RootMetrics®
By IHS Markit

5G FAQ

A comprehensive look at key elements behind the real-world 5G experience

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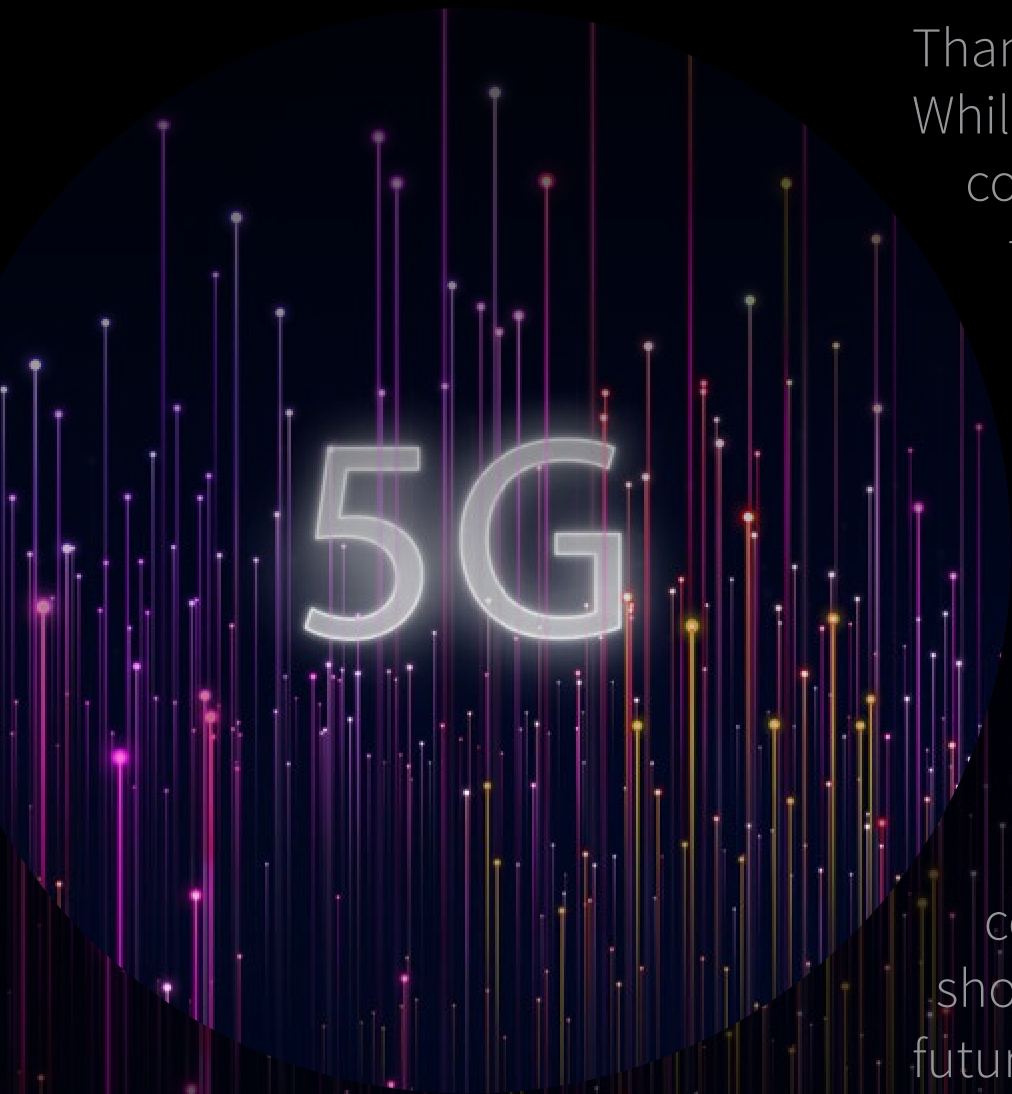
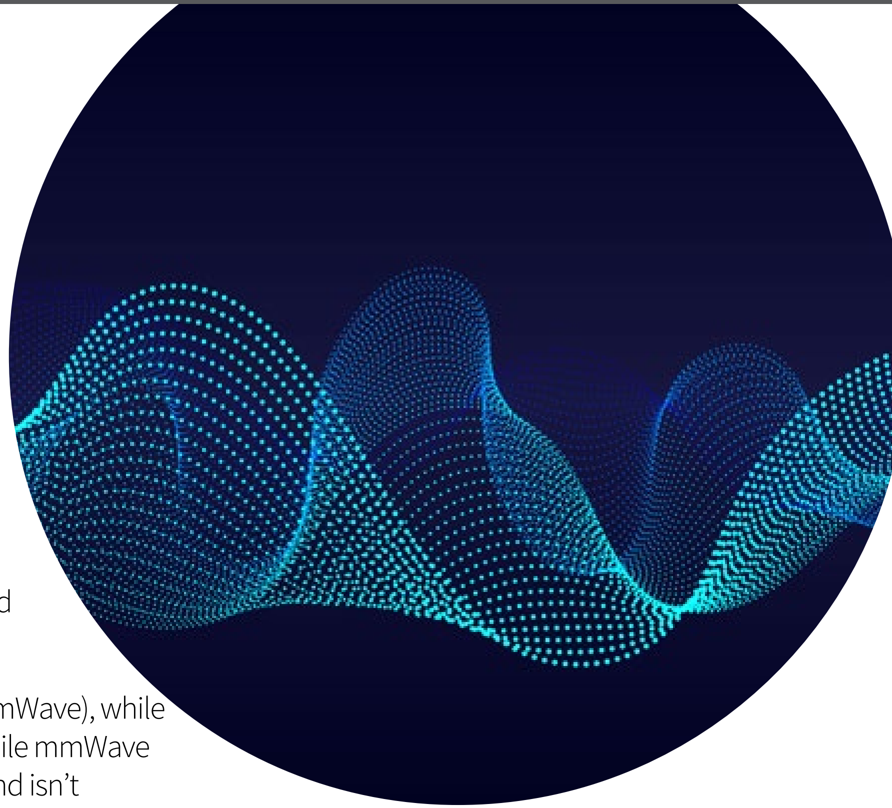


Thanks for downloading our 5G FAQ eBook. While the future of 5G and our connected communities is clearly bright, the terminology behind 5G can sometimes be murky. To help make 5G easier to digest, we've created a series of 5G FAQ articles to break down important yet complicated elements of 5G into easy-to-understand pieces. From massive MIMO to mission-critical applications to spectrum and much more, this eBook brings together 14 RootMetrics 5G FAQ articles to help make the complex topic of 5G even simpler and show just why 5G is so important to the future of connectivity.

What's the difference between mmWave and sub-6 GHz spectrum?



What is spectrum?

Spectrum is the range of electromagnetic radio frequencies used to transmit sound and data through the air.

When consumers use their mobile devices, their devices are not transmitting haphazardly over the entire spectrum of radio communications. Rather, they are connected over specific frequency bands. These bands are like invisible channels or pipes through which information is delivered. Generally speaking, the bigger the pipe, the greater the capacity and the more information that can be carried.

In the context of 5G, higher band spectrum above 24 GHz is considered millimeter wave (mmWave), while spectrum at or below 6 GHz can be separated into "low-band" or "mid-band" spectrum. While mmWave spectrum is used only for 5G, low- and mid-band spectrum is also used for 4G LTE service and isn't intended solely for 5G.

A delicate tradeoff

Given the coverage and performance implications for different types of spectrum, mobile operators must manage a delicate tradeoff based on what they hope to provide to users and the spectrum they have available. The tradeoff becomes a question of offering potentially slower speeds but broader coverage with sub-6 GHz spectrum or providing faster speeds but smaller coverage areas with mmWave spectrum.

6 GHz spectrum is the tipping point

In terms of spectrum and the 5G experience, 6 GHz is a tipping point, with potentially very different 5G results at higher frequencies compared to lower frequencies. For instance, a user's 5G experience with mmWave spectrum (which is above 24 GHz) could be markedly different than those on sub-6 GHz spectrum because propagation can vary significantly between low and high frequencies. In simple terms, signal propagation is the movement of radio waves as they travel back and forth between networks and mobile devices.

Lower frequency spectrum, including sub-6 GHz, can travel farther and penetrate solid objects like buildings better than a higher frequency spectrum such as mmWave. In fact, even a user's hand has been shown to block mmWave signals (though device makers are taking steps to mitigate this). In short, mmWave spectrum doesn't offer the broad coverage that sub-6 GHz spectrum supports. With mmWave spectrum's sensitivity to external factors and its smaller coverage areas, the benefits of mmWave (ultra-fast data speeds, for instance) will likely be felt the most in locations where limited coverage isn't a major concern, such as pockets of densely populated urban areas or in crowded indoor locations like sporting events, airports, or concerts.

While both sub-6 GHz and mmWave spectrum should, in theory, provide much faster speeds compared to LTE, mmWave technology offers the potential to deliver lightning-fast speeds theoretically as high as 5.0 Gbps or faster, compared to 100 to 200 Mbps for existing 4G LTE services. Why is mmWave potentially so fast? Returning to the pipe analogy, spectrum is crowded at the lower, sub-6 GHz frequency bands most often used for cellular communications. At higher mmWave frequencies, in contrast, there's more bandwidth available. To continue the analogy, at lower frequencies there is only room for smaller pipes, while at higher frequencies like mmWave, there's more real estate and the chance to utilize bigger pipes for carrying cellular information. In short, mmWave spectrum allows for large bandwidth, which paves the way for potentially faster speeds. Sub-6 GHz spectrum, meanwhile, has limited bandwidth and therefore its speeds could potentially be slower than possible with mmWave spectrum.

5G infrastructure

What is non-standalone architecture?

What is massive MIMO?

What is Fixed Wireless Access (FWA)?

What are small cells?

What is beamforming?

What is non-standalone architecture?

5G network infrastructure is still in the relatively early stages of deployment, and as the world continues to develop the required components that will enable a ubiquitous 5G experience, 5G cannot yet "stand alone." Rather, **most current 5G deployments utilize non-standalone architecture (NSA), meaning they require the support of current LTE architectures to operate.** From the tower to the IP network via all telco infrastructure nodes, LTE is still the "master" background architecture, and 5G must be added to the LTE infrastructure while it is still in development.

When will 5G be able to stand alone?

While some networks implemented standalone 5G architecture in 2020, it will likely be late 2021 or even into 2022 before it becomes the norm. While 5G is expanding in several countries, LTE remains the default mode for end-user devices, even in areas with 5G coverage. Yet, as 5G coverage expands, 5G mode will eventually become the default and the 5G infrastructure will develop on its own.

Is NSA the only option?

Simply put, no, 5G NSA is not the only option. It is a solution that many service providers are using as they bridge from 4G LTE to 5G for their customers who already have 5G-enabled devices. These service providers can utilize their existing network to deliver high-speed connectivity now, and they can be at the cutting edge of the market. There are two distinct disadvantages to this approach, however, including upswitching and data transfer:

Upswitching

Upswitching means that, in simple terms, if an end user is on LTE by default and then initiates a data task that requires 5G, there is additional time needed to "upswitch" from LTE mode to 5G mode before that task can be completed. As long as upswitching is necessary, download latency will be affected at the beginning of that data task. Upswitching time will impact the majority of real-world use cases and result in slower latency.

Data transfer

As users move around, their connection will pass from one tower to another. When that connection is moved, the LTE master will be in control and there will be short interruptions to data transfer until the handover is complete.

On the other hand, some service providers are waiting for 5G standalone (SA) before launching what will be a new end-to-end network. The advantage in waiting is that, while not the "first to market," they can instead have a powerful, reinvented architecture that can powerfully deliver on new applications and market use cases without dependence on LTE—what some consider a soon-to-be outdated network model.

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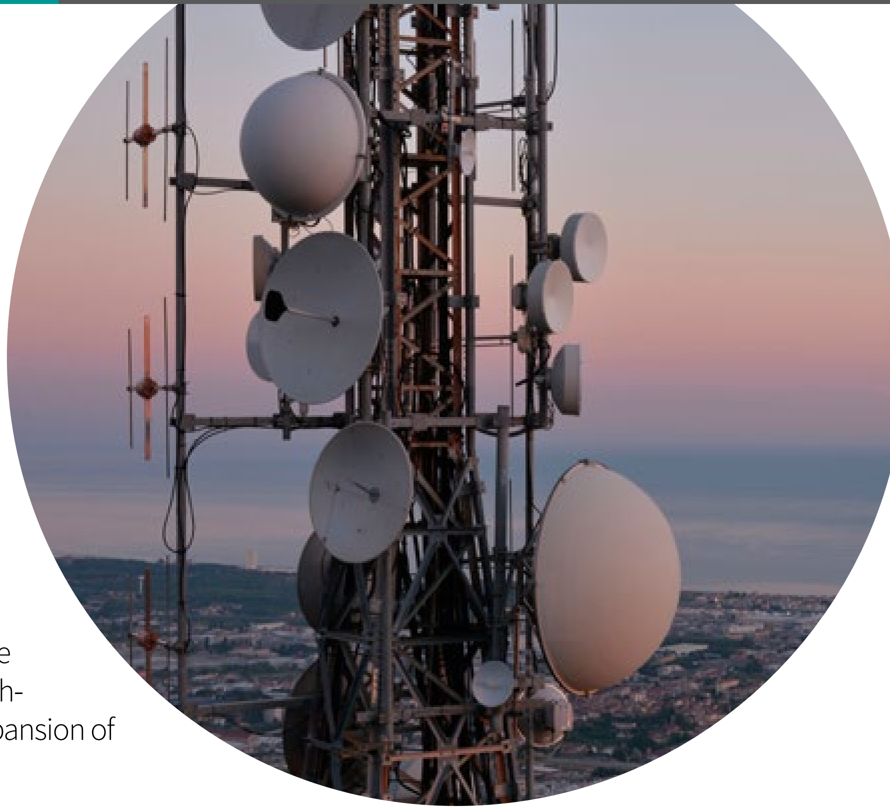


What is massive MIMO?

Multiple Input, Multiple Output (MIMO) refers to using multiple radio antennas at both the tower and the device. MIMO helps minimize transmission errors and improves capacity, coverage, and transmission speed of cellular networks. LTE currently makes use of either 2x2 or 4x4 MIMO. In a 2x2 system, there are two antennas on both the tower and device, and with 4x4 there are four antennas on both the tower and device.

Taking advantage of mid- and high-band spectrum, 5G will continue to benefit from the growth of massive MIMO and its enormous number of potential antenna configurations, which could reach up to 256 on a given base station. This jump in scale, moving from today's 4x4 configuration to hundreds of antenna elements, is directly tied to higher spectrum frequencies. In a nutshell, lower frequencies require larger antennas. From a practical standpoint, there just isn't room on base stations or mobile devices to support a massive number of large antennas, essentially removing low-band 5G deployments from the massive MIMO equation. However, as you reach the higher frequencies of mid-band and high-band (or mmWave), the size of antennas shrinks considerably and allows for a "massive" expansion of MIMO.

Much of 5G infrastructure and devices won't be ready to accommodate such huge antenna configurations, but the pathway will exist to grow in this direction due to the much smaller antenna sizes possible at higher frequencies. Currently, mobile carriers are limited in their adoption of massive MIMO by their spectrum holdings. For example, T-Mobile uses 2.5 GHz (mid) band for its 5G network along with 600 MHz (low) band but only mid-band uses Massive MIMO. Verizon has begun to utilize massive MIMO for its high-band/mmWave deployments. In the UK, meanwhile, none of the operators are currently using massive MIMO.

How massive MIMO will drive 5G effectiveness

Massive MIMO offers a host of advantages that will support mid- and high-band 5G network connectivity such that consumer expectations of the 5G era will be met or even exceeded. Specifically, massive MIMO offers the following advantages:

- A higher data rate enables faster upload and download speeds.
- Advanced signal processing algorithms enable a reduction in bit error rate (BER) when transmitting data from tower to device.
- Processes such as space time block coding and beamforming extend cell coverage areas.
- The wider coverage area supports more mobile subscribers per cell.
- Increased spectral efficiency offers a higher quality of service from the network provider.

Current obstacles to widescale massive MIMO adoption

The primary obstacle preventing widescale massive MIMO adoption, in addition to the specific spectrum holdings by different carriers, is cost of implementation. Initial 5G networks are typically non-standalone, which means they are built on the existing 4G LTE tower and node infrastructure. Because the existing infrastructure cannot physically hold the number of antennas required to meet "massive" MIMO capacity, network operators will need to build standalone networks in order to accomplish full-scale adoption.

Building a new, standalone infrastructure takes time and carries a significant hardware and installation expense. Until large-scale 5G standalone networks are up and running, we will not see widespread massive MIMO in action.

Massive MIMO is one of many 5G-related technologies that, when combined, will help fully support the high demand of data consumption and increased connectivity of our world now and into the future. Ultimately, massive MIMO will be a crucial component to achieving fast and seamless connectivity in homes, businesses, and on the go.

What is Fixed Wireless Access?

Fixed wireless access (FWA) uses 5G cellular technology instead of fiber to provide high-speed broadband internet access powered by antennas installed at the service location such as the home or office. FWA promises to deliver gigabit internet speeds at a fraction of the time and cost of cable and fiber installations. As with a traditional broadband model, routers will then distribute the bandwidth as needed. FWA is ideal for locations where fiber cannot be laid out and with applications that require low latency, or low network delay, because the antennas quickly communicate with nearby base stations with transceivers that act as a data transfer hub.

FWA offers several advantages to traditional installations

Lower cost – Existing high-speed internet connections can be quite expensive to install and maintain, especially in dense urban areas (high traffic) and sparsely populated rural areas (large open spaces). 5G and FWA require much less in terms of physical infrastructure, which will enable fast, reliable services for areas that had slow or no service before.

Low latency – Lower latency will substantially reduce lag and help improve streaming applications like online gaming, video calling, and interactive live sports experiences, among others.

eMBB – FWA will help provide additional infrastructure for a successful enhanced mobile broadband (eMBB), which provides a network with seamless cellular connectivity that can handle capacity for peak data rates in large crowds plus users on the move.

Low energy use – Compared to cable connections, FWA 5G requires relatively little energy to connect transceivers to antennas and transmit the data between.

Provider competition – A common complaint of households, especially in suburban and rural areas, is that they are limited to just one internet service provider. When service speeds are slow and unreliable, consumers have no choice to switch providers. FWA service will improve reliability, speed, and it may prompt a rise in provider competition as service areas expand.

Challenges in FWA deployment are slowing a full roll-out of the technology

Configuration debate - While FWA seems like a no-brainer next-step for operators and service providers, there are a number of challenges that are limiting its deployment. Because some forms of FWA require direct line-of-sight from the transceiver to the antenna, there is some debate over what configuration is best in areas such as city centers with widely varying building heights and in suburban areas with uneven terrain. Some FWA configurations will not require direct line-of-sight but will introduce other challenges such as limited scan range or spectrum availability.

Upfront costs - Further, while FWA will be less expensive overall, the upfront structural costs can be significant when FWA-specific hardware is in the early stages. Some service providers are in no hurry to implement FWA and are waiting until the technology and hardware matures before investing. However, FWA offers operators a means of either reaching untapped markets or delivering high-speed connectivity upgrades to existing ones, so motivation is high for large operators and service providers to embrace the technology sooner rather than later.

Urban priority - As noted earlier, FWA will be a great boon in particular for rural areas that are difficult to cover with traditional broadband. However, 5G is first being deployed in more densely packed urban environments, which means that while the use case is strong for rural locations, the infrastructure is being prioritized for early rollouts elsewhere.

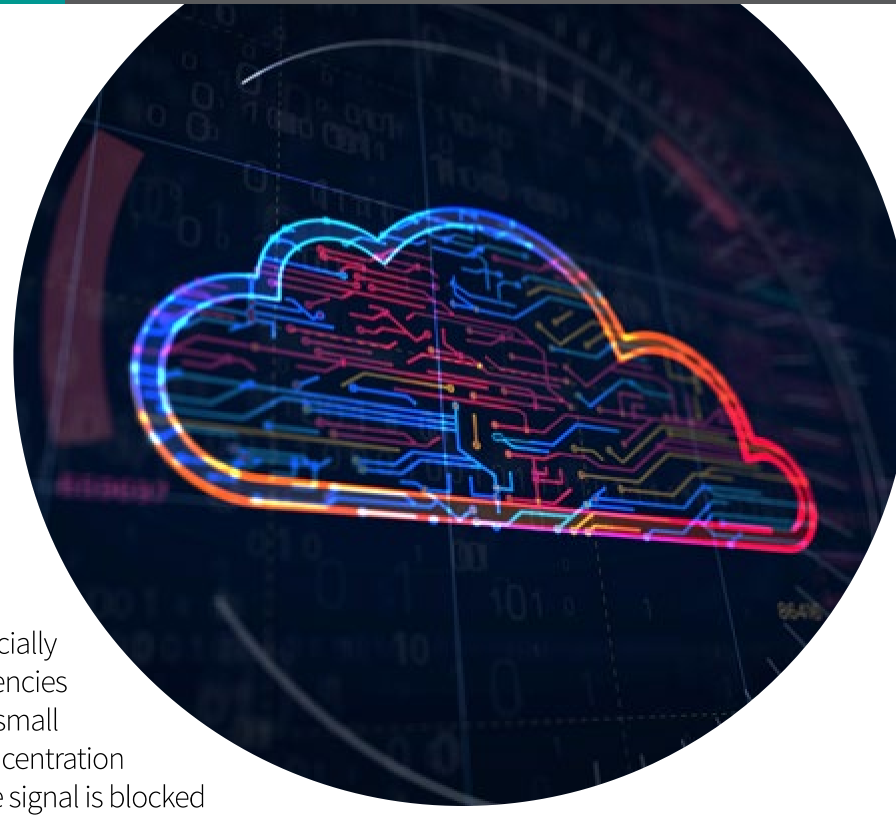
Community eyesore - Consumers have voiced concern over the eyesore of large transceiver antennas on city infrastructure such as street lamps and utility poles, as well as an antenna on the exterior of every serviced home. However, many transceivers will be mounted on existing cell towers and the antennas are similar in size to cable TV satellite dishes—all existing “eyesores” in our connected world.

Operator understanding – To correctly dimension a FWA base station that supports multiple homes, operators must understand the number of people in each household, usage patterns, peak hours, and potential non-FWA users on that same base station.

FWA gaining traction despite these challenges

Early signs are that 5G FWA is gaining traction, with a growing product ecosystem and an increasing amount of trial and deployment activity by operators. Growing revenue outside of the base market is an evergreen challenge for operators, and this is achieved by building networks that offer potential subscribers something better than they currently get.

With customers already demonstrating an appetite for higher-speed broadband, FWA could prove to be a strong new revenue stream for service providers in some markets, but the path is not easy—success in FWA will take time to learn and a willingness to invest.



What are small cells?

Small cells are very small base stations that break up a cellular network into smaller pieces, increasing the macro base station's data capacity, speed, and network efficiency at the edge. Adding small cells to an existing network is a component of network densification, a trend that increases capacity in networks in order to meet the needs of growing broadband demand at a relatively low cost.

Small cells are typically used in densely populated urban areas including indoor and outdoor locations, busy intersections, sports venues, shopping malls, transit hubs, and tourist areas. Small cells are here to help large existing cell towers handle the larger data packets that come with increased video, gaming, and live stream consumer mobile activity. With 5G, that demand will be even greater.

While small cells can support any mobile network technology, 4G or 5G, small cells are especially crucial for 5G networks operating on high-band, or mmWave, frequencies. High-band frequencies are fast and powerful, but they often cannot penetrate walls or buildings. Small cells have a small radio footprint, so for mmWave deployments, small cells are perfect for providing a high concentration of 5G power in a small urban area. Small cells also relay the mmWave signal to the user if the signal is blocked by a solid object. Mobile operators launching their 5G networks using mmWave spectrum are especially eager to install small cells throughout their coverage areas and have launched public awareness campaigns as well as lobby campaigns to help gain approval for small cell installations.

Challenges in small cell installation

The most prevalent challenge in small cell technology is not the technology itself, but rather public opinion surrounding the installation of what many consider a potential community eyesore. While most small cells are being installed on existing structures such as light poles and roofs, and are therefore largely unnoticed, there are some cases where a new pole must be installed. Power sources for the small cells are also a concern, as many installations may not be able to tap into existing utility connections.

And while operators can certainly install their own small cell on a shared pole, there is further public concern that multiple small cells in the same location will be unsightly. Some US cities are pushing back on small cell installation, using lengthy and complex permitting processes as a way to deter operator installation. However, in the US, the FCC ruled in 2018 that cities cannot block small cell installation nor charge excessive fees, which has helped relieve roadblocks for operators. Despite this ruling, not all cities are prepared for these considerations as new technologies outpace public understanding, and the learning curve varies from city to city.

In the UK, the Electronic Communications Code took effect in 2017, making it easier for network operators to install and maintain network apparatus on public and private land, yet cities are careful to minimize disruption to the public. Councils work closely with small cell network providers to approve site designs and expedite the planning process. UK mobile operators are also working together to develop significant cost reductions in small cell configurations through a shared model in which the operators share not only a physical location but also backhaul fiber link and antennas.

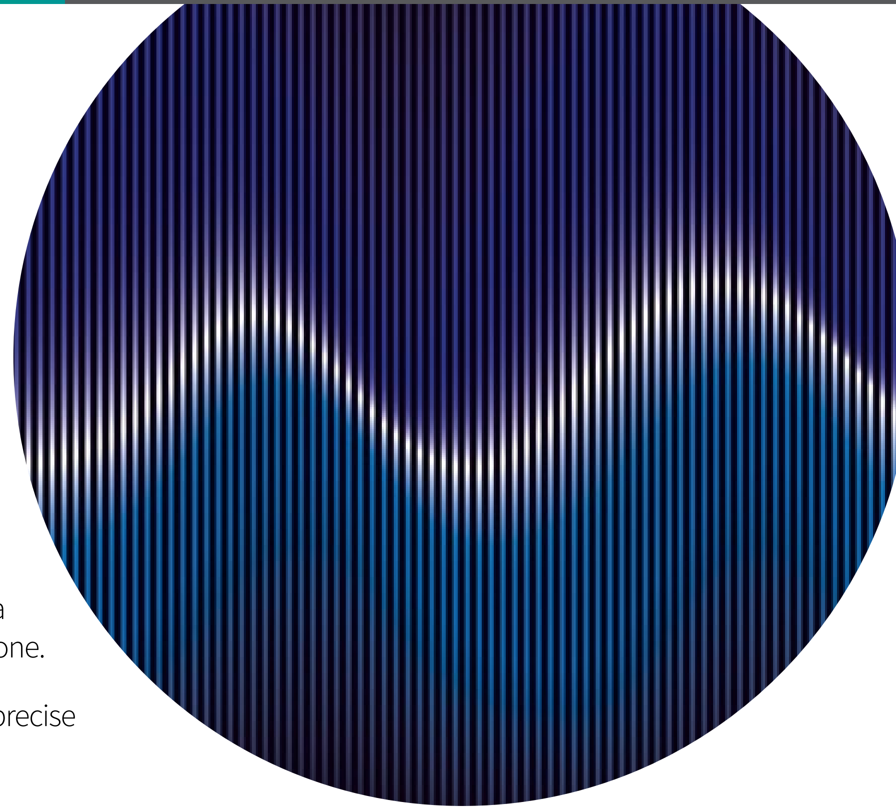
While the UK is indeed taking a more collaborative approach to small cell installations, it has not been altogether a smooth road. Just as in the US, some citizens voice concerns regarding the eyesore of small cell installations, compounding the general apprehension surrounding 5G's feared impact on health. 5G deployment and adoption has been an uphill battle in many ways, and small cell installation is no exception. For more information on 5G and health concerns, download our comprehensive eBook 5G and your health: Misconceptions, realities and benefits. As our eBook shows, there are no known health impacts tied to 5G.

There are other potential challenges that can be introduced when using small cells, which typically have different transmitting power and radio propagation characteristics compared to a macro cell. For instance, any time a repeater such as a small cell is added to a network, the increased noise caused by overlapping signals can inadvertently degrade the consumer experience. To offset this issue, networks are increasingly utilizing advanced interference mitigation methods, such as multi-cell synchronization and/or auto-adjustment of transmission power to decrease noise where needed and ensure the best end-user experience.

The future of small cells

For most experts, small cells are a key component of 5G delivering on its promises, and with the launch of technologies such as massive MIMO, small cells are critical. For 5G, network operators will deploy small cells as quickly as possible in order to further their densification strategies, and consumers may not realize that their appetite for data and fast speeds will not be satiated without the powerful heterogenous network architecture that macro base stations, small cells, advanced antenna array, massive MIMO, and beamforming will create.

5G will fundamentally change the ways we communicate and operate in our daily lives, and with that fundamental change comes considerations that may pain some to accept. There will be more antennas, more wires, and more small cells—but it's likely these will be absorbed as part of the everyday landscape just as large cell towers have over the past 20 years.



What is beamforming?

Beamforming is a key component of 5G and massive MIMO that uses advanced antenna technology to focus a wireless signal in a precise direction instead of across a wide area.

Imagine walking down a busy city street and enjoying a consistent and strong 5G signal as you grab a coffee, walk into an office building, and get on an elevator. While finding strong service within a building in a crowded city center can be inherently challenging, beamforming can make it possible to experience consistently smooth service regardless of a user's external conditions, whether geographical, architectural, or topographical.

Signals generally originate from towers and are spread across a wide range, making it difficult for those signals to be consistent (whether good or bad), but beamforming creates a concentrated, direct signal from a tower and focuses that signal directly to a user's smartphone.

Like a laser beam instead of a floodlight, beamforming allows a cellular signal to travel to a precise location rather than over wide area, like a traditional signal.

In a massive MIMO system, in which multiple radio antennas are used at both the tower and the device, beamforming allows signals to radiate at both horizontal and vertical angles from network towers toward mobile users, creating a type of "3D" effect to provide a more direct connection that is both faster and more reliable than a typical cellular signal.

While beamforming techniques have been used for decades (most recently for Wi-Fi and 5G) and were first introduced to improve sonar capabilities during World War II, beamforming is becoming central to the world of 5G. Beamforming is especially important when it comes to millimeter wave (mmWave) spectrum signals, which are primarily used in dense urban areas and are incredibly fast but don't travel very far or penetrate solid objects well. Millimeter wave signals are also particularly vulnerable to signal blockage, with even a user's hand capable of obstructing mmWave signals.

However, beamforming can mitigate that vulnerability and help generate stronger, more reliable connections in busy urban environments where finding strong service can be problematic. The use of beamforming also makes it less likely to encounter interference from other signals travelling through the airwaves.

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Key benefits of beamforming include:

- Faster connectivity for consumers.
- More reliable mobile connectivity when users are on the move.
- Better signal quality, which means information travels faster and with fewer problems.
- Reduced interference from other users.
- Signals aren't "wasted" due to the focused nature of beamforming.

Beamforming clearly has many tangible benefits, but it's a complex undertaking that also has challenges and obstacles. Some of those obstacles include:

– Multiple signals are sent to a receiver, and depending on the location of that receiver, the signals could work against each other if not properly implemented.

– The hardware and software required to launch and maintain an antenna system that utilize beamforming comes at a high cost.

– Beamforming can be impacted by many external factors such as outside temperature and humidity, as well as from physical objects surrounding antenna arrays that could cause signal interruption.

Beamforming and other supporting technologies of the 5G era will prove crucial as we move closer to 5G ubiquity. As network operators continue to invest in and improve 5G infrastructure over time, beamforming could change from a cutting-edge technology to just another part of the everyday 5G experience, working constantly behind the scenes to improve the end-user experience.

Supporting technologies and more

What is backhaul?

What is ultra-wideband (UWB)?

What is Dynamic spectrum sharing (DSS)?

What is 5-carrier aggregation?

What is massive IoT?

What is latency?

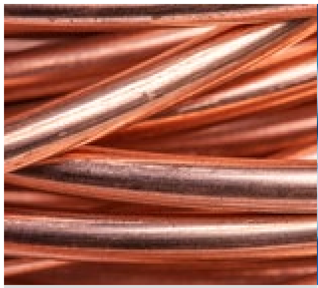
What is enhanced mobile broadband (eMBB)?

What are mission-critical applications?

What is backhaul?

You likely know that your cell phone is basically a portable radio. When you make a call, you're sending radio waves over the air and connected to a cell tower. But what you might not know is that there's more to the story after your signal connects to the tower. This is where backhaul comes in. It's the next stage to connection, and it's critical to moving your call from the tower to the global internet at the network's core. **Backhaul essentially refers to the portion of the cellular network between data centers at the core and the subnetworks at the edge.**

Technology options for mobile operators vary, and what technologies are used for a successful backhaul infrastructure depend on many factors including coverage area, topography, population, and more. Backhaul technology options include:



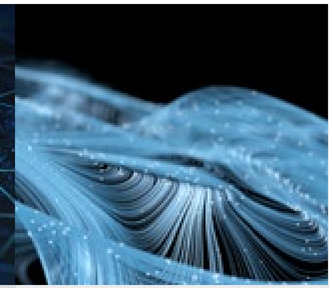
Copper lines
This was the primary backhaul technology for 2G/3G networks, but with 4G/5G deployments, copper has been replaced mostly by fiber.

Fiber optic lines
While fiber can largely withstand bandwidth demands, it carries a significant cost and time requirement for installation and maintenance.

Wireless/microwave
Fiber is often the preferred choice for operators, yet wireless/microwave is the most common backhaul technology because of its capabilities, lower cost, and ease of deployment.

Satellite
This solution is used mostly for remote areas and sometimes for temporary measures, and it can deliver strong downlink and uplink throughput but struggles to deliver strong latency times.

Wi-Fi
The use of Wi-Fi for backhaul is an emerging solution in its early days, and it suffers from obstacles ranging from licensure to privacy issues to limited range.



Integrated access backhaul (IAB)
IAB allows operators to install 5G transmitters in locations where they do not have fiber connections, allowing the antenna to backhaul traffic via wireless link.

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These technologies can work together to deliver the quality of service that users expect (and require). Quality of service expectations include:

- Reliable and robust network timing and synchronization
- High capacity for fast end-user speeds
- Adequate network availability
- Acceptable accommodations for operations, administration, maintenance, and provisioning (OAM&P) requirements

How 5G impacts mobile backhaul

Consumer demands for data, bandwidth, speed, and capacity are increasing around the world, and those demands will continue to grow with the launch of 5G in more locations (and as more users purchase 5G-enabled phones). Not only are consumers accessing the mobile network more often, they are also watching more videos, downloading larger files, and performing other tasks they previously would not have dared without a Wi-Fi connection. In order to keep up with consumer demands, packet-based backhaul infrastructure is expected to dominate the entire global network infrastructure with the ubiquity of 5G.

Operator considerations for backhaul requirements

Mobile operators are investing in their backhaul infrastructure more and more in efforts to prepare for the ubiquity and growth of 5G. Mobile backhaul networks are critical to the health of a network's overall strengths and capabilities—and, ultimately, that network's success in meeting the expectations of data-hungry consumers.

A 5G network that still uses copper lines for backhaul, for instance, isn't making the most out of that 5G signal. It's like running a relay race with the sprinter handing the baton off to a power walker in the final leg. Speed in that last leg is just as important as the speeds leading up to that point. Thusly, network optimization to improve the end-to-end pathway must include upgrading backhaul as well.

There is no one-size-fits-all solution for mobile backhaul, and new solutions are beginning to emerge. Mesh, multi-access edge computing (MEC), Cloud RAN, and other architectural configurations are expected to help backhaul networks keep up with the demands of our increasingly connected world and help the operators who are continuing to innovate in order to keep up.

What is ultra-wideband (UWB)?

Ultra-wideband (UWB) is a radio technology that uses low energy levels for short-range, high-bandwidth communications >500 MHz. While not directly connected to 5G, UWB is an important enabling technology for greater data throughput and better location precision for high-speed wireless network applications. In our increasingly connected world, UWB is an exciting connectivity component that will provide opportunities for better and faster wireless communication.

The high-precision location services of UWB will be a key benefit for end users. For instance, imagine using your phone to find lost keys or other important items around the house, with your phone acting as a real-time detector that beeps faster the closer you get. Imagine also that you want to share a picture with a friend at a crowded event, and you aim your phone at their phone to quickly and safely transfer the file. You also want to start your car, turn the seat warmers on, and defrost the windshield while getting ready to leave. UWB chips in your phone will enable these sophisticated positioning abilities with its unprecedented location technology.

UWB-enabled technologies will potentially touch a wide variety of industries, from defense to automotive to public safety and everyday mobile transactions. The advantages of UWB should be felt the most in applications used over short distances that require high precision (such as starting your car or finding your lost keys). The most popular use cases include:

- Faster communication between PC peripherals and office equipment like wireless monitors and printers
- Real-time location systems
- Hospital operations like vital sign monitoring, as an alternative to continuous-wave radar
- Ground-, wall-, and object-penetrating radar for military operations
- Public safety operations such as locating objects or people on subway tracks
- Automobile functionality, like digital keys, automated valet/driverless parking, automatic toll billing, and garage door access

Advantages of UWB

For many applications, precise location may not be important, and "close enough" will suffice. But for applications where exact location data matters, the precision of UWB could be a game-changer compared to older technologies like Bluetooth, Wi-Fi, or GPS. For example, UWB positioning accuracy is between 10 and 30 centimeters, whereas Bluetooth's accuracy is 1 to 3 meters and Wi-Fi is 5 to 15 meters. That is a massive difference. GPS, meanwhile, is quite accurate outdoors but suffers a great deal indoors; some GPS chips can receive enough satellite information to determine a location inside a building, but the location is not typically accurate enough to be useful. That's especially troublesome for applications in which precision is paramount.

Bluetooth and Wi-Fi depend on signal strength to determine distance: the stronger the signal, the more accurate the location. That said, signal strength can be unreliable because signals can be boosted to appear closer than they actually are, which can affect location accuracy.

With UWB, two elements play a key role in location accuracy: the distance and angle of signals. The round-trip signal time is used to determine the distance between devices. Through multiple antennas, UWB can also measure the angle the signal is arriving from, and a precise angle combined with a precise distance delivers a pinpoint location. UWB is also expected to provide security advantages compared to Bluetooth and Wi-Fi. Industry experts are buzzing with ideas of what UWB can offer because of its ability to locate and interact with objects faster, with more precision, and with greater security.

Early adopters

Currently, much focus is on how UWB can revolutionize the automobile industry, and many early adopters are operating within the auto realm. For instance, NXP Semiconductors, BMW Group, and Continental announced in late 2019 they were working jointly to implement UWB through the Car Connectivity Consortium (CCC) and IEEE to integrate vehicle, mobile, and consumer devices. Vehicle security is a primary focus, and UWB-enabled devices are predicted to replace Bluetooth-enabled car key fobs in response to keyless car thefts.

Apple was also an early adopter. The iPhone 11 series was the first to come with UWB built in. Some analysts believe that including UWB in the iPhone 11 series could signal a revolution in how people use their smartphones.

When it comes to 5G, ultra-wideband radio technology is just one component of a rapidly changing connectivity landscape that includes faster speeds, greater data throughput, higher precision, and more reliable connection.

What is Dynamic spectrum sharing (DSS)?

In short, DSS allows mobile operators to use the same spectrum for both 5G and 4G LTE services and dynamically allocate the amount of spectrum in a given area depending on the number of users. The primary benefit of DSS is that it lets operators expand 5G coverage by using existing 4G spectrum—rather than investing in new 5G infrastructure—and switching it to 5G service. It's important to note, however, that DSS cannot be used with mmWave spectrum. That is, a 4G LTE device won't be able to access mmWave spectrum, even if DSS is implemented.

Ultimately, DSS could be a catalyst that boosts 5G coverage for operators sooner rather than later, bringing the benefits of 5G to more people in more places and in a more efficient manner. While DSS doesn't increase the amount of spectrum an operator has at its disposal, DSS will enable operators to make more efficient use of the spectrum available. And as operators acquire (and utilize) more and different types of spectrum over time, DSS will offer a cost-effective means of utilizing that spectrum while ultimately increasing 5G availability.

DSS will primarily benefit operators, but end users will also see indirect benefits from DSS. In addition to broader 5G coverage (and as a result, faster 5G speeds and lower latency), users could also experience stronger 4G LTE performance in the short term because 4G LTE devices will have access to additional spectrum that had been reserved for 5G, provided that spectrum is cleared for 4G LTE usage.

5G spectrum usage in the US and UK

The real-world 5G experience today largely depends on what type of spectrum operators are using for 5G deployments. Operators in the US are using a mixture of different spectrum types, with different networks utilizing low-band, mid-band, and/or mmWave for 5G. T-Mobile is currently the only US carrier using all three for its layer cake 5G strategy. In the UK, meanwhile, all four major operators—EE, O2, Three, and Vodafone—use mid-band spectrum for 5G deployments across the country.

Mid-band spectrum, while widely used in the UK, is much more difficult to come by in the US because it's largely reserved for US government entities like the military and emergency services agencies. That said, mid-band spectrum was made available at auction in December 2020, so other networks besides T-Mobile could soon introduce mid-band to their 5G repertoires.

Mid-band is often considered a "sweet spot" of spectrum because it can deliver much faster speeds than low-band spectrum while offering much broader coverage than mmWave. To learn more about spectrum, read our article Understanding spectrum.

The following offers a quick look at the pros and cons of the three primary types of spectrum utilized for 5G in the US and UK, as well as which operators are using each type of spectrum:

Low-band spectrum

Used by all three carriers in the US, low-band signals can cover vast distances and penetrate structures well, but its speeds are comparable to those on 4G LTE.

Mid-band spectrum

A highly coveted type of spectrum utilized by all four major UK operators as well as T-Mobile in the US (thanks to its merger with Sprint), mid-band offers faster speeds and broader geographical coverage than low-band, with decent penetration of buildings and other structures.

Millimeter wave (mmWave) spectrum

Verizon currently uses mmWave for its 5G (in addition to low-band with DSS), while AT&T and T-Mobile utilize mmWave in combination with low- and/or mid-band spectrum. Millimeter wave signals can't travel nearly as far as low- or mid-band signals, but mmWave is capable of providing much faster speeds, theoretically as high as 5.0 Gbps.

DSS gaining popularity in the US and UK

AT&T was the first operator in the US to use DSS, enabling the technology for certain 5G devices (Samsung Galaxy S20 5G, LG V60, and the Samsung Note 10+) in areas of North Texas. In a blog posted on AT&T's website in June 2020, Igal Elbaz, SVP of Wireless Technology at AT&T stated: "Simply put, DSS allows carriers to share the same channel between both 4G and 5G users simultaneously. It turns up 5G without turning off LTE – creating a seamless experience for users, and a graceful spectrum transition for carriers."

Verizon began utilizing DSS with its low-band spectrum in late 2020, in addition to its mmWave 5G solution. Verizon's usage of DSS helped the carrier launch its nationwide 5G service, expanding its 5G footprint. Mobile operators in the UK have not used DSS.

While DSS is clearly gaining traction in the US, it should also help operators (and by extension, end users) in the UK and elsewhere, and at the end of the day, it's likely that every major operator in the US and UK will eventually use DSS.

What is 5-carrier aggregation?

In effect, carrier aggregation (CA) is a tool in a mobile carriers' toolbox that can be used to provide faster speeds to subscribers. While many factors can influence data speeds, carrier aggregation is an important component of the real-world, end-user speed experience that should continue to play a significant role moving forward.

How does it work? Carrier aggregation lets mobile carriers combine separate channels to increase bandwidth and provide faster speeds than could be achieved with just a single channel. To use an analogy, think of channels as invisible "pipes" that transmit information; the larger the pipe, the greater the capacity, and the more information that can be delivered. Carriers can create bigger "pipes" by combining more than one channel, which allows data to travel through those pipes at faster rates.

Carrier aggregation currently allows for the combination of up to five channels, and in general, the more channels that can be combined, the better. It's important to note, however, that in order for a carrier to combine five channels to utilize 5CA, a carrier must hold spectrum in five channels.

It's also worth noting that carrier aggregation isn't specific to 5G; it can also be used for 4G LTE. That said, we're including this article in our 5G FAQ series because 5CA does have implications on 5G.

5CA in practice: AT&T's 5CA led to faster speeds in early 2020

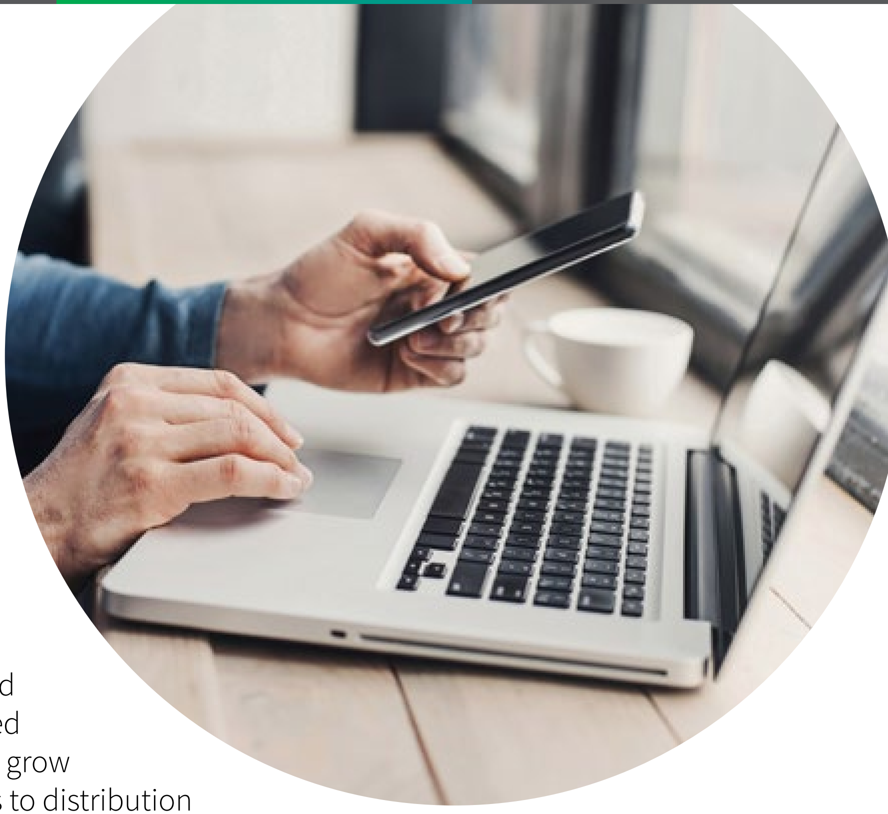
As an example of how 5CA can lead to faster speeds, AT&T was the only carrier in the US using 5CA on a wide scale in early 2020, and its speeds improved in 51 of the 55 cities we tested in the first half of 2020 before we paused scouting due to the pandemic. However, while 5CA certainly played a role in the carrier's boost in speeds, it wasn't the only reason for AT&T's improved results. AT&T also added new cell sites in cities across the US and increased the efficiency of the five channels it combined by utilizing 4x4 MIMO (Multiple Input Multiple Output) technology.

Looking ahead to carrier aggregation and 5G

Carrier aggregation can be used for both 4G LTE and 5G, but until 5G availability reaches a point of ubiquity in which it's the default technology for the vast majority of users, the primary effects of carrier aggregation will apply to 4G LTE performance. That said, the future of carrier aggregation and 5G is filled with interesting possibilities, especially once standalone (SA) 5G architecture becomes the new normal.

While T-Mobile introduced its standalone (SA) 5G service at the beginning of August 2020, AT&T, Verizon, and all four UK operators are currently using non-standalone (NSA) architecture for 5G, which places 4G LTE at the foundation of the end-user 5G experience. However, once SA 5G deployments become widespread and 4G LTE is no longer the backbone of 5G, the need for CA on 4G LTE networks could become obsolete, and carriers will be able to add bandwidth for 5G by combining channels across spectrum types dedicated to 5G. For instance, a carrier could in theory add capacity by combining mmWave spectrum with low- or mid-band spectrum.

As 5G continues to expand around the world, carrier aggregation will remain a tool that the carriers can use to increase capacity, boost speeds, and provide end users with a smooth connected experience in general.



What is massive IoT?

Massive IoT is an enormous number of IoT sensors and devices communicating with one another. Today, through 4G LTE-powered IoT, you may ask your personal assistant to send driving directions to your mobile phone, answer the doorbell of your home while at the office, or pre-heat your smart oven while checking out at the grocery store.

With 5G, however, the IoT will ramp up to a massive capacity previously unimaginable. With the high speeds, ultra-low latency, and increased bandwidth of 5G, the IoT will be virtually everywhere. The number of "things" connected will be tens of billions within the next few years, and yet full-scale massive IoT isn't expected for another ten.

So, what is possible with massive IoT? At this stage, new use cases are imagined every day. Experts predict that massive IoT sensors and devices will touch every industry and every home. For example, when we sit down to eat dinner, massive IoT will have played a hand in every stage between the farm and the table. From sensors that help farmers grow crops, to real-time monitoring of the transportation systems used to haul those goods to distribution centers, to the smart factories that produce your smart appliances, to the voice-controlled operation of those appliances, the entire process is digitized and in constant communication. This ubiquitous IoT experience will also apply to office spaces, public transit, construction sites, utilities infrastructure, security systems, retail stores, and beyond.

IoT capacity now and in the future

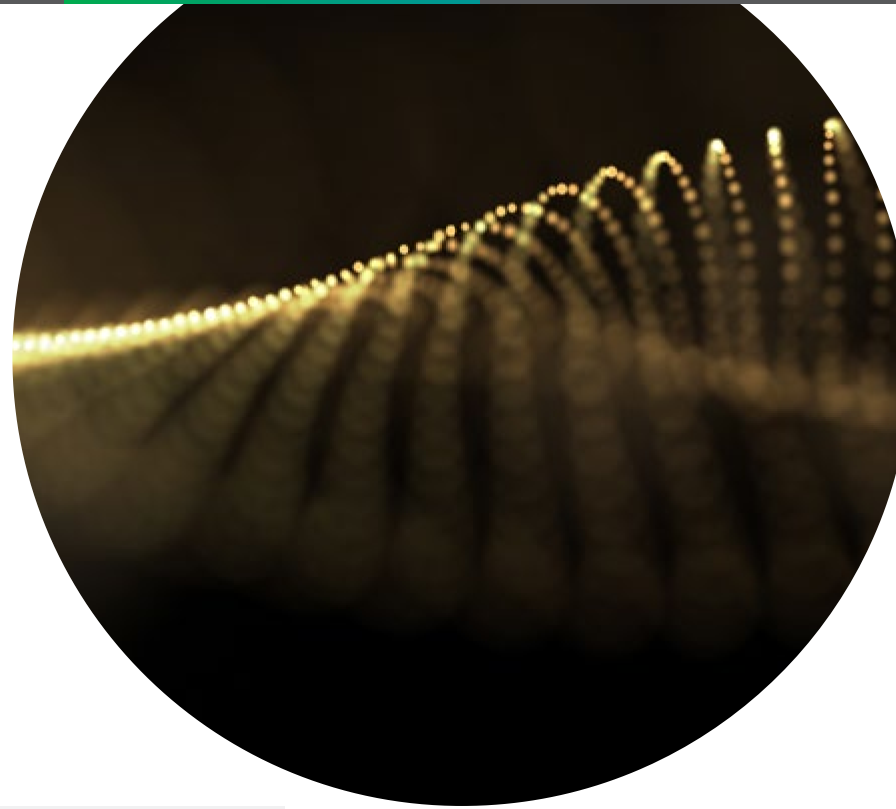
The standard set for 5G-enabled IoT is 1 million devices per square kilometer at minimum. In contrast, the 4G LPWA standard supports only 60,680 devices at the same coverage area. As we move into massive IoT, there are a few key considerations:

- **What is a connected device?** Currently, connected devices include only electronics, but in the future, it will expand to everything living and non-living.
- **How long is the device connected?** Those connected devices will vary in their configuration—some will not need to actively "talk" to the network, but rather remain attached to the network for a long time while periodically confirming its presence. This means that the network will need to be able to support a large number of "dormant" devices as well as "active" devices. The period of dormancy can vary based on the use case of the device.
- **Where are the devices are connected?** Some will be mobile, like for example, wearables such as fitness trackers. As a person runs across several serving towers, the connected will transfer in and out. With the popularity of wearable devices, the network will need to be dimensioned such that thousands of devices are accommodated as they move across a service area.

Combining these three considerations of type of device, time connected, and the movement across the network, the current capacity of 60,000 per km2 can quickly run out. However, as of now this capacity is quite sufficient for the number and type of IoT devices in use.

Why 5G matters for massive IoT

As use cases increase and the 5G network coverage area continues to expand, it is difficult to speculate when the scale will tip and 5G will be necessary to accommodate the IoT, but it will eventually happen. 5G capacity and coverage will be critical for the growth to 1 million connected devices per km2. Right now we can only imagine what 5G-enabled massive IoT will look like as the world builds the infrastructure necessary to bring it to fruition.



What is latency?

Latency refers to the response time, or delay, between a user request and an action being taken by a simple function, application, or machine.

The ultra-low latency that 5G promises will eventually transform everyday life through reduced lag time—from improving the online gaming experience (which we're already seeing happen in some areas) and live sports streaming to enhanced AR/VR to life-saving medical procedures. Reducing the lag time between request and action will transform manufacturing, remote healthcare, smart grid management, drone operations, autonomous cars, and more. In short, it is the key enabling factor for the 5G functionality of our wildest imagination.

Latency goals and expectations

In 2020, the International Telecommunication Union (ITU) established the following minimum latency KPI requirements:

- 4 milliseconds (ms) user plane latency (actual results experienced by users).
- Control plane latency of at least 20 ms or less (signaling and control functions).

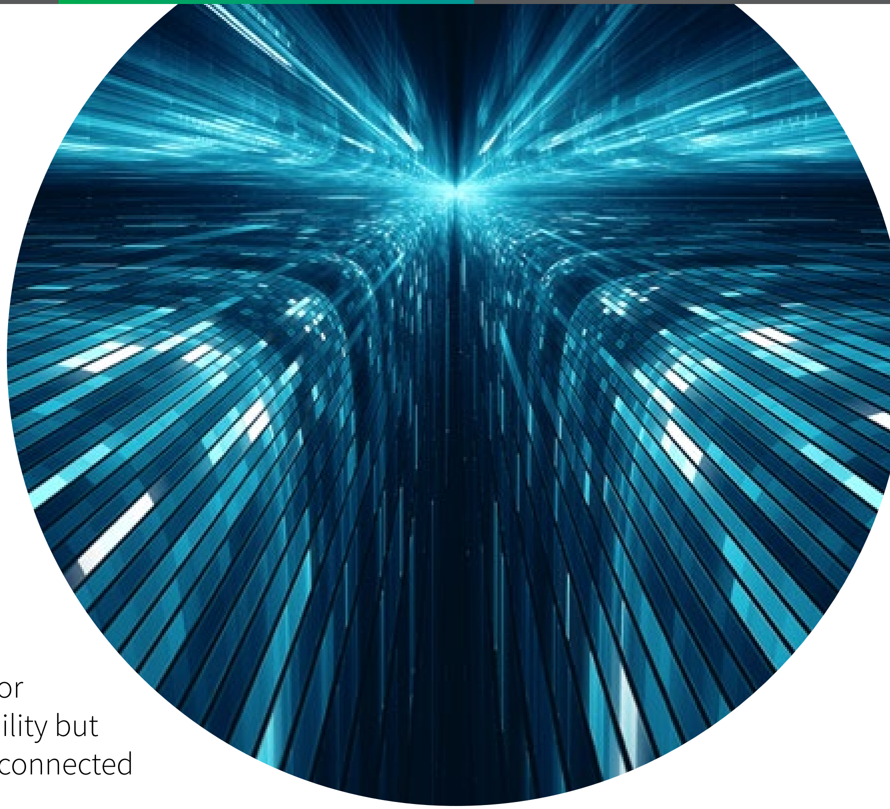
Obstacles to achieving those goals remain

In order to meet the KPIs set by the ITU, there is more work to do on 5G network infrastructure. Most current 5G deployments utilize non-standalone architecture, in which (and in simple terms) LTE is still the master, and 5G cell towers are added based on coverage and used based on a user's need for data. The background architecture—from the tower to the IP network via all telco infrastructure nodes—is still LTE-based.

To grasp the whole picture for 5G latency, it's important to understand what upswitching is and why it is fundamental to reaching these KPIs:

- 5G is not the default mode for end-user devices with NSA 5G implementations, even in areas covered by a 5G network. As coverage and availability expand, 5G mode will eventually become the default, but for now, only large, resource-draining data tasks will take advantage of 5G service.
- This means that, in simple terms, if an end user is on LTE by default and then initiates a data task that requires 5G, there is additional time needed to "upswitch" from LTE mode to 5G mode before that task can be completed.
- As long as upswitching is necessary, download latency will be affected at the beginning of that data task. Upswitching time will impact the majority of real-world use cases and result in slower latency. In those scenarios, differences in vendor implementations and network implementation by MNOs will become even more significant.

Upswitching time will impact the majority of real-world use cases and result in slower latency. In those scenarios, differences in vendor implementations and network implementation by MNOs will become even more significant. As more 5G towers become the master, upswitching will become less common and latency will ultimately decrease to levels that will enable the performance potential of 5G.



What is enhanced mobile broadband (eMBB)?

Enhanced mobile broadband (eMBB) is, in simple terms, an extension of services first enabled by 4G LTE networks that allows for a high data rate across a wide coverage area. eMBB will provide the greater capacity necessary to support peak data rates both for large crowds and for end users who are on the move. For data-hungry consumers and enterprises, this is the key to a faster, more reliably connected experience across many applications.

Dense usage and high mobility

Depending on the use case, eMBB will need to adapt to difference scenarios. Where there are many users who are not moving quickly, like fans at a sporting event, the network will need a high traffic capacity but a lower mobility requirement. However, for passengers on a commuter train, for example, there will be a greater demand for mobility but at a lower capacity. In any case, seamless coverage is the ultimate goal: users can get connected and stay connected as they move anywhere within the eMBB service range.

While early use cases will focus on the consumer entertainment market, like faster multimedia downloads without the use of Wi-Fi, eMBB will also enable cloud access while people are on the move, allow field employees to communicate with the home office, help create immersive AR/VR experiences, and support 360° streaming video—all with low latency and reliable, uninterrupted connections.

The path to fulfillment

eMBB promises a better and seamless user experience by delivering faster data speeds and greater coverage. For eMBB to be successfully launched and maintained, 5G must deliver in three key areas:

Capacity

Access to broadband (at least 100 Mbps) will need to be available in both indoor and outdoor locations in densely populated areas. Examples include congested city centers, public venues like stadiums and transportation hubs, and even large office buildings. This will improve upon the current scenario where 4G struggles during periods of network congestion and slows to speeds close to that of 3G.

Connectivity

Users must have consistent broadband connectivity everywhere. This eliminates the need to jump onto private Wi-Fi or joining to the 4G LTE network as backup.

Mobility

As people move throughout their day from home to work to meetings to recreation, they must remain connected. This includes public transportation as well as personal and work vehicles.

Looking ahead

On the whole, eMBB is a step towards full and seamless connectivity at home, at the office, and everywhere in between. It will provide the building blocks for a network that powers smart homes, smart offices, smart cities, and instant entertainment at our fingertips.

What are mission-critical applications?

Simply put, mission-critical applications are those that must work as designed and expected every time without failure, error, or downtime. Traditionally, the designation “mission-critical” was applied to services in healthcare, emergency response, and power systems – industries in which failure may mean loss of life. For example, with remote surgery and autonomous vehicles, milliseconds will matter.

However, with the advent and expansion of the IoT and now 5G, mission-critical applications are becoming more common and are influencing industries from manufacturing to smart cities and public safety and more. To enable mission-critical applications, network infrastructure must offer certain characteristics, including:

The value of mission-critical applications

When accuracy and response time and the exchange of crucial information is the difference between life and death, there is no question that mission-critical applications are beneficial. But what about applications that are not directly linked to life-saving measures? What does this mean for manufacturing, construction, municipal services, farming, and other industries? While examples of mission-critical applications vary a great deal by industry, the benefits are similar:

Real-time monitoring
Using sensing equipment and connected devices strategically placed in a particular system, systems analysts can readily identify status and quickly respond to anomalies in the data.

Improved decision-making
For enterprises, a comprehensive solution can break down data silos to share valuable insights across end-user types and leadership roles.

Real-time and predictive analytics
Many applications include artificial intelligence and machine learning, which can immediately flag issues and even predict future system breakdowns based on historic data and real-time conditions.

Operational cost savings
When system issues are discovered faster and with greater accuracy, problems can be resolved faster and therefore the impact to productivity is reduced.

Where we currently stand

The major enabling factors for mission-critical applications are ultra-reliable low-latency connectivity (URLLC) and network slicing, which is essentially the ability to prioritize data transfer based on importance. As of now it is estimated that we are 5-10 years away from a 5G infrastructure that can support these fundamental requirements. For more information on what is needed to enable mission-critical 5G and IoT, IHS Markit has produced a short video explaining the 5-to-10-year outlook.

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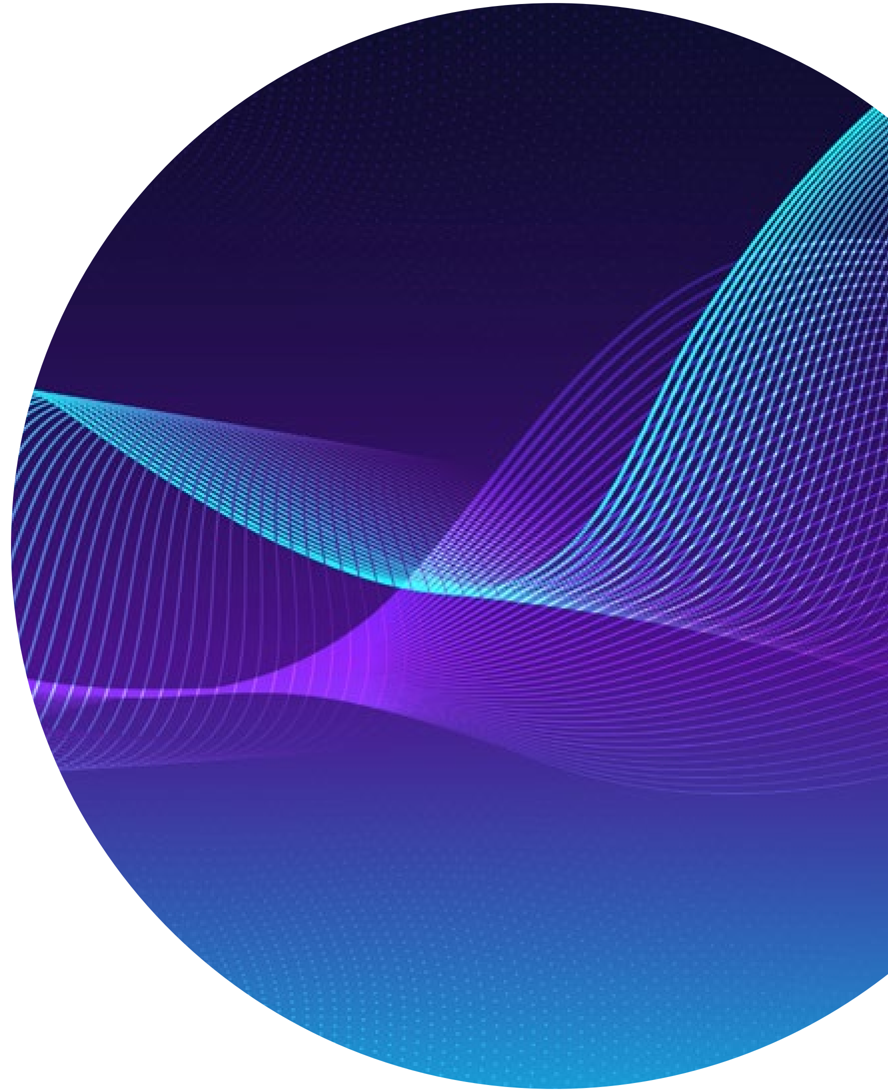

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