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THE ARCHITECTURE OF 5G NETWORKS

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The Architecture of 5G Networks

What Is Open RAN Technology? And What Does It Mean for 5G?

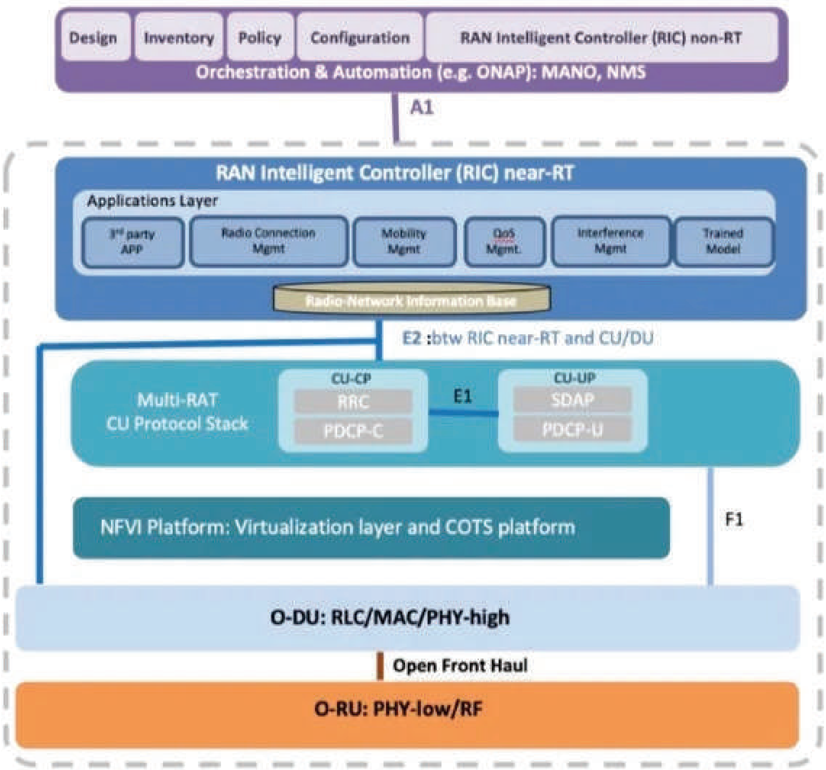
Openness and intelligence are the names of the game at the O-RAN Alliance.

The multinational telecom carrier Telefónica has tapped Xilinx and a host of other hardware and software companies—including Altiostar, Gigatera Communications, Intel, and SuperMicro—to advance O-RAN, or open radio-access networks, within Telefónica's 4G and 5G wireless network. These improvements are projected to take place throughout the UK, Germany, Spain, and Brazil this year.

But what is Open RAN anyway? And how might it make a difference at a timely moment with the roll-out of 5G?

Open-RAN vs. Traditional RANs

O-RAN technology is said to allow service providers to speed up 5G network development through its open architecture.



O-RAN architecture.

There are several other benefits of O-RAN technology over traditional RANs, according to the O-RAN Alliance. The O-RAN Alliance is comprised of a network of major industry players including Telefónica, AT&T, and Verizon. These giants driving the development of O-RAN technology have two core principles to define O-RAN and distinguish it from other RANs.

The first is its open interface, which the O-RAN Alliance's whitepaper says will allow smaller vendors to introduce their own services and allow operators to customize the network as needed. It will also allow multiple vendors to deploy their technology on the network, thereby enabling competition and reducing costs.

The second core principle of O-RAN is intelligence. The deployment of 5G and the applications that come along with it will increase network complexity to the point that it is no longer viable for humans to operate and optimize the network. The network must be able to operate on its own and learn as it goes along, which is why the O-RAN Alliance calls for embedded intelligence at all levels of the network.

O-RAN Initiatives and the Push Toward Off-the-Shelf Hardware

The O-RAN Alliance's white paper on use cases and deployment scenarios outlines three main initiatives of O-RAN:

1. Blaze a trail toward RAN virtualization, open interfaces, and AI-capable RAN
2. Minimize proprietary hardware and promote a push toward merchant silicon and off-the-shelf hardware
3. Specify interfaces and APIs to drive "standards to adopt them as appropriate" and explore "open source where appropriate"

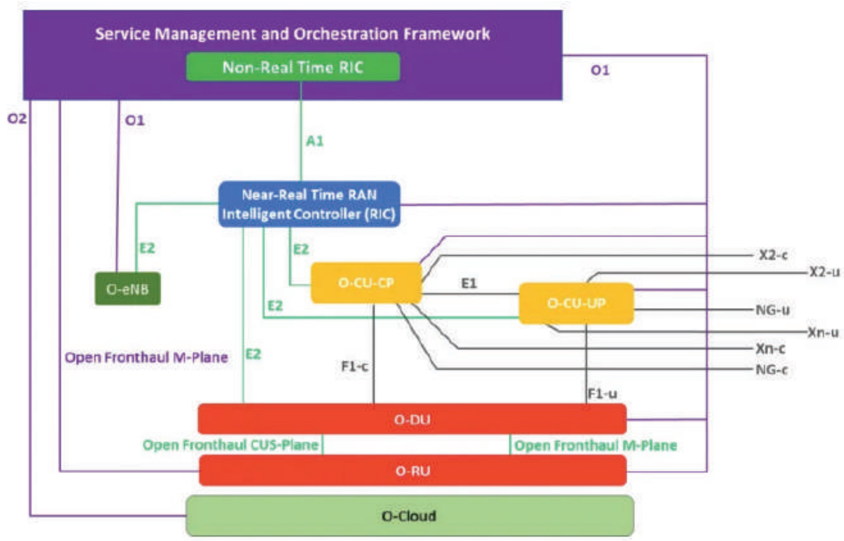


Diagram of the overall logical architecture of O-RAN.

The alliance's commitment to minimizing proprietary hardware reflects their efforts to make the network more accessible to a broader range of hardware designers. Instead of having to integrate specialized hardware in their designs, engineers can use off-the-shelf hardware to deploy their technology with O-RAN. Furthermore, cutting back on propriety hardware will drive costs down and allow a broader supply chain to provide materials, thereby enabling faster implementation of new technology.

Making Way for 5G Base Stations

The O-RAN Alliance explains that its open interface could support white-box hardware design and development. Specifically, the alliance has promised reference designs for white-box base station hardware. To enable both baseband units (BBUs) and remote radio units (RRUs), the alliance has also mentioned reference platforms, which will provide a decoupled approach along with detailed schematics for hardware and software architectures.

This will help engineers in the telecom sector to design energy-efficient base stations, especially as 5G rolls out. An additional goal of this use case is to reduce the research and development costs that may prohibit smaller companies from entering the telecom industry.

O-RAN Players

The open architecture of O-RAN is designed to give as much freedom as possible to designers in order to encourage innovation in the industry. To this end, the O-RAN Alliance is paying considerable attention to attracting industry players as partners.

Since the O-RAN Alliance is relatively new, having been founded in early 2018 by AT&T, China Mobile, and other telecom giants, there is still significant room for improvements on both the hardware and software sides of the technology, many of which will likely be explored by some of the smaller players or newcomers to the industry.

O-RAN Alliance operators.

Aside from those already mentioned, notable members of the O-RAN Alliance include T-Mobile, SK Telecom, Sprint, and China Telecom. The contributors of the alliance have some big names that will be even more familiar to engineers: Analog Devices, IBM, Infineon, Keysight Technologies, Nvidia, NXP, Qualcomm, Samsung, and Texas Instruments, among others.

The Benefits and Potential Drawbacks of the Switch to 5G Antennas

5G is the latest wireless technology for mobile devices and promises considerably higher data rates, lower latency, and increased number of instantaneous connections. But how will current infrastructure cope with the change and what will this mean to current 4G hardware?

What Is 5G? 4G vs. 5G

5G is the 5th generation of cellular network technology and, like each predecessor, offers higher data rates than the previous, lower latencies, and better bandwidth.

When compared to 4G, 5G offers bandwidths greater than 1 Gbps, a latency of less than 10ms, and an average speed of 200 to 400 Mbps, whereas 4G only offers a bandwidth of 200 Mbps, a latency of 20ms – 30 ms, and an average speed of 25 Mbps.

Even though 5G is incredibly new with its full roll-out expected by 2020, some countries are well into the process of adopting the new network. South Korea, for example, has installed 86,000 5G base stations. Meanwhile, several network operators in the UK have just released 5G in the past month.

While the technology is now available, only a handful of devices on the market actually support 5G and so wide access to 5G won't be expected until the technology matures.

The Tradeoffs of 5G

So, it can be seen that 5G offers significantly more of everything, but surely there must be a catch to the far superior specs?

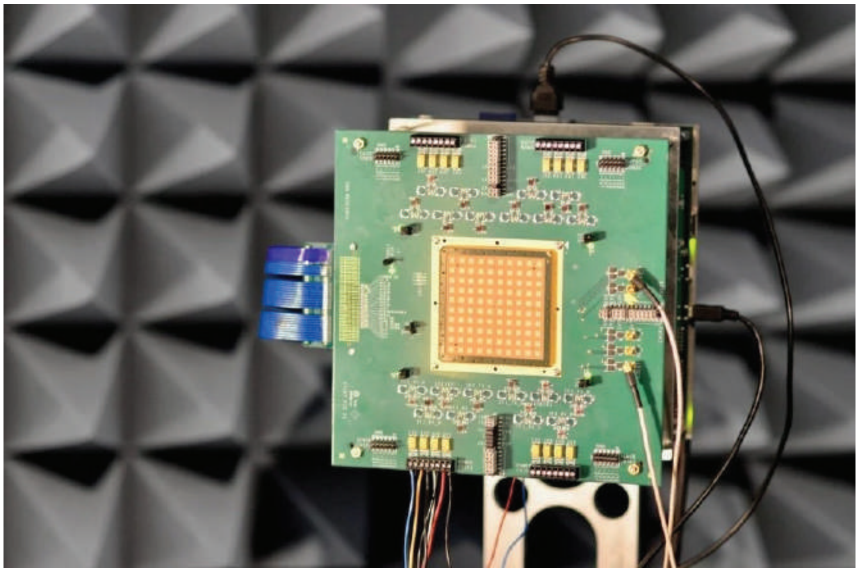
As a matter of fact, 5G does have an issue with implementation and it comes down to the frequencies at which it operates.

Technologies such as 4G operate at three main frequency bands which are 800MHz, 1800MHz, and 2600MHz—which have wavelengths in the centimeters (for instance, 2400MHz radio waves have a wavelength of approximately 12cm). This wavelength allows large radio masts to have a range of up to 35km—but, due to practical limitations, cell towers will often be placed within several km of each other.

5G, on the other hand, operates on several frequencies which include the already-used LTE bands (600MHz to 6GHz) but also the millimeter-wave bands of 24GHz to 86GHz.

The result? While higher frequencies allow for higher bandwidths, they come at the cost of the wavelength.

As the wavelength of radio waves reduces, its effective range reduces for a number of reasons, including interference, diffraction, and reflection. Since 5G operates at significantly higher frequencies, as well as having higher bandwidths, it is not able to fully operate on 4G radio masts and therefore new 5G base stations are required.
But the replacement base stations are not just differently-shaped metal rods attached to some coax; they are a whole new type of antenna with some incredible capabilities.



The move from passive antennas to active antennas is expensive. Image of a millimeter wave phased array antenna module.

5G Antenna Technologies: The Advantages of Beamforming

Radio antenna come in many wonderful shapes, sizes, and forms. From horn antennas that search the cosmos for microwaves to dipole antennas that "listen" to Jupiter to inbuilt PCB antennas in IoT devices, antennas are everywhere.

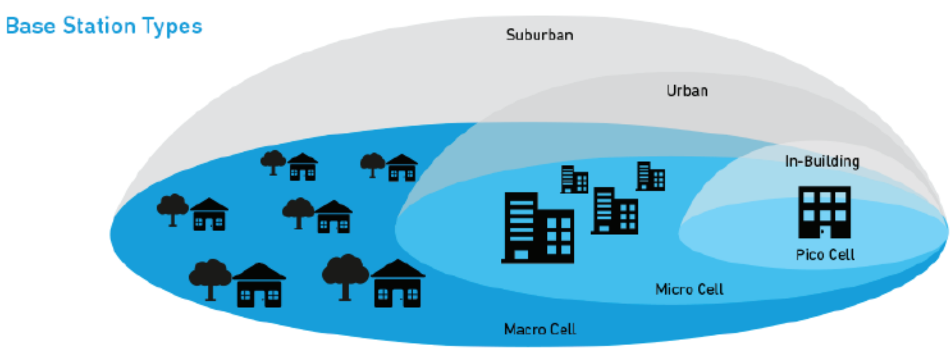
But the radio antenna in 5G networks are arguably a whole new class of antenna with some rather incredible abilities.

The combination of small wavelength radio waves and the requirement for many simultaneous connections means that 5G masts need more than 100 radio elements that make up a phased array.

Since there are many elements next to each other in grids, this allows for some incredibly intelligent beam steering to individual users. When combined with complex algorithms, the 5G radio base station can determine the best way to steer the beam to provide the highest data connectivity. The use of beamforming therefore also helps to reduce the energy wasted by the mast as individual users are targeted rather than radio waves being emitted in all directions.

The use of beamforming additionally helps with reducing interference with other base stations. The result is a further increase in bandwidth. Another way to look at it is that the more devices that share the same frequency band, the less time each device has access to that frequency band (they all have to take turns to use the band). If individual devices are targeted with a beam, each device can maximize their use of the band without interfering with neighboring devices as they will only be communicating via the beam.

Concerns About the Rise of 5G?



Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

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Since the rise of radio communications to daily prominence, there have been various parties concerned with the effect of radio waves on health. The onset of 5G has somewhat revived these concerns as new hardware presents fresh opportunities for misunderstandings, but also for education.

Many experts dispute the idea of health-related concerns because the radio waves used in mobile technology are in the centimeter range, which are non-ionizing (though they can cause heating). 5G, however, uses much higher frequencies which are in the millimeter range. Since the higher frequencies put the 5G radio signals closer to the ionizing range—and with the increased number of base stations needed—there are those who question the technology's safety. Some of these concerns are borne from extant studies, such as one that showed an increase in heart cancers in rats when constantly exposed to mobile radiation. Others anxieties arise from the argument that more studies are needed on the long-term effects of exposure to EM radiation.

The other concern of 5G is how and who implements the technology. Despite concerns from the US, the UK is implementing 5G with technology supplied by Chinese megacorporation Huawei, which has some questioning whether Huawei's 5G systems will be secure due to the heavy involvement of the Chinese government (to the point where each company will have an appointed official who monitors the business).

Because the adoption of new technologies can be contingent upon public opinion (as in the case of consumer trust affecting IoT adoption; link opens PDF), these issues will likely need to be addressed over time for a smooth transition to 5G.

Unlike its predecessors, 5G is a revolutionary change to network infrastructure with reliance on phased arrays, beam steering, and considerably higher frequencies.

Network providers will have to completely rehaul their infrastructure in order to be able to provide 5G. Not only are the new antennas far more complex than their predecessors, many more antennas will be needed due to their limited range.

Will 5G be the first worldwide urban Wi-Fi? Could 5G replace urban Wi-Fi entirely? Will communities be able to implement the new infrastructure smoothly? Only time will tell!

5G Network Structure

The Fifth Generation of Cellular Network Technology (5G) has already begun to deploy in multiple regions around the world. While the name implies that the 5G network will replace the existing 4G network, the reality is more complicated than that. The 5G network will have a different, more dynamic and diverse structure than the traditional networks of previous generations.

The benefits of 5G are manifold: higher bandwidths and data rates, more devices and lower latency (See Figure 1). These network upgrades enable a broad range of new applications such as seamless mobile broadband, autonomous vehicles, smart factories and much more.To achieve these improvements, the new network utilizes different frequency bands with varying properties, which leads the bands to be used in different points in the network.

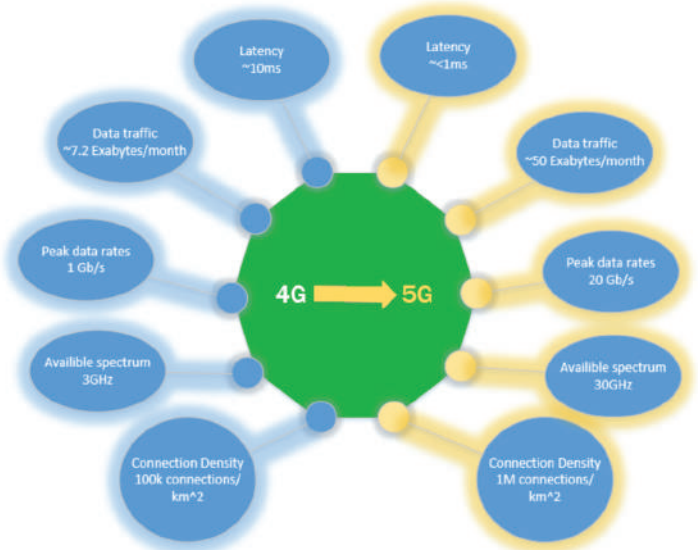


Figure 1

5G frequencies take advantage of several different bands including some that are already in use for 4G LTE networks, such as 800MHz, 1.8GHz and 2.6GHz. The 5G spectrum ranges from 600MHz to 6GHz in Range 1 and from 24GHz to 86GHz in Range 2 (so-called mmWave). The lower bandwidth tier, below 2GHz (often 700MHz) is for broader coverage areas and uses similar bands as the existing 4G, with somewhat higher connection speeds. It can provide service over hundreds of square miles and is more efficient than 4G LTE, but not by a large amount. The greatest yields in benefits comes from the mid to higher band frequencies that 5G is mainly known for. Around 3GHz would be used in a mid-band tower which can serve a several mile radius. The highest millimeter wave frequencies cover an even smaller area for each tower but carry much higher data rates and allow for the reduced latency. However walls, windows and even water absorb radio waves at these higher frequencies, which reduces the usable distance range for the spectrum. The short range of the mmWave frequencies has a strong influence on the network structure.5G-enabled devices and infrastructure will be able to tune into any one of these frequency bands.

The best way to understand it is by breaking down some of its use cases:

- Large area networking
- Small Cells
- In-Building

Large geographic areas are served by the macrocells, which normally are comprised of a base station along with an active antenna array (AAA). The antenna is a phased array, which can be as big as 64R x 64T, and allows for Beamforming, which reduces the power needed to transmit signals by focusing the signal to a particular user rather than broadcasting to all devices in range. The Beamforming in an AAA uses constructive and destructive interference to optimize a user's connection strength through multiple antennas to achieve spatial selectivity. This allows many more nodes to be supported for the same radio power. The macro cell covers diverse environments from sparse, rural areas to the dense urban core with a wide network to provide the minimum level of 5G service. In the denser areas, additional types of cells are needed due to obstructions and the number of users.

Small cells, also sometimes referred to as micro or Pico cells (See Figure 2), typically have a smaller base station and limited number or just a single antenna and are deployed in urban environments to provide the bandwidth, latency and connection density needed. These small cells also fill in areas where the macrocell signal may be impeded by buildings or other signal obstructions.

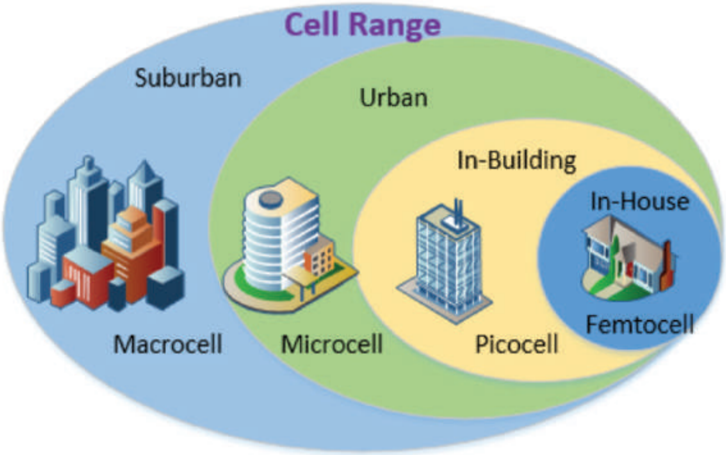


Figure 2

As the highest frequency bands have the highest bandwidth, there is a challenge to provide the highest data rates inside offices, residential building and malls because the building may absorb the high frequency radio waves. In these situations, there may be a small cell on top of the building with fiber or POE connection through the building to a number of so-called femtocells, which could serve a whole floor or wing of the structure.

There are many other types of environments which we can imagine for future 5G applications. One example is the highway and road system. The low latency and large number of connection nodes is required for safe driving by autonomous vehicles. A combination of macro cells and small cells could cover most of the transportation system with more cells in dense urban environments.

Another use case is the smart factory, sometimes called Industry 4.0. Here, local handling and security of data might be the most important considerations. A private 5G network allows the factory or other piece of critical infrastructure operate in a more secure and reliable manner. To create a private network, the end user could install separate hardware or use existing infrastructure and carve out a virtual private network using software. In most cases, a wireless infrastructure provider and/or a network operator will be involved to maintain the network and ensure its reliability.

There are already groups working on smart lampposts and other infrastructure for the smart city. These are another use case for 5G networks. The lampposts may use the network to relay data and take commands or they may become 5G network cells in their own right. The frequency bands served by smart city infrastructure will depend on the density of the streets they are on. For example, a residential neighborhood might have relatively lower bandwidth and speeds, while a busy commercial thoroughfare needs higher bandwidths and greater connection density to support the peak shopping and traffic hours.

When considering these diverse use cases, one notices that the network is very complex and highly heterogeneous. In addition, these use cases will grow and morph over time. These factors point to a highly dynamic system where network operators add cells to densify coverage as needed and are continuously optimizing the software and control systems. Recent efforts around creating a more standard and open-source ecosystem of hardware and software will streamline the growth and development of the 5th Generation of wireless services.

The 5G network will continue to grow and adjust as it rolls out in more locations and into private networks. As people introduce new applications, the network requirements will evolve and wireless providers will design equipment to target the new application challenges. The one thing we can be sure about is that the network will continue to change.

Powering the 5G Network

As the 5G cellular network continues to grow and expand, the challenges of providing power to it will also increase. Because of the complex structure and highly diverse equipment of the network, it will need a wide variety of power supply solutions to ensure reliability and efficiency. Underpinning those solutions are families of power electronic devices and circuit topologies which make it all possible.

The 5G network will have a huge range of deployment options to cover the range of environments in which it will operate. For example, large rural areas will need different towers and density of cells than a dense city. To simplify, we can divide the cellular connection nodes into several categories, shown in Table 1.

The largest ones are the so-called macro cells, which are typically large radio units mounted on a tower. There will be a base station connected to the backhaul network and an array of radio heads.

X-cell	Cell Radius	Users	Power	Use case
Femto-	10 – 100m	10^1	<100W	Home/Office Broadband, PMN
Pico-	100 – 200m	10^2	100W-500W	Dense Urban, Building roof, PMN
Micro-	200m – 2km	10^3	2 – 5 kW	Suburban Coverage, Industry 4.0, Building roof
Macro-	8 – 30km	10^4	10+kW	Large scale network, City-wide

Table 1

This array configuration is referred to as an Active Antenna Array (AAA) and allows for beamforming.

Beamforming is important to energy efficiency, as it allow the radio energy to be concentrated to a specific user instead of broadcasting in all directions. Besides the power for the antennas, there are a number of computing and analog loads inside the base station including one or more ASICs, specially designed for network management. In addition, there will increasingly be server-like content in 5G base stations to support edge computing for time and latency critical services.

The category of "small cells" (Micro/Pico) are really a continuum of equipment tailored for various environments. Small cells will be deployed where a higher density of connections, higher bandwidth and lower latency are required. In addition, they are used in places with large obstructions and complex layouts to ensure good cellular signal strength throughout. Some examples are a suburban mall complex, an industrial site or a residential building.

Finally, Femto cells provide bandwidth within homes, offices and other buildings. Fiber or Ethernet might connect the femto cells to a small cell on the roof or outside the buildings, where the small cell provides the gateway to the rest of the network.

The wide range of deployment options will require a wide range of power solutions starting from the grid, all the way to the individual loads within the equipment. The first step in the power tree is to convert from the AC grid to a DC voltage, nominally 48V. Telecom systems have operated at -48V, actually as a legacy of the original telephony system. -48V was chosen because it caused any corrosion to occur in the chassis of the equipment, not on the conductors. The other key to 48V was that the safety voltage for human interaction is 60V, as certified by organizations such as UL (in America) or the IEC (in Europe). Therefore, 48V gives some margin below the limit for human safety. If the system experienced higher voltages then additional insulation and isolation would be required, raising the cost. It is also a convenient voltage for Pb-acid battery back-up power, since you just need four in series. In actuality the voltage supply might range from 44V to 54V.

Table 1 shows the approximate power for each of the cells, which sets the rating for the AC-to-DC power supply needed. Different power converter topologies are best to supply different power levels. For example, an interleaved PFC stage followed by a resonant LLC DC-DC stage is the right solution for the high power levels needed for a macro cell, while an H-bridge is optimal for a range of small cells. The specific switches, controllers and interfaces to realize the power supply are where power electronics come into play. The primary side of the power supply will be composed of super junction MOSFETs, though silicon carbide (SiC) MOSFETs may eventually supplant them. Mid-voltage MOSFETs will perform the synchronous rectification on the secondary side of the supply.

The next conversion stage might be an intermediate bus converter from 48V to 12 or 5V. There is also another bus, around 28V, which supplies the radio unit. A fan or climate control unit might be powered from the 48V or 12V bus. From 12 or 5V, a point of load converter, often a buck converter, steps the voltage down to anywhere from 3.3V to 0.8V, depending on the final load device. The main loads in the base stations will be a number of ASICs, which handle the signals and data and switch that data between the backhaul and the cellular network. There will be considerable real-time calculation resources to manage the beamforming, massive MIMO and software defined networking capabilities. The last large load in the base station might be a server deployed at the edge of the network. Placing computing at the edge reduces latency for those applications that need immediate feedback, such as augmented reality (AR).

For Femto cells, the small power requirements allow for more power supply options. Power-over-Ethernet (POE) is one method to supply the smallest cellular nodes. In this case, Ethernet would connect each femto cell to a small cell on the roof of the building, say, for power and data. However, some older buildings are not wired for Ethernet, so the femto cell would use a wall plugged power supply containing a flyback converter or other low power topology.

In all wireless infrastructure, there is a need for bus protection. This can be implemented using a controller and a MOSFET. The MOSFET sits in the power current path, and can disconnect the input power from the downstream load. For bus protection, wide Safe Operating Area (SOA) MOSFETs are best to ensure reliability during in-rush, overvoltage and breakdown events. Integrated devices are also available for bus protection, where the controller and MOSFET are integrated into the same package or same piece of silicon, sometimes known as an eFuse. Besides overvoltage and overcurrent protections, an eFuse also can have features like power-good signal, fault reporting and slew rate control (which limits in-rush current spikes).

The wide range of equipment and loads in 5G networks requires a similarly wide range of power conversion, delivery and protection solutions. As the 5G network grows and evolves, so too will the power electronics to support it.

5G Automotive: What We Can Expect and The Challenges with Implementation

5G may still have a long way to go, but its potential for connected car applications are already unmistakable.

We look at how best to define ‘5G automotive’, the chief authorities behind its research and development, and both the current and future landscape of 5G-based connected cars.

Defining 5G Automotive

To tackle the matter of fifth-generation wireless in connected cars, it’s worth first confirming that ‘5G automotive’ (which will soon be defined) is only in its R&D stage at the time of writing. 5G automotive is a future prospect, perhaps even a promise—but it’s not yet a reality. Fifth-generation wireless itself, in fact, is currently in its infancy.

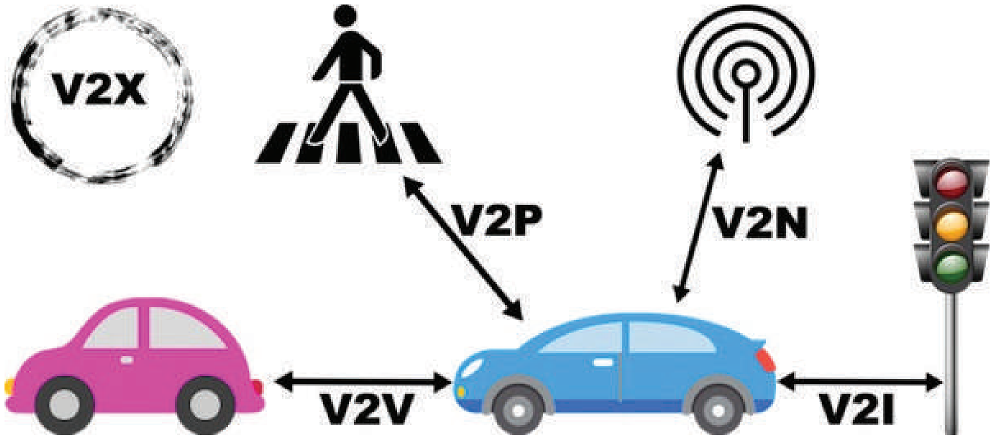
Accordingly, the realization of 5G automotive would involve a time at which engineers and manufacturers have successfully utilized 5G as a platform to enhance the following two areas to the point of achieving real-time transport communication, for a more efficient, safe, and eco-friendly driving experience:

1. Vehicle-to-everything (V2X) communications—This is a short-range wireless vehicular system through which vehicles communicate with, not only other traffic, but the very environment around them.

V2X is collectively formed of vehicle-to-vehicle, vehicle-to-pedestrian, vehicle-to-network, and vehicle-to-infrastructure communication (respectively, V2V, V2P, V2N, and V2C, as per the below picture).

2. Cooperative Intelligent Transport Systems (C-ITS)—This is when two or more ITS subsystems, e.g. vehicle and roadside subsystems, collectively offer better safety and efficiency in the transport network.

C-ITS goes hand in hand with V2X to ensure that the given vehicle maintains a safe distance from both road and roadside obstacles. (C-ITS can even reduce emissions—thanks to the economical transport that comes with such cautious, well-planned driving.)



An infographic using graphics and acronyms to represent the dynamics of vehicle-to-vehicle, vehicle-to-pedestrian, vehicle-to-network, and vehicle-to-infrastructure communications—all under the umbrella of V2X, or vehicle-to-everything.

As both technologies hinge upon one another, the former, V2X, will need to be enhanced to realize the large-scale commercialization of the latter, C-ITS (and vice versa). Experts, such as the GSMA (Global System for Mobile Association), ascertain that this will require the utilization of 5G.

With the previous points now discussed, note that '5G automotive' is used in this discussion to mean: 'a future point at which 5G will become the basis for V2X operations, which will in turn facilitate fifth-generation-based C-ITS in connected cars'.

Such a definition of '5G automotive' is chiefly based on the vision of the 5GAA (5G Automotive Association), a leading authority on 5G automotive R&D: "5G", says the organization, "will be the ultimate platform to enable C-ITS and the provision of V2X".

Before we re-visit C-ITS, V2X, and further smart vehicle research organizations, let's now discuss the current landscape of fifth-generation R&D in the context of connected cars.

What is Already Being Done?

While, as touched on, 5G automotive may exist only in the fairly distant future, many modern vehicles already have built-in satnav, voice-controlled AI assistants, and driver assistance functionalities. So, as we speak, it appears that the seed has in fact already been planted for 5G automotive, given how much demand for such connected car capabilities already exists.

Nevertheless, a particular challenge, as is the case with general 5G itself, is in further developing and optimizing the latest cellular network. And for as long as that hurdle is yet to be overcome, the resulting limitations on connected car features mean that they currently run on the current cellular standard, 4G Long-Term Evolution (or failing that, 2G or 3G for the less developed connected vehicles).

To reach the next generation of connected cars, automotive engineers, manufacturers, and regulatory bodies must cooperate to ensure the best possible 5G standardization, through which all fifth-generation-ready connected cars can communicate. As explained in logistics and transport giant Wallenius Wilhelmsen's interview and research article, 'How will 5G affect the automotive industry and mobility?':

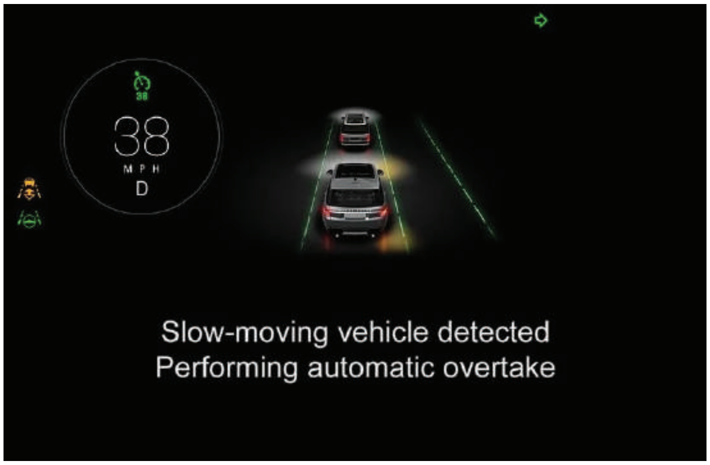
"it would be ... expensive and counter-productive for all the automotive brands to develop their own next-generation wireless communications system.

By supporting the development of 5G, and in turn defining the specifications that smart cars need, they [engineers and manufacturers] are speeding up the progress of 5G leaving the test labs and making its way into the real world."

This, again, reflects the fact that 5G automotive is still in its R&D stage: ensuring the successful roll-out of 5G itself, along with the cooperation of a great many manufacturers, is key. This leads us back to the 5G Automotive Association—alongside other connected car authorities—and the question of how close such organisations are to realising 5G automotive.

How Close Are We to Seeing 5G Automotive?

Again, the 5GAA is the leading authority on realizing 5G automotive: it's formed of automotive, tech, and/or telecom companies (including BMW, Huawei, and Apple)—all working to "define and develop



An example of an intelligent transport system function that is facilitated by vehicle-to-everything connectivity: automatic overtake, which is triggered by the detection of a slow-moving vehicle.

the next generation of connected mobility" while "support[ing] the idea that 5G will be the ultimate platform to enable C-ITS and the provision of V2X".

The 5GAA's belief in the importance of enhancing cooperative intelligent transport systems and vehicle-to-everything brings us to two major efforts that are, respectively, focused on C-ITS and V2X: the Car 2 Car Communication Consortium and the Connected Vehicle data Exchange (ConVEx) project.

Taking Stock of the Current Progress into 5G Automotive

It's in view of such authorities as the 5GAA, the collective ConVEx members, and the C2C-CC, that it's clear that the R&D into connected car technologies is set to thrive indefinitely.

Human error may one day no longer be enough to endanger road users. Pictured: a steady flow of traffic (represented by a constant stream of vehicle headlights and brake lights) passes through various city roads.

However, having technologies work on paper and having them work in practice are very different things. After all, we've talked about the obstacles that come with installing 5G infrastructure before.

The truth is that there's no saying when 5G authoritative will happen, and therefore, it stands to reason that the next generation of connected cars won't be rolled out for some time. So, with no planned date (although Ford is aiming for 2022), it's hard to promise that it will materialize in the foreseeable future.

Nevertheless, the points covered—namely manufacturers' collaboration in 5G R&D, the public's rising interests in (and therefore demand for) connected vehicles, alongside the steady improvements in transport connectivity and cellular networking—all point to the realization of 5G automotive being a question of 'when': no 'if' about it.

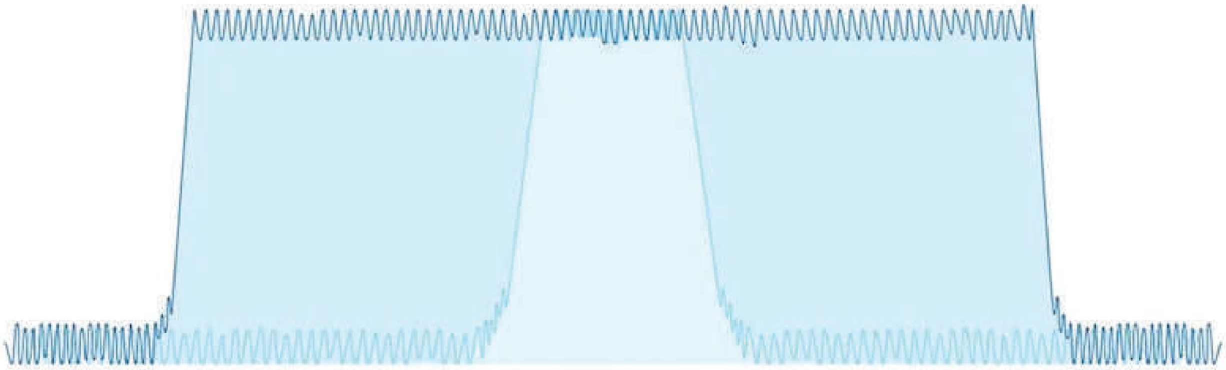
A New Era of Upgraded T&M Equipment Helps Designers Vault 5G Challenges

As 5G comes closer to reality, 5G designers face several obstacles in regard to test and measurement (T&M). In a paper from National Instruments, engineers designing and testing 5G devices faced a unique set of challenges.

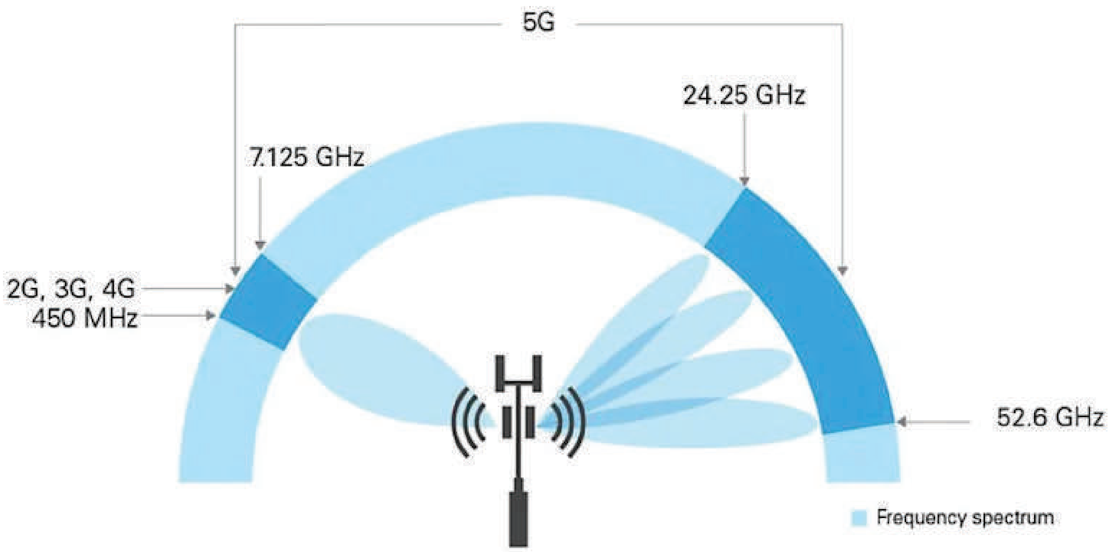
The Challenges 5G Designers Face

For one, **the waveforms are more complex**, such as various types of orthogonal frequency-division multiplexing (OFDM). The below image illustrates a type of digital modulation in which digital data is encoded onto multiple carrier frequencies.

Another issue is the **huge frequency ranges** of 5G. Instruments generating and measuring these waveforms must perform linearly over frequencies ranging from hundreds of megahertz to tens of gigahertz.



Digital modulation that enables digital data to be encoded onto multiple carrier frequencies.



Instruments geared for 5G must be both wideband and linear.

Component characterization is also more difficult because units must operate at super-high 5G frequencies as well as over lower legacy (2G, 3G, and 4G) bands. 5G designers must also **work with MIMO** or multiple-input-multiple-output technology; 5G beamforming systems introduces the complex necessity of spatially dependent measurements.

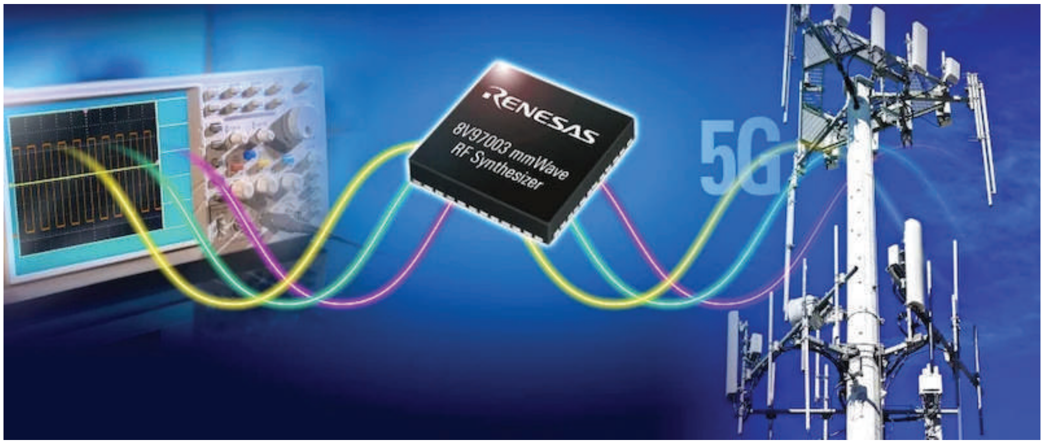
High-volume testing is also a burdensome factor considering the sheer volume of low-cost 5G components.

Companies Optimizing T&M for 5G

Although most existing test and measurement equipment will certainly be compatible with 5G devices, a few companies have gone above and beyond to optimize T&M tools for the new generation of wireless technology.

Renesas' Wideband Millimeter-Wave Synthesizer

Renesas' new wideband millimeter-wave synthesizer, 8V97003, is built for 5G and broadband wireless. It can serve as a local oscillator for millimeter-wave beamforming and as a precision reference clock for high-speed data converters used for T&M functions.



The 8V97003 for 5G.

In addition to its efficacy in generating frequencies for test purposes when developing 5G devices, the 8V97003 also serves in end-product 5G devices.

“We developed our new 8V97003 for the latest generation of high-performance mmWave radios, ensuring it meets our customers’ most demanding frequency range, phase noise, and output power requirements,” said Bobby Matinpour, VP of timing products at Renesas’ IoT and infrastructure business unit.

“With its best-in-class performance in a single-chip design, the 8V97003 is particularly well-suited for emerging applications above the 6 GHz carrier frequency, including broadband wireless, microwave backhaul, and 5G radios.”

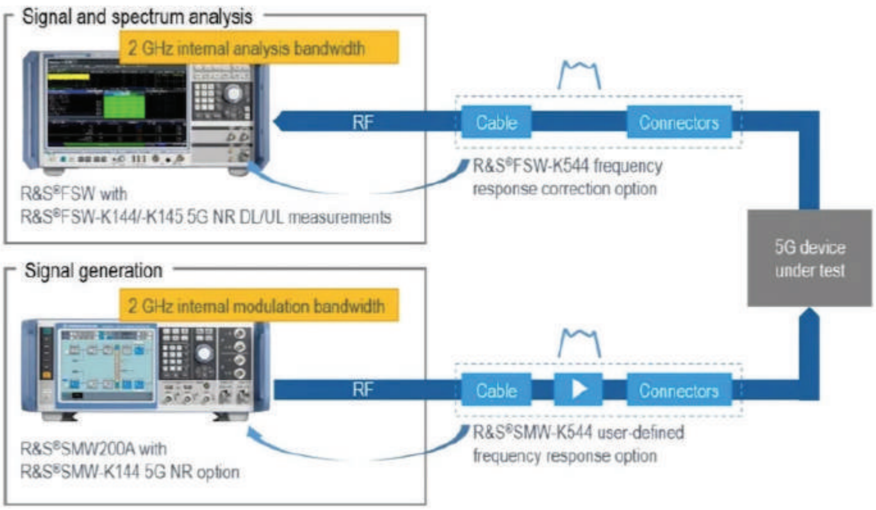
As a synthesizer/phase lock loop (PLL), the 8V97003 operates from a VCO and generates outputs up 18 GHz with an octave’s tuning range. The unit’s 32-bit fractional feedback divider combined with its output divider allows for the full exploitation of the wideband capabilities of the VCO.

The unit offers a notably low output-to-output phase skew drift, measuring less than 10° across all frequencies and operating conditions. This serves to reduce radio path recalibration occurrences in beamforming applications. This feature is of critical importance for the successful implementation of 5G radio card massive MIMO systems.

Rohde & Schwarz’s Vector Signal Generator and Signal Spectrum Analyzer

As Rohde & Schwarz sees it, the cellular industry faces daunting challenges working with the new spectrum that exists above 6 GHz—simply from the high frequency alone. Additionally, 400 MHz channel bandwidth, plus the multiple carrier aggregations can add up to a total bandwidth requirement of up to 2 GHz.

Illustrated below is a test setup employing the company's SMW200A vector signal generator and the FSW signal and spectrum analyzer.



Test setup using the SMW200A and the FSW signal and spectrum analyzer.

With this test setup, a frequency range of up to 40 GHz and a 2 GHz internal modulation bandwidth allows the generation and analysis of realistic 5G scenarios. The need for external downconversion devices is eliminated by a carrier frequency of up to 90 GHz and up to 2 GHz of internal analysis.

The pair will have utility in R&D as well as in testing due to the many 5G-ready integrated personalities.

Keysight's VXG Microwave Signal Generator

The VXG is a dual nel, 44 GHz signal generator with a 2 GHz modulation bandwidth.

The VXG microwave signal generator.

Keysight explains that in order to overcome system path loss, multi nel MIMO is inherent to millimeter-wave devices. Previously, this required actual over-the-air test methods. The VXG eliminates this troublesome step. The device enables quick switching from a blocker and interfere tests to dual nel MIMO and beamforming tests. It does so without any requirement for hardware adjustment.

Additionally, the device provides access to a range of evolving 5G standards for testing base stations. It also includes receivers with channel coding and multi-antenna support and mobile terminal transmitters.

Will T&M Continue to Up Its Game?

As seen in the case of Renesas, Rohde & Schwarz, and Keysight Technologies, there are several ways to go about preparing for 5G—both in the stage of testing prototypes and in fine-tuning end-products.

Although current T&M equipment can indeed handle 5G testing, it seems that the more purpose-built a T&M device is, the better equipped it will be to overcome the challenges of complex waveforms, huge frequency ranges, component characterization, MIMO, and high-volume testing.

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The Architecture of 5G Networks

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