

Ensuring A Quality 5G Wireless User Experience: Applications And Technologies

ADAM SMITH



Introduction

Until now, each new generation of cellular network technology was designed to provide better voice or data performance for mobile devices. With 5G, however, this is changing.

5G is being conceived for a brand-new world of diverse wireless applications that ranges from broadband wireless access to the internet of things (IoT). Mobile device users will benefit from 5G technology, but the real impetus for 5G is new wireless applications like autonomous cars, industrial automation, broadband wireless last mile, and others that need a pervasive wireless WAN capability with a unique feature set that is different from today's network technology.

Given these diverse needs, 5G will look different from previous technology generations. A significant part of wireless industry 5G activity is focused on developing the capabilities of multiple technologies that serve these applications and, in some cases, developing the ability for devices to seamlessly switch between multiple technologies. Standards body work regarding 5G cellular RF technology is ongoing.

For designers considering the evolution of their products to 5G networks, some challenges that will need to be factored into test plans revolve around user experience testing and adapting testing to the application.

This is the first part of a two-part series that will look at what is known about 5G networks today, as well as examine some of the use cases. The next article in the series will examine what product designers should know about the RF testing challenges that lie ahead for 5G products.

5G Defined By Emerging Wireless Use Cases

A driving factor behind the development of 5G technology is the multitude of existing and emerging use cases that depend on wireless technology, but are not served with today's cellular or wireless LAN technology. Some of these include:

IoT — Data collected wirelessly from a large number of mobile or fixed sensors provides intelligence to improve processes. Examples include smart parking, street lights, trucking, and farming. These applications don't always need a lot of bandwidth, but it's important to have low latency, to accommodate a lot of sensors, to have high quality of service, long battery life, long signal range, and security.

Broadband Everywhere — This is envisioned as a replacement for fiber optics in high-bandwidth fiber-to-the-curb, backhaul, and last mile applications. Wireless technology for this application requires multi-gigabit bandwidth, long range, and significant network capacity.

Remote Device Operation — In this application, a trained professional or operator controls a device remotely, with applications including machinery operation, factory automation, and even remote surgery. The wireless network in these examples is primarily sending control signals which require low latency, quality of service, and security.

Autonomous Vehicles — This is one of the hottest topics in automotive industry, and the advanced guidance systems that make it possible depend heavily on wireless communication between sensors in the car and in other cars, street lights, and the road. Wireless networks supporting this application must be very responsive with low latency and quality of service along with long range and security.

Media Everywhere — Streaming video and audio are already very popular wireless use cases; improvements in 5G networks will provide added capacity, range and bandwidth needed for this trend to continue growing.

Fig. 1 provides an overview of each of these use cases and the wireless network features that are important to them.

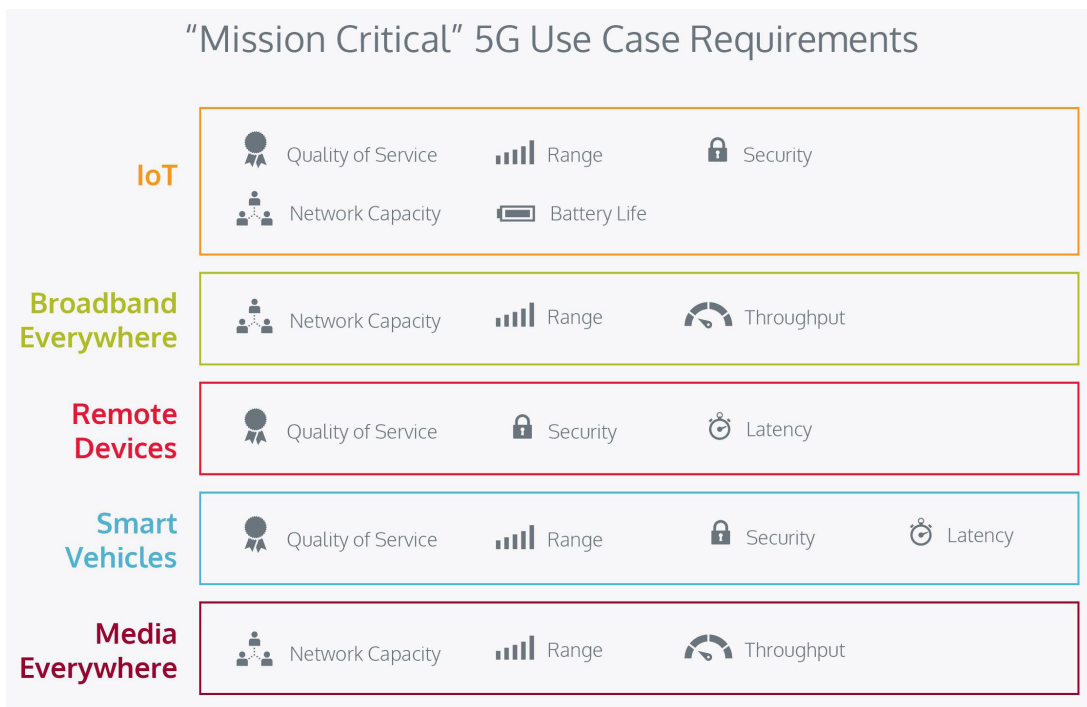


Fig. 1 — 5G Use Case Requirements

5G Is A Toolbox Of Technologies

No one wireless technology can cost-effectively serve all of these needs. Thus, the industry is expected to move forward with a toolbox approach of different technologies for different needs. In the toolbox are cellular technologies, as well as wireless LAN (WLAN) and low-power wide area network (LPWAN) technologies.

5G Cellular: Evolution And New Standards

The cellular networks that will play a big role in 5G include evolving 4G/LTE standards and 5G New Radio (NR) Technology. Cellular standard development is managed by the 3rd Generation Partnership Project (3GPP), which has defined cellular network evolution in a series of technology releases: LTE-Advanced (Releases 10-12), LTE-Advanced Pro (Releases 13-15), and 5G NR (Release 16 and future).

LTE-Advanced — In 2011, the LTE-Advanced standard was put into development, and it now is starting to be rolled out to market by a few mobile network operators. The new standard aims to achieve 1 Gbps peak upload speeds and 500 Mbps peak download throughput with latency of 10 ms.

To improve performance, LTE-Advanced features carrier aggregation, which combines the data transmitted across up to five frequency carriers and bands. Spectrum utilization is expanded to include both FDD and TDD duplexing techniques, which makes additional bandwidth available.

The LTE-Advanced standard makes expanded use of multiple input-multiple output (MIMO) antenna systems. MIMO helps to overcome multipath limitations by utilizing the multiple signal paths that exist between a transmitter and a receiver. This improves the throughput available on a given channel. MIMO technology supporting two antennas (2x2) was implemented in LTE, but the LTE-Advanced standards include eight antennas (8x8) on the downlink and four antennas (4x4) MIMO on the uplink.

LTE-Advanced Pro — The goal of LTE Advance Pro is to increase peak throughput levels to 3 Gbps, with latency of only 2 ms. The LTE-Advanced Pro standards (Releases 13-15) will build upon features added to LTE-Advanced, as well as add some new capabilities. Carrier aggregation will be improved with up to 32 different carriers specified, up from five in LTE-Advanced. Support for different RF frequency bands, primarily the 5GHz band used for Wi-Fi, also is increasing with the addition of Licensed Assisted Access (LAA), enhanced LAA, and LTE-Wi-Fi Aggregation (LWA).

5G New Radio Technology — 5G NR is being developed with no requirements for backward compatibility to previous LTE technologies. 5G NR is just now being defined with trials targeted for 2018 and a final standard to be delivered in 2020. The development requirements for 5G NR include:

- Up to 10 Gbps peak data rates
- 1 ms end-to-end latency
- 100 Mbps data rate at cell edge
- 1000 times increase in bandwidth per unit area
- 10-100 times increase in number of connected devices
- 90 percent reduction in network energy usage
- Improved coverage, with a perception of 100 percent coverage

One of the more intriguing 5G scenarios is leveraging millimeter wave (mmWave) frequencies, which reside in the 30 GHz-300 GHz frequency band. Several industry leaders and standards bodies are actively researching this, and the FCC has proposed new rules for the 28, 37, 39, and 64-71 GHz bands that could help the development of 5G technology at this frequency.

There's a lot of bandwidth available in mmWave frequency band, but working with these high frequencies has been a design challenge in the past. Existing mmWave solutions are focused on point-to-point, short-haul broadband applications. The technology has not had widespread success due to its short transmission range and potential for weather-related interference.

Even as the industry considers mmWave for mobile devices, its transmission range will remain short. Thus, a very high-density network of small cells — estimated by some as one cell per 12 homes — will be required for adequate coverage. The impact of 5G mmWave technology will be to deliver massive bandwidth for broadband, streaming, or virtual reality applications to a device while also supporting LTE-Advanced Pro for mobility.

5G Wireless LAN

Other advances are emerging for WLAN technology for 5G applications. Some of the key WLAN technologies in development include:

802.11ax — This technology is expected to have an early roll out in 2017 and has been lab tested at nearly 11 Gbps max throughput with connection speed of 1.4 Gbps. Even though the new technology has more bandwidth, the key objective of 802.11ax is to support more users; its goal is to support 10 times more simultaneous users than the previous 802.11ac technology. The technology uses some of the same techniques for performance as the cellular standards, including 4x4 MIMO.

For improved spectrum efficiency, 802.11ax adopts Orthogonal Frequency Division Multiple Access (OFDMA), a signal modulation technique that delivers better spectral efficiency and is less sensitive to frequency-selective fading. Just like Wi-Fi today, 802.11ax offers high-bandwidth and in-building mobility, and could be a good alternative for both data-centric use cases and in-building cellular offload.

WiGig — WiGig (802.11ad) promises low latency connections up to 7 Gbps and complements Wi-Fi for very high bandwidth, short-range applications, such as connecting a computer to HD/UHD displays via the WiGig Display Extensions, providing peripheral connectivity wireless connections to storage or servers via WiGig Serial Extension, WiGig Bus Extension or WiGig SDIO Extension. For consumers, WiGig will provide a great experience for virtual reality, medical, or similar high-bandwidth applications.

But, like 5G NR, WiGig operates in the mmWave frequency band, meaning that it is restricted to in-room, short distance applications. It is anticipated that devices supporting WiGig also will have radios that will transmit on LTE or Wi-Fi frequencies (2.4GHz and 5 GHz).

5G IoT Standards

IoT is a significant 5G use case that will need its own technology. Some IoT applications can utilize cellular or WLAN networks, and others — like wearables — will take advantage of personal area networks. But most of the applications now envisioned require low-power wide area network (LPWAN) technologies.

Applying Technology to 5G Use Case Requirements

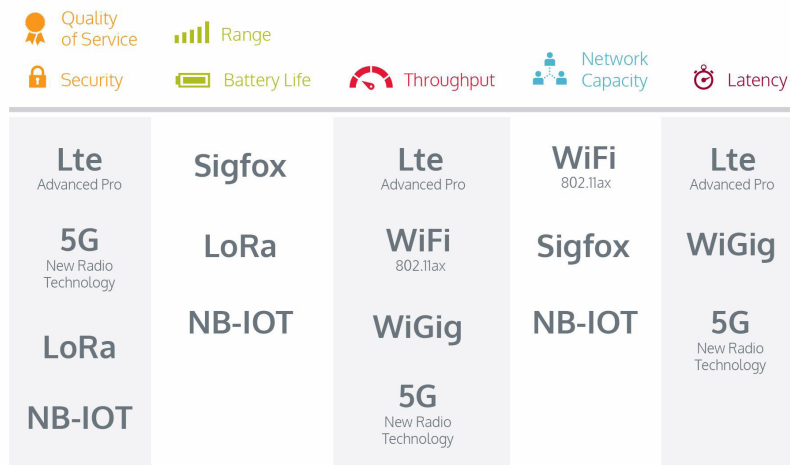


Fig. 2 — Application Benefits of Some 5G Technologies

There are several LPWAN market leaders and emerging technologies, including LoRaWAN, Sigfox, and NarrowBand IOT (NB-IOT). What they all have in common is that they facilitate long range, low bit rate communications to and from battery-operated sensors that are either mobile or static. In many cases, service providers have set up LPWANs operating complementarily alongside their higher-speed cellular networks. Except for cellular-based LPWANs (NB-IOT), most operate in the unlicensed ISM band.

Base Station, Multi-RAT Handoff More Complicated

Some 5G devices will need to support multiple devices, which will require improvements in handoff technologies. Today's mobile devices have reliable, low-latency base station handoff mechanisms to facilitate seamless mobility, but switching a data or voice session from one radio access technology (RAT) to another (LTE to Wi-Fi, for example) still has significant latency that causes a session to drop during hand off.

New 5G mechanisms must be developed to facilitate this handoff while not backing off on link connection speeds. 5G handoff management is made more difficult by lower latency applications, higher bandwidth, increased number of RATs, and HetNet density, necessitating more frequent handoffs.

Successful 5G base station handoffs will be enabled through better base station understanding of quality of service considerations, signal-to-interference ratio (SIR), and how much time is required for the handoff. Ideally, the base station can collect this data from the mobile devices and compare against a threshold value to know at what point it must hand off the session to another base station.

For RAT handoff, intelligence must be built into the mobile device so that it can analyze signal strength and quality from its own base station or access point. If these values fall below a certain threshold, then the device must scan other nearby access points or base stations to understand their traffic load, spectral efficiency, and transmitted power levels. Once the analysis is done, the device must be able to select and connect to the best connection point.

Some of these capabilities are in today's mobile devices, but they will need to be further developed to accommodate the low latency, multi-RAT environment of 5G.

Conclusion

The 5G "toolbox" approach is delivering the technology capabilities needed for a very diverse range of applications. The increased number of wireless technologies gives developers new tools to develop the wireless products of the future. But, this toolbox approach also increases complexity, which could negatively impact customer experience unless properly designed and tested. In the next article in this series, I'll look at the testing challenges that developers need to plan for to ensure a quality user experience.

About The Author

Adam Smith is the Director of Marketing at LitePoint and a 15-year veteran of the RF industry, with expertise in cellular and connectivity technologies. A member of the LitePoint team since 2012, Adam's knowledge and experience has been instrumental in driving product strategy for LitePoint test solutions.

Key Test Considerations For A Quality 5G Wireless User Experience

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In part 1 of this series, we explored the variety of wireless technologies that make up 5G — a family of technologies optimized for a variety of use cases. Technologies considered in the 5G wireless family include high-bandwidth millimeter wave wireless, such as the 5G New Radio and WiGig, and the continually evolving LTE cellular and Wi-Fi (802.11ax) standards. Additionally, lower bandwidth, sub-GHz protocols, such as LoRa and SigFox, round out use cases in industrial IoT applications.

While all these technologies are considered in the 5G taxonomy, the testing requirements for higher bandwidth wireless LAN (WLAN) and cellular technologies are different from those of the lower-speed IoT technologies. This article will focus on the testing challenges facing these higher-bandwidth technologies.

Millimeter Wave / 802.11ad / 5G New Radio

Millimeter wave (mmWave) radio technologies take advantage of 20 GHz of underutilized spectrum in the 28 GHz, 39 GHz, and 60 GHz bands for a range of new, Gigabit-plus throughput wireless services. Among the 5G technologies leveraging mmWave is WiGig (802.11ad), which is designed to offer a maximum of 7 Gbps of throughput and operates in the 57 GHz to 66 GHz frequency range. Also, mmWave frequencies currently are undergoing trials for future 5G New Radio (NR) cellular technology.

Like other next-generation, high-bandwidth wireless technologies, mmWave leverages massive multiple-in multiple-out (MIMO) antenna configurations and adaptive beamforming to focus significant amounts of RF energy onto a receiver for high-bandwidth services. Massive MIMO — loosely defined as anything more than 16 antennas, and potentially up to hundreds of antennas — provides much higher spectrum efficiency thanks to spatial reuse, as well as higher capacity, with a reduction in latency and jitter. These performance parameters make mmWave service appropriate for emerging applications like autonomous vehicle control and industrial automation.

mmWave Testing Challenges

mmWave systems can no longer be tested in a controlled 50-ohm cabled environment, where the tester is physically connected to the device under test (DUT). This testing environment was the best practice for testing wireless systems operating below 6 GHz. While not capturing real-world conditions, these cabled testing environments did allow for more repeatable results. For mmWave systems, over-the-air (OTA) test methodologies are required for more practical testing, given the frequencies involved.

OTA systems are optimized to test beam forming, which leverages multiple antennas to direct a single RF beam to a receiver. OTA testers can efficiently test that each antenna's phase shifter is working properly, validating that the antenna array can point the energy to the end device.

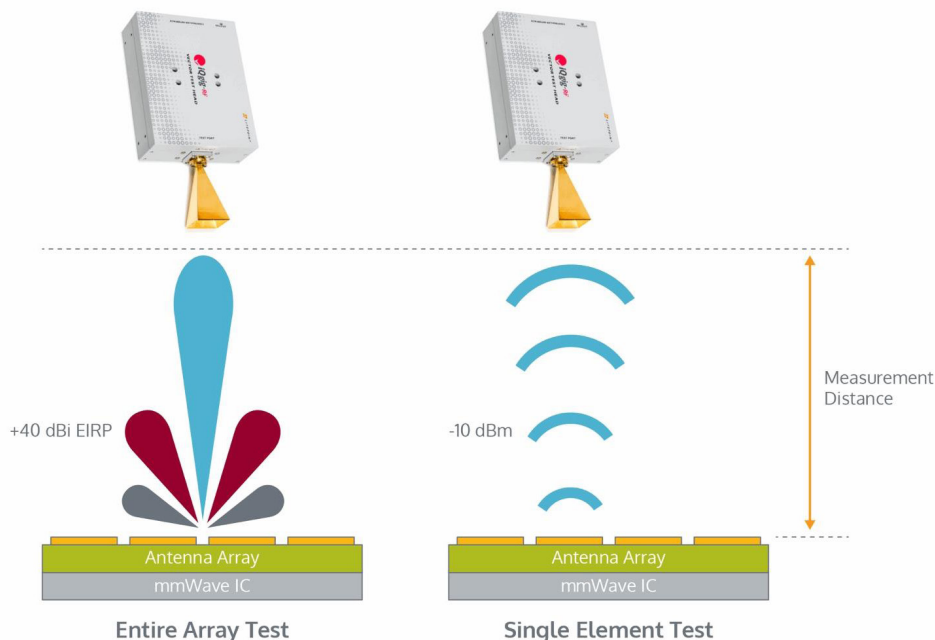


Fig. 1 — Testing antenna arrays and individual antennas within an array

There also is a need to test the antenna integrity both separately and as an array. Due to the significant amount of path loss at mmWave frequencies, massive MIMO leverages the gain of all the antennas acting together. But, within that array, an individual antenna could have performance issues. The tester must stress both the array and each individual antenna. This requires a tester with a high dynamic range to capture the power range between the low of the individual antenna and the high of the antenna array.

Recognizing that in many systems, mmWave will coexist with 2G, 3G, and 4G radio access technologies (RATs), a last challenge for mmWave testing is to evaluate the system control plane that must hand off data between RATs. The tester needs to measure the timing of these handoffs to ensure they fall within latency boundaries to not impact voice or data transmissions. Automating this process is critical, as there are many co-existence and hand-off permutations, so this testing needs to be done rapidly with high repeatability.

Next-Generation 4G/LTE

Next-generation 4G/LTE wireless technologies still will be a key part of the 5G network, delivering higher bandwidth in the short-term and augmenting 5G NR networks for many years to come. In fact, many consider LTE Advanced Pro, which is designed to deliver Gigabit+ throughput, to be within the 5G taxonomy.

A critical feature for 4G/LTE test equipment is test sequence automation, which lets the tester trigger the automated test sequences that chipset manufacturers build into their chips. The ability to execute these test sequences minimizes test setups and back-and-forth programming of some of the standard chip functionality tests. These sequences are becoming more thorough, adding new tests with very small step sizes — sometimes less than 1 millisecond per step. This requires the tester to have very fast settling times for its signal generators and analyzers, so that they can reset and be ready for a new test in less than 100 microseconds.

Because of increasingly complex board designs in today's mobile devices, intersystem noise can be a significant factor that needs to be tested. Intersystem noise is created from electrical signal radiation that interferes with data signals due to the densely packed traces. This interference can desense the Wi-Fi or LTE signal, impacting wireless performance when the device is at the edge of its signal range.

Testing for signal desensing involves turning on the LTE signal and then measuring signal strength while other phone systems are turned on and off; and then repeating the process for the Wi-Fi, Bluetooth, and other radios. This testing requires an OTA connection for accurate, real-world measurement of the signal strength, as well as extensive automation to facilitate the large series of tests.

There also are some testing challenges brought on by the use of carrier aggregation (CA) in LTE Advanced Pro for higher data rates. CA combines multiple channels of LTE spectrum in a single mobile device. This can be done with up to five component carriers, depending on the desired data rate. Ideally, the carriers are adjacent or close together, but that's not often found due to the very fragmented LTE RF spectrum. To compensate, inter-band carrier aggregation was created to combine channels from completely different LTE bands — some with over 1 GHz in spacing. This situation challenges the aggregation function in the RF front end, so multiple radios are being built into the mobile device to simplify the architecture. From the test perspective, each of the radios needs to be calibrated and tested, driving up test times.

5G For The WLAN – 802.11ax

Both in terms of bandwidth and the number of users that can connect to the AP at any one time, 802.11ax promises much more wireless LAN capacity. A key change to the Wi-Fi standard to achieve these objectives is the adoption of orthogonal frequency division multiple access (OFDMA), the modulation techniques used in LTE/4G networks.

In OFDMA systems, each access point allocates time and frequency to attached devices, expanding the capacity from previously used WLAN modulation schemes, which allocate the entire bandwidth of a connection to a single user for the duration of the transmission. An OFDMA AP can dynamically control the frequency, giving more to a user watching a streaming video and less to one sending email. Test systems must account for timing synchronization, frequency alignment, and response time characteristics to ensure APs perform correctly.

Also, 802.11ax features power control, which provides fair access to the network for both high-power devices (those nearest to the base station) and low-power devices (those far from the AP). Without power control, high-power devices could desensitize the system, effectively reducing the channel capacity. APs measure the power of connected stations (STAs) via a received signal strength indicator, and can signal STAs to reduce or increase their power levels to ensure fair access. This capability is refined by the 802.11ax standard, which designates device classes based on power control accuracy. Class A devices offer +/-3dB of power control, which means more STAs can connect to an AP than a class B STA, which features +/- 9dB power control.

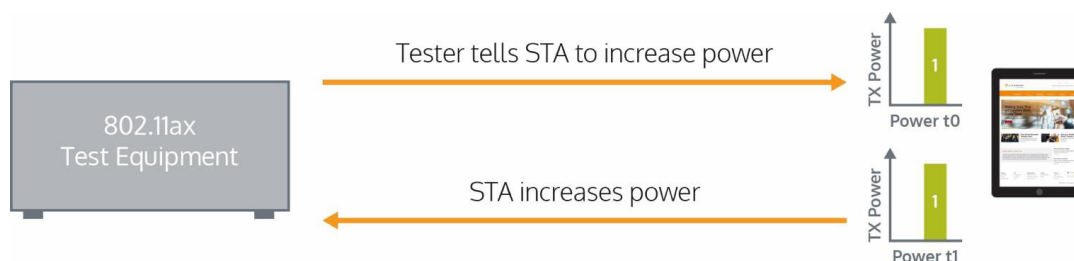


Fig. 2 — Testing power control in an 802.11ax network

The test system must emulate the real-time power control responses of an AP. In essence, the tester acts like an AP and sends power level information (coded in a packet header), and then measures the response from the STA DUT. The tester evaluates the power level and sends out a command to increase or decrease the power level, and measures the accuracy of the response. The test also should determine the settling time it takes for the DUT's power level to reset due to power amplifier response times or power control loops. To achieve the real-time performance and low latency (~200 ms) for power control testing, it's critical that test systems deliver this functionality via hardware.

802.11ax Timing Issues

Multiple users simultaneously using an 802.11ax AP can increase intercarrier and intersymbol interference, which can reduce overall system capacity. To minimize interference, the 802.11ax standard features a timing requirement that all STAs must transmit within 400 ns of each other to minimize interference. The AP coordinates this synchronization using a trigger frame that is sent to each STA, which provides the timing requirements for their transmissions, as well as information on the frequency sub carriers they can use.

To test for this, an 802.11ax tester must emulate the AP and generate the trigger frames. The tester measures the time from when the trigger frame packet left the tester to when the DUT packet was received. This time needs to be the short interframe space (SIFS) time +/- 400 ns. Another timing test helps to calculate the carrier frequency offset — the frequency error in the STA after it has been synchronized — to ensure it meets the standard of 350Hz. Like the timing error test, the tester sends the DUT a trigger frame, which is decoded by the DUT and used to align its clock before the device responds by sending a packet back to the tester, which then is used to calculate CFO.

Conclusion

High-speed 5G technologies promise a great foundation for use cases ranging from video streaming to autonomous cars, but these applications will depend on reliable performance from the network technologies. The added complexity of these technologies means the potential for longer test times, which negatively impacts production volumes. This is an age-old dynamic for the wireless industry. Test system manufacturers are responding with more automation and faster systems to minimize the cost of test. With these systems, it's possible to ensure the maximum performance and quality for 5G users.

About The Author

Adam Smith is the Director of Marketing at LitePoint and a 15-year veteran of the RF industry, with expertise in cellular and connectivity technologies. A member of the LitePoint team since 2012, Adam's knowledge and experience has been instrumental in driving product strategy for LitePoint test solutions.

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