a real network, so the desire is to determine its behavior in normal operation. This also reduces the risk of the device performing differently during a test compared to the typical user experience. On the other hand, for much of the conducted conformance test of typical cellular radios, specific test modes are often called out in the standard to enable the required testing. The test methods for the 5G NR must address both of these requirements.

Current discussions in the test method WI have acknowledged the need of a test mode to put a beamformer in a known configuration. Depending on how far this is taken, it may actually be contrary to the black box approach described above, since simply targeting a beam to say normal incidence (all phase elements at zero) would still potentially be an arbitrary direction on the DUT relative to a chose direction in the test system. Likewise, controlling the beam to point in a specific direction in the test system may correspond to a non-optimal beamforming orientation for a given antenna, resulting in reported differences in performance of devices with similar actual performance.

Another proposed test interface function would help support receiver testing by allowing access to the aggregate magnitude and phase information reported by each receiver chain. This is similar to the mechanisms currently supported by some chipsets and used for indirect OTA techniques like radiated two stage testing. While certainly useful, this information is limited to the magnitude and relative phase information obtained by the chipset from the demodulated baseband signals. Much of the information about the behavior of the array and the like will not be available.

Device manufacturers will likely need a number of other custom test functions not currently being discussed in 3GPP. The ability to selectively enable/disable elements and iterate through each element of an array will be a critical feature for production testing to determine if all elements are functioning as intended. The current work also hasn't addressed the need to test the adaptive components of these new adaptive antenna systems. Much of a device's real world performance will depend on how well it can adapt to track a signal. While methods for evaluating this sort of behavior have been presented previously [5], so far the industry has not reacted to the need for this additional level of testing.

Channel Models

One additional challenge of the move to mmWave communication is the need to develop and implement spatial channel models reflecting the various propagation channels that are likely to occur in the various usage cases. From there it's necessary to implement test cases and methodologies for evaluating the device performance under these modeled conditions. Since the beamforming abilities of both the DUT and the base station will play heavily in the actual channel seen by the two radios, and the TDD channel sounding used requires a symmetrical communication channel, the challenges involved in developing a test system are significant. Attempting to replicate the RF environment simulation approach used for MIMO OTA testing of wireless devices below 6 GHz is not practical for mmWave frequencies. The Nyquist resolution requirements for a boundary array suitable for a device of any significant size would be impractical to implement a continuous array solution. Add to that the cost of the necessary radio components to feed each antenna and it becomes obvious that another solution is needed. The good news is that the beamforming functionality at both ends of the link means that there is no real need for omnidirectional multipath within the test environment. There are likely to only be a handful of narrow beam directions with signals that would be appropriate for a DUT to choose between. Thus, the active emulated channels for UE testing likely will not require any more channel emulation resources than existing sub 6GHz systems. The issue will be the need to flexibly move the location of those emulated spatial channels relative to the DUT in order to exercise its ability to react to the environmental changes. Whether that will be accomplished through mechanical motion of clusters of antennas or through electrical switching between sets of fixed antennas remains to be seen.

Conclusion

This paper has touched on just a handful of the issues facing the development of test methods for the 5G New Radio standard being developed in 3GPP. Some of the proposed methods have been presented, but it is evident that just like the 5G NR development itself, there is still plenty of work to be done before a standardized set of test methods can be applied to evaluating these new devices. There are fundamental physical and practical challenges that must be overcome in order to successfully complete this effort. And of course all of the proposed methodologies have associated measurement uncertainty considerations that are at the forefront of the discussions. A test method that provides too large of a measurement uncertainty is not very useful.

References

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