C-band spectrum: how it’s transforming 5G

white paper

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Introduction

Operators are currently undertaking a massive investment in upgrading the infrastructure of both wireline and wireless networks. The need to upgrade and change is fueled by the billions of connected devices belonging to the IoT ecosystem and the new demands they will place on 5G fronthaul networks as operators begin rolling out 5G. Significant capacity will need to be added to support this unprecedented network evolution and expansion. To enable this transformation, new spectrum bands and advanced technologies are being deployed, innovations that will help operators profitably deliver the promise of 5G.

Most pioneering 5G markets have focused on mid-band spectrum, particularly the 3.5 GHz band, as it provides the perfect balance between coverage, capacity and performance. This white paper will discuss C-band—a mid-band spectrum—and the important role it plays in the successful delivery of new 5G services.

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5G spectrum

There are many bands allocated to 5G networks and each can be grouped into one of three categories: low bands (450 MHz - 1 GHz), mid bands (1 GHz - 7 GHz) and high bands (24GHz - 52 GHz). C-band has become the key mid band spectrum for 5G. Its original range of frequencies covered 4 GHz to 8 GHz. However, the Federal Communications Commission (FCC) in the United States designated the range between 3.7 GHz to 4.2 GHz as C-band spectrum. There are already live networks currently operating over C-band, with over 40 countries rolling out 5G wireless over C-band across 175 networks[1]. In addition, a significant auction of C-band spectrum was held earlier this year in the United States. As well, there are live networks already deployed in European countries including the UK, France and Germany, and multiple countries in the Asia Pacific region including China. Essentially, most countries are planning or already deploying some rollouts of 5G using the C-band spectrum.

What is C-band spectrum for 5G?

The C-band spectrum frequency was previously used by satellite TV providers. Theseproviders used the 3.7 GHz to 4.2 GHz range for downlink communications. As customers moved away from satellite TV, less spectrum was required for that service. Consequently, the FCC moved the spectrum assigned for satellite TV to the upper bands, freeing up that part of the mid-band spectrum which was subsequently repurposed for 5G.

1. Layton, Roslyn. "It's Time For the U.S to let 5G in the C-Band Take Off", Forbes. January 14, 2022 (referenced April 19, 2022) www.forbes.com/sites/roslynlayton/2022/01/14/its-time-for-the-us-to-let-5g-in-the-c-band-take-off/?sh=3c0d7de32289

C-band gives operators the ability to operate over a spectrum range that is efficient—efficient from a coverage and a throughput perspective—creating an optimal 5G network.

One of the important first use cases for C-band involves fixed wireless access (FWA). With fixed-wireless access, cell towers transmit to customer premise equipment (CPE) which resides either inside or outside a home (see Figure 1). 5G FWA will offer fast internet services to rural areas with no fiber access.

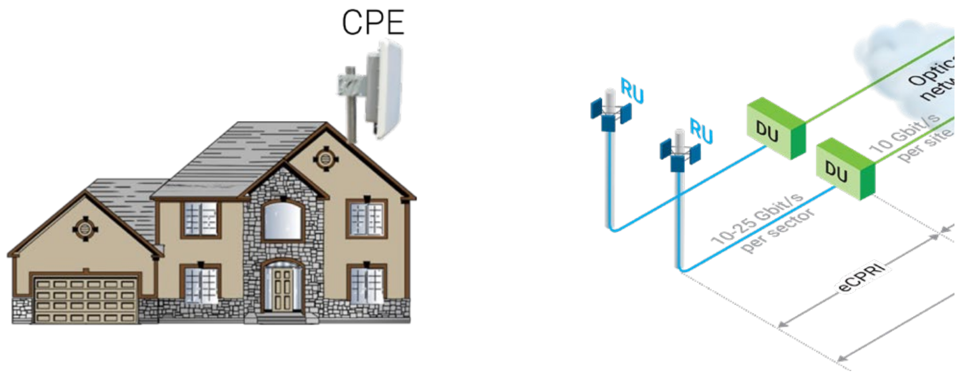

Figure 1. FWA with 5G mid-bands.

Initially, as the industry was preparing to launch 5G, there was a lot of talk about the use of millimeter wave (mmWave) spectrum in high frequency bands (FR2) to accommodate the exponential increase in data usage and consequently transmission of large amounts of data. Even though millimeter wave is key to unlocking the real potential of 5G, these frequencies offer limited coverage as they can't travel as far or penetrate obstacles like lower frequencies can. As a result, more cells must be deployed to offer the same coverage as lower frequencies(see Figure 2). C-band (in the mid-band range) represents a happy medium since it encompasses wider bandwidth and higher capacity than the low spectrum bands currently in use and can travel relatively further distances than mmWave—allowing operators to deploy 5G faster and reach more users with fewer cells. (see Figure 3).

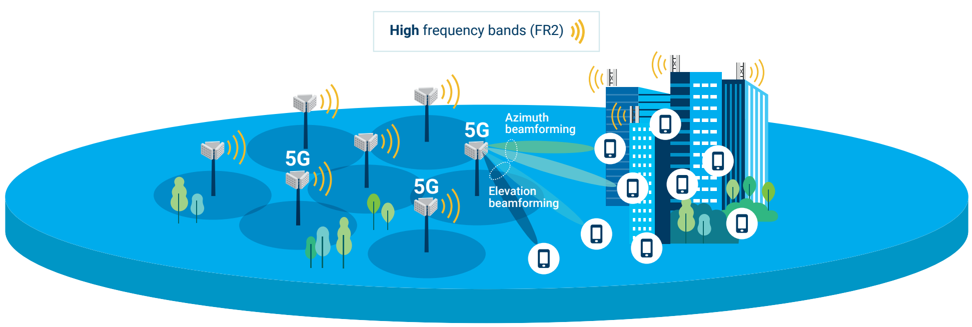

Figure 2. FR2/mmWave spectrum for 5G.

In short, C-band gives operators the ability to operate over a spectrum range that is efficient—efficient from a coverage and a throughput perspective—creating an optimal 5G network, one that's ready to offer 5G to customers.

Since they offer the best balance between coverage and throughput, mid-band frequencies deliver the ability to unlock the potential of rolling out more 5G services quicker than expected.

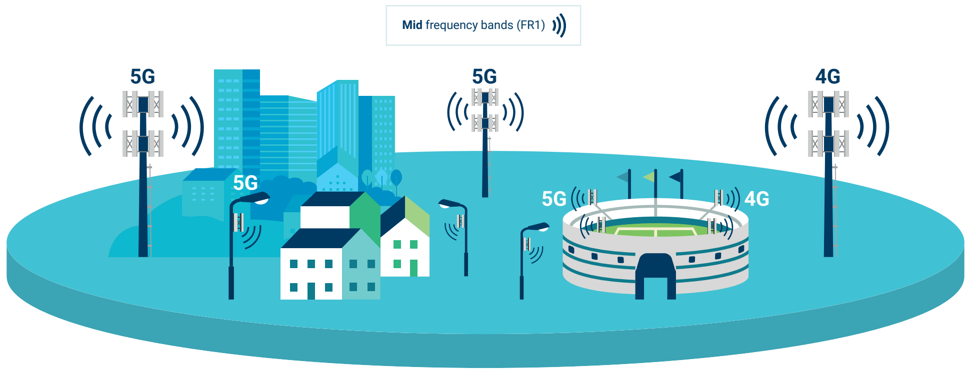

Figure 3. 5G mid-bands, including C-band.

Low-, mid- and high-bands

So, what's the difference between low-, mid- and high bands? With low bands, and specifically where LTE sits in the low-band range, network coverage is excellent, so signals can reach long distances—tens of kilometers long. However, since throughput is quite low at these bands, speeds available to mobile devices are low (see Figure 4).

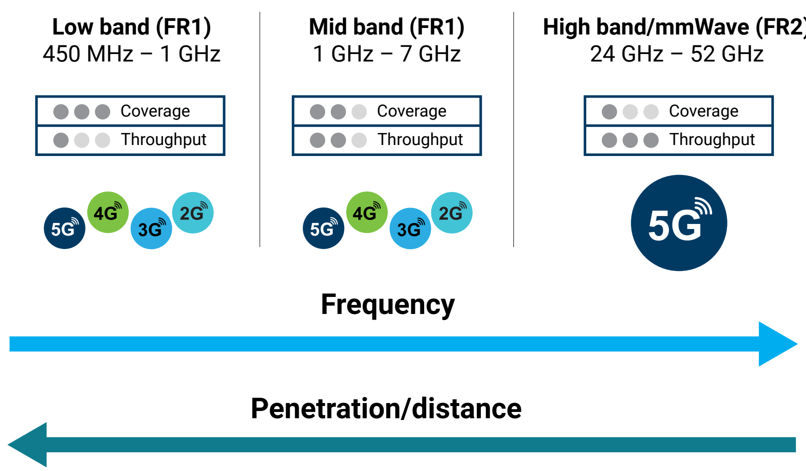

Figure 4. Low-, mid- and high-bands for 5G.

Comparatively, in higher bands (i.e., mmWave or FR2) the signal range is short, providing less coverage, yet throughput is very high. However, deploying this technology will require a bigger investment from operators. Since at FR2/mmWave we have access to a wide range of unused spectrum and bandwidth as high as 400 MHz, this spectrum range theoretically unlocks the potential for more 5G applications that require ultra-low latency—not only on mobile devices, but with connected cars, smart cities, connected industries and more. However, with coverage of 100 m in distance, mmWave is proving to be an excellent fit for use in venues or stadiums where, for example, customers are attending an event while accessing the 5G network to stream live performances in real time.

That brings us to 5G's superstar, the mid-band range. Since they offer the best balance between coverage and throughput, mid-band frequencies deliver the ability to unlock the potential of rolling out more 5G services and quicker than expected.

Even though mid bands are the standout, once the complete 5G offering is online there will be a mix of all bands. The reason is the desire to reach speeds that are closer to the FR2 range (i.e., 400 Mhz bandwidth) and achieve high throughput capacity while getting the good coverage available in the low- and mid-bands. That means there's going to be a mix of the FR1 low band, FR1 mid band and FR2 high band (see Figure 5). This best-of-all worlds strategy will play a key role in the type of 5G services that operators will provide to their customers, all the while enabling new applications to emerge.

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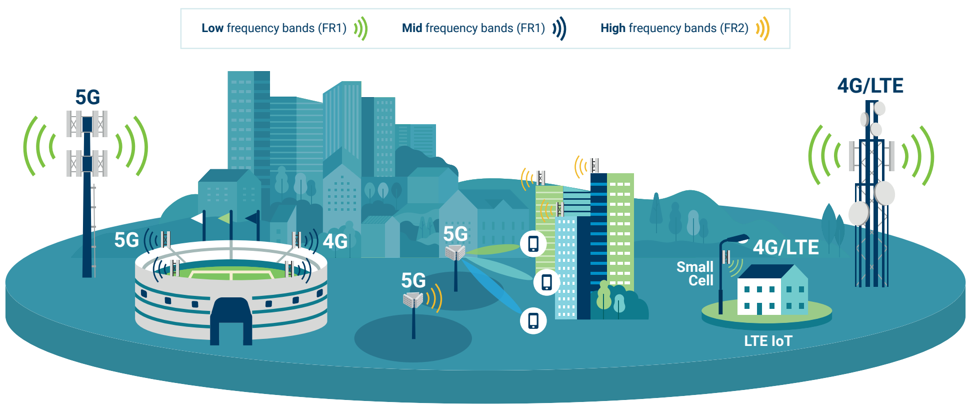

Figure 5. Complete 5G offering.

Navigating the technology challenges of 5G C-band

Before we delve into 5G C-band technology challenges, let's take a quick look at the general set up of 5G cell sites as they relate to C-band (see Figure 6). As soon as we jump into the mid band, remote radio heads (i.e., radio unit (RU) with integrated antennas) become part of the architecture. With fiber directly to the antenna, coax is no longer in the mix, and not necessarily requiring the certification of cable and antenna system performance through measurements like site VSWR and other traditional PIM metrics. Nonetheless, internal PIM can still be present (i.e., in the radiating elements of an antenna) but most of the PIM issues on these sites will be due to an external source.

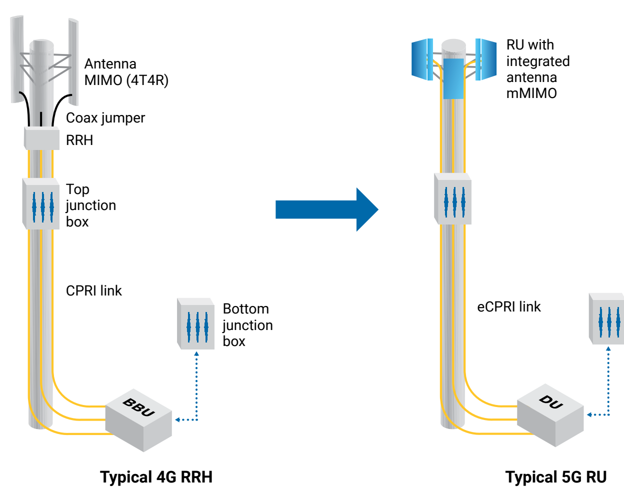

Figure 6. What's different in 5G C-band.

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Beamforming is a signal processing technique that will help overcome the different technical challenges present with 5G (e.g., wider channels, higher frequencies).

There are several dominant technologies in the mid band/C-band range including massive MIMO which enables beamforming and time division duplexing (TDD). Let's take a look at some of those technologies.

Beamforming

Beamforming is a signal processing technique that will help overcome the different technical challenges present with 5G (e.g., wider channels, higher frequencies). To explain beamforming, let's look at what happens at a music concert featuring a live band. When the house lights come on during the concert, the spectators can see the entire band, but not any individual band member in more detail. When a spotlight is focused on one band member, spectators will focus in on that person more than on the others. This is similar in concept to beamforming, where instead of a wide radiation pattern, the antenna will be able to radiate narrow beams to better focus the signal on a specific receiving device (see Figure 7.) Beamforming antennas make use of multiple radiating elements, grouping them in multiple subarrays, with complex signal processing techniques, in which phase and amplitude of the different radiating elements are modified to play with the direction of the beam. Being able to focus the RF signal in a specific direction helps reduce the impact of certain types of interference by reducing propagation losses normally experienced at higher frequencies thus providing a higher signal quality to the user, which is key to addressing different 5G scenarios.

Making use of the new antenna technologies, the sector is divided into multiple beams, and those power and quality KPI's (RSRP, RSRQ and SINR) will be populated for each of those individual beams belonging to the same physical cell ID (PCI). In FR1, we can have 4 beams in the low frequency bands and up to 8 beams in the mid bands. In FR2, in order to overcome higher propagation losses, we can use more complex beamforming schemes, using up to 64 beams per PCI.

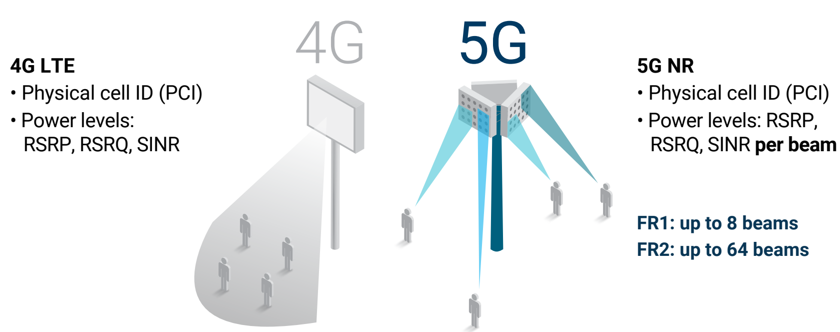

Figure 7. Beamforming in 5G.

Demodulating LTE vs 5G signals

With LTE signals, the synchronization signal is located over the center frequency. When configuration is performed, the center frequency is set and then the LTE signal is demodulated to discover the PCI and all the different metric power levels. With 5G, the sync signal—referred to as synchronization signal blocks (SSBs)—can be located anywhere within that channel. Since it's not easy to manually find that sync signal, an automated SSB scanner is needed to enable users to locate the SSB and demodulate 5G NR.

Time division duplexing (TDD)

TDD is defined as a spectrum usage technique that allocates different time slots for the uplink and downlink over the same frequency. In the mid- and high-frequency bands, TDD is used to make sure the uplink and downlink propagation conditions are the same. To learn more, let's take a step back and look at frequency division duplexing (FDD).

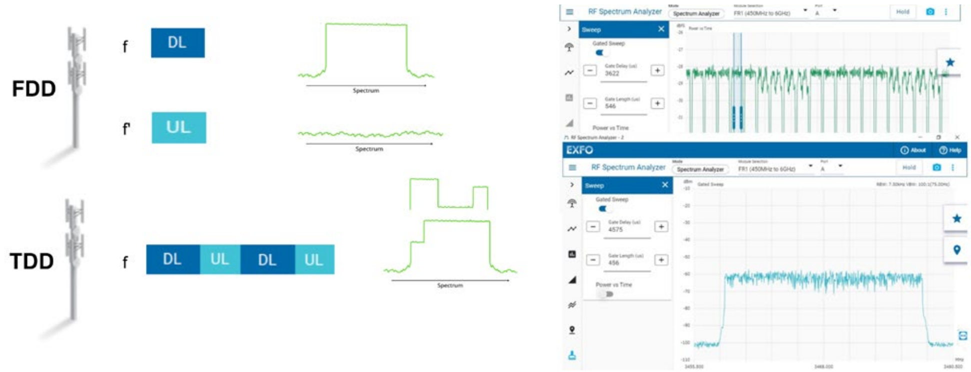

Figure 8. FDD and TDD.

In an FDD system (see top part of Figure 8), uplink (UL) and downlink (DL) channels are continuously transmitted, each defined by their own number (e.g., eARFCN in the case of LTE) which represents the center frequency. As a result, having dedicated subchannels for transmitting and receiving means that the base station and user equipment are continuously transmitting. At both endpoints (i.e., base station and user equipment), a duplexer is used to separate or combine both subchannels. In contrast to FDD, TDD systems (see lower part of Figure 8) use the same frequency channel for both UL and DL, and both channels are separated using different time slots. Using TDD allows a flexible configuration in terms of how many timeslots are being used for DL and UL, and in being able to change the weight of DL traffic versus UL traffic.

Using TDD allows a flexible configuration in terms of how many timeslots are being used for DL and UL, and in being able to change the weight of DL traffic versus UL traffic.

But there are important considerations when dealing with TDD systems. When looking at the spectrum and trying to analyze and troubleshoot the behavior of a TDD system with a traditional spectrum analyzer (i.e., a swept spectrum analyzer in which the instrument uses a swept local oscillator to cover a certain frequency range), the result is that the base station is changing from transmission to reception with the timeslots. At the same time, while the spectrum analyzer is sweeping to cover the desired frequency range, the represented signal will be bouncing up and down since in most cases the TDD format and instrument sweep speed will not be synchronized. As a result, an RF analysis is not possible for either DL or UL.

To overcome this challenge, the RF spectrum analyzer uses the time-gating feature. Time gating allows a user to look at the signal in the time domain, specifically the symbols/slots being used in DL and UL, and select one of those slots to use in order to analyze the behavior of the system. For example, if applying the gate in the DL slots, a user could analyze the spectrum being transmitted by the base station (e.g., power, shape, width, etc.). Applying the gate in the UL slots enables the user to analyze other aspects such as the existence of external interference that might be affecting the system. TDD requires a synchronization clock to limit drift when looking at the UL or DL slots. Usually the synchronization source is a GNSS. However, state of the art RF spectrum analyzers have the ability to synchronize on radio frames which removes the need for a GNSS.

C-band spectrum testing requirements

Best practices for validating C-band

5G presents a new and challenging testing environment. The challenge for mobile network operators (MNOs) is to make sure that a radio site is working properly before going live. When deploying 4G LTE sites, fiber testing, CPRI/eCPRI link validation and coax testing are key for making sure a cell site is operational.

With 5G NR architecture, things become more complex. For example, fiber is much more prevalent in 5G than in previous generations—reaching directly up to the antenna and working at much higher data rates to deliver the different services 5G promises. And all these fiber links need to be tested. At time of installation, it is important to perform fiber inspection and fiber characterization to identify faulty fiber links from the beginning and avoid any failure in further testing stages. After the physical layer checkup, the transport layer also needs to be validated. This involves testing of the eCPRI links between the radio units and the distributed units to ensure the cell site is ready to go live.

5G base stations have complex antenna systems that will make use of beamforming to compensate for the additional challenges RF signals will encounter in 5G systems.

The RF perspective in 5G testing is also rather complex. 5G base stations have complex antenna systems that will make use of beamforming to compensate for the additional challenges RF signals will encounter in 5G systems. These base stations radiate across three 120° sectors (i.e., alpha, beta, gamma) with multiple beams in each of the sectors. In FR1 a 5G base station can transmit up to 8 different beams, while in FR2 it can transmit as many as 64 different beams, all of them requiring testing. Ideally, the first RF test to be performed in the 5G base station would involve checking that all beams are being transmitted, and then taking a snapshot of the situation to keep for future reference.

In addition, a quick check of the power levels in each of the beams is necessary. This power level, as well as quality level can be validated with the readout of the metrics given by the SSS (included in the SSB), which are RSRP, RSRQ and SINR. Each of the beams will have their own power and quality metrics (see Figure 9).

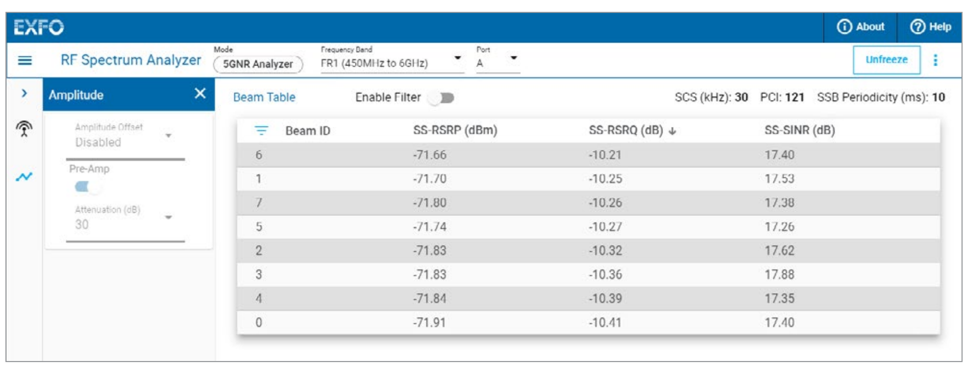

Figure 9. Beam analysis.

A further step could be to perform a second power check, but in different locations. For example, a technician could walk in an arch (120° circumference) in front of the antenna to validate that the power level variation follows a logical pattern. All these different RF tests are critical because if not done, the only thing that one can hope for is that the user device receives a signal and is operational. But if the phone does not connect, one would need to go back to the beginning and start testing everything again.

Additional references

Products

5GPro Spectrum analyzer - RF spectrum analyzer

FTB 5GPro - complete, all-in-one 4G and 5G test solution

Webinar

C-band spectrum: what it means for accelerating 5G deployments

Blog

RF and 5G new radio: top 5 questions answered

What is C-band and how will it accelerate 5G deployments

Infographic

RF spectrum in today's 5G world

Last but not least is to include is the creation of a cell-site birth certificate—going from fiber inspection to fiber characterization, link validation and then RF validation (i.e., beam analysis). Should a degradation arise in the future, this can be used as a benchmark to reference during troubleshooting, helping to reduce the time required to resolve the problem.

5G fixed wireless access (FWA) installations

Instead of mobile user equipment, these FWA installs involve customer premise equipment (CPE) with antennas fixed to the side (or inside) the house. Fixed-wireless access installations vary from one customer to another, so troubleshooting can be challenging since WiFi issues can be due to many different factors.

Customer expectations for 5G are high, especially when service levels are promised to be in the 500 Mbit/s to 1000 Mbit/s range. When new services are deployed to the home and WiFi issues unfortunately arise, the first step is to verify whether promised speeds to the home are being achieved.

This can be done through a quick test to assess if the CPE is installed correctly. If there is a problem with the CPE, beam analysis can be performed by demodulating the 5G signal. If everything is good from a demodulation perspective, the next step in the troubleshooting process is to ensure that the signal is clean and that no interference is present.

Conclusion

5G C-band strikes the perfect balance between low bands and high bands. Operators are now in a race to deploy C-band since it delivers the reasonable speed and throughput values required for the current 5G applications. Emerging technologies such as beamforming and TDD have been added into the mix which adds to the level of complexity particularly when analyzing RF spectrum and interference issues. A simple-to-use, intuitive 5G test solution reduces complexity—it's the ideal tool to check for issues and can lead to up to a 90% time savings for frontline technicians. Due to these added complexities, implementing testing best practices, as well as using easy-to-use and easy-to-interpret test tools for validating 5G networks will be key.

Discover how EXFO is helping operators deploy 5G C-band networks three times faster and more reliably with the 5GPro Spectrum Analyzer.

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