IHS Markit®

The promise and potential of 5G:

Evolution or revolution?

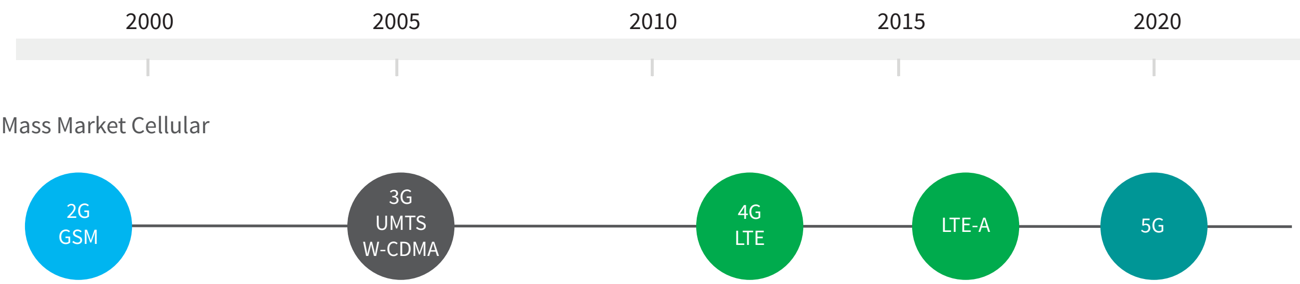
Excitement, confusion, and incredible possibilities

As the first wave of commercial 5G deployments start to take hold, excitement is building for what 5G could mean for our increasingly connected communities. Without question, 5G is helping set the stage for incredible changes, but it remains a confusing landscape, with varied and sometimes conflicting interpretations of what 5G is and what to expect from it. This confusion is impacting not just consumers but also complicating the industry's ability to measure itself against a standard set of 5G expectations and requirements.

To give consumers a complete picture of the 5G landscape, we've put together an overview of what 5G is, what challenges remain, and why there's so much excitement about the future of 5G networks.

> There are varied and sometimes conflicting interpretations of what 5G is and what to expect from it.

The path to 5G



> The full range of planned 5G capabilities will not be available during initial 5G launches and will be implemented in a phased approach over the next few years.

What is 5G and is it already available?

At the most basic level, 5G simply stands for the fifth generation of mobile network technology and is the successor to current 4G LTE standards. But the 5G story isn't as straightforward as that simple definition implies. In an effort to maximize mind and market share, some companies have tried to position their products and solutions by offering non-standard definitions of "5G." This isn't a new phenomenon, and the industry has experienced this type of positioning before – most recently and notably in the last technology transition from 3G to 4G. It does, however, make it difficult to have any meaningful conversation around 5G without first establishing a more objective, standards-based definition.

Additionally, while the technical standards for 5G are lofty and will eventually enable applications that hold the potential to transform everyday life, open new business opportunities, and enable new business models, the full range of planned 5G capabilities will not be available during initial 5G launches and will be implemented in a phased approach over the next few years. This phased approach between the promise of what 5G will eventually enable and what is actually ready to be realized during these initial launches has caused some confusion among potential customers.

Interest continues to grow

The number of articles that featured 5G prominently, as tracked by IHS Markit:

35,686
articles in 2018

98
articles per day

248%
increase from 2017

In short, the development of 5G is a story in the making, and while press attention and operators often direct attention to where 5G will ultimately take us, it's equally important to understand where 5G currently is and what will be available with these early rollouts.

The need for clarity

In order to optimize short-term and long-term 5G adoption, it's imperative that clarity regarding what 5G is and when each capability will be available is established for both consumers and the ecosystem. To that end, IHS Markit follows the official 3GPP definition of 5G but also believes that this description needs to be understood within the context of everyday experience and concepts.

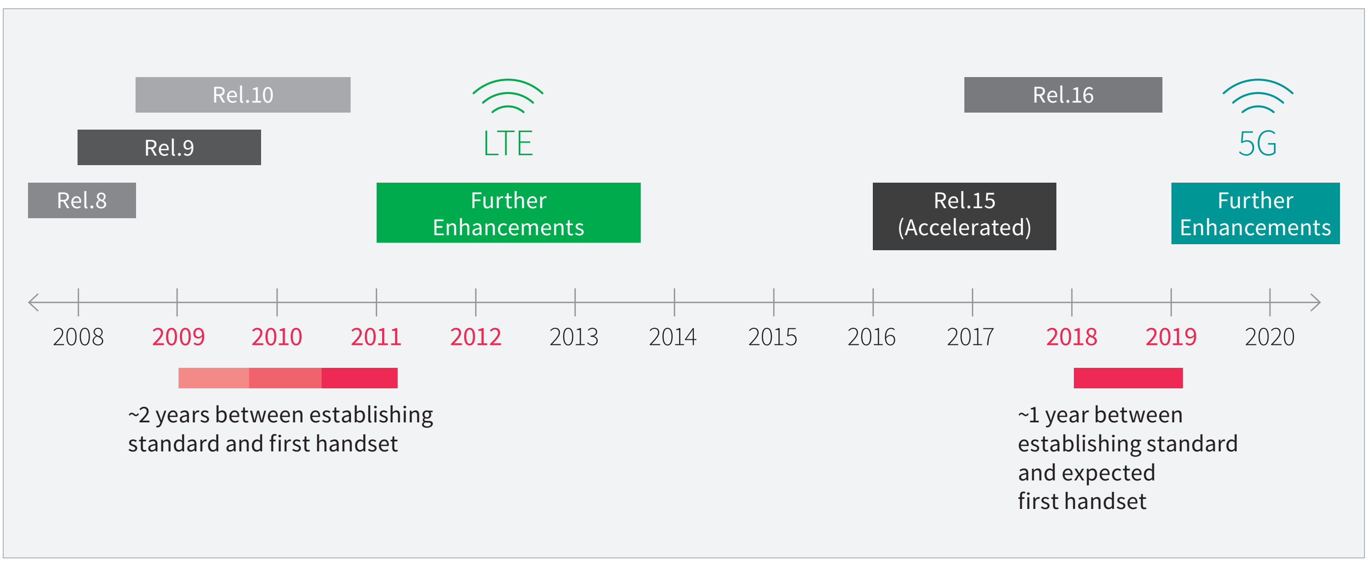
The technical definition and standards

First, the technical definition. IHS Markit defines the commencement of 5G commercial deployment with the rollout of networks and devices compliant with Release 15 of the 3GPP specifications corresponding with NR Phase 1.

Key characteristics of Release 15 include but are not limited to:

- Non-standalone mode of operation (e.g., utilizing LTE core and LTE as an anchor carrier)
- Component carrier bandwidths of up to 100 MHz in spectrum below 6 GHz; up to 400 MHz component carrier bandwidths in spectrum above 6 GHz
- Support for carrier aggregation
- Support for both digital and analog beamforming
- Variable subcarrier spacing

As with previous generational rollouts, IHS Markit expects that 5G will continue to be enhanced through the implementation of Release 16 NR Phase 2 compliance as well as subsequent releases of the standard (see figure below for dates when standards were defined and when handsets then became available).



Why 5G matters

The development of 5G is coming at a critical juncture. The importance of fast and consistent network connections has never been greater. Whether at work or at home, enterprise and consumers alike demand a fully connected experience, wherever they are, whenever they need it. Typical mobile activities that require buffering on today's 4G-based mobile networks will happen instantaneously with 5G. But as seen below, 5G is about more than speed alone. It also ultimately promises the capacity, reliability, and ultra-low latency required for mission critical services and the growth of massive IoT.

5G-enabled mobile handsets:

37 million
in 2019

525 million
in 2023

78% of key influencers stated they expect 5G to have high to significant impact on their industries over the next twelve months.

Learn more at **https://technology.ihs.com/610403**

As our connected communities continue to grow, 5G will bring three primary benefits to consumers: **faster data speeds, lower latency, and increased connectivity.**

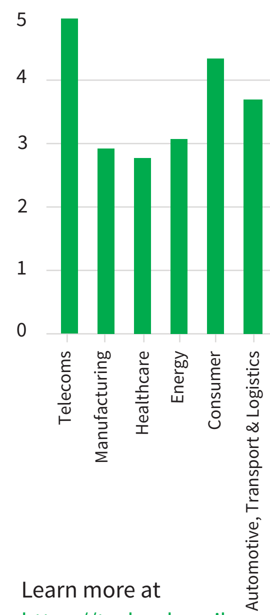
Faster data speeds

With today's 4G LTE service, downloading a high-definition movie might take 10 minutes, but with 5G technology this could take a matter of seconds. In practice, these faster speeds will allow for the seemingly instant transfer of data, allowing businesses to work quicker and more efficiently.

Lower latency

Latency refers to the response time between a user request and an action being taken by a simple function, application, or machine. The lower latency of 5G will substantially reduce lag and help improve streaming applications like online gaming, video calling, and interactive live sports experiences, among others. The manufacturing sector will also benefit from lower latency, with smarter factories gaining the ability to process more information, react quicker, and create products at a potentially cheaper cost. Lower latency will also be a key factor in sensing and command and control applications, from autonomous vehicles to smart grid management to remote healthcare and more.

5G Readiness by Vertical
(Comparative scores provided by IHS Markit Digital Orbit)



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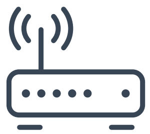
Increased connectivity

The greater capacity offered by 5G will allow networks to support more devices and enable more data-intensive tasks. From this perspective, 5G will serve as a key component in the expansion of daily connected activity.

5G will help improve existing services and provide the capability to make new use cases possible



Always-on, seamless connectivity

Substantial increases in bandwidth

Immersive entertainment and virtual reality with zero delay

Zero-lag video calls

Driverless cars

Zero-latency gaming

Uninterrupted video

IoT growth and development of smart cities, smart homes, and smart industries

Why the confusion surrounding 5G?

Part of the confusion surrounding 5G has developed because there are actually three distinct use cases for 5G: enhanced Mobile Broadband (eMBB) and fixed wireless access (FWA), Mission Critical applications, and Massive IoT.

These three use cases present at times contradictory technical requirements, but excitement for 5G is high because it aims to support these divergent needs within a single network architecture. Creating that type of umbrella architecture is a critical step toward achieving the economies of scale and technical coordination needed to make the use cases envisioned for 5G not only possible but also technically and commercially viable.

In the transitional stage we are currently at, however, the different requirements of these use cases has helped create a fragmented understanding of what is actually necessary for 5G and when 5G will be fully achieved.

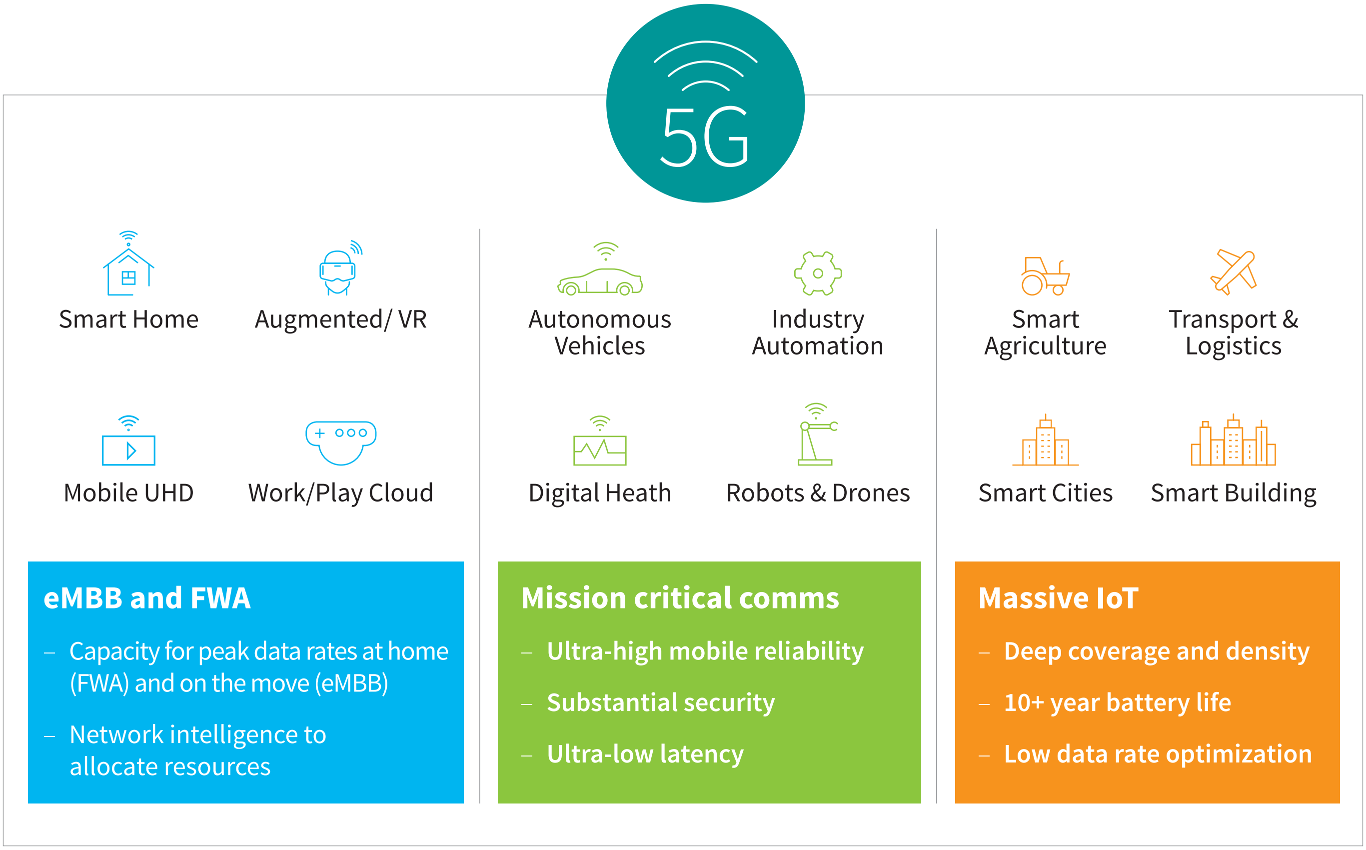
> Differing technical requirements have created a fragmented understanding of when 5G will be fully achieved.

- **eMBB and FWA**
  - eMBB is in many ways an extension of services first enabled by 4G LTE networks. eMBB promises a better and seamless user experience by delivering faster data speeds and greater coverage. To meet this goal, eMBB will need to provide both higher capacity in crowded situations and enhanced mobility coverage for commuters and others on the move.
  - FWA follows the current home broadband model but uses wireless mobile technology to deliver internet to a household, with a home router then distributing the bandwidth as needed. Current deployments utilize 4G LTE infrastructure to deliver broadband speeds up to 12 Mbps. With 5G FWA, much higher bandwidth is theoretically possible, up to 1 Gbps in some cases. However, achieving these speeds will require an outside receiver, as the frequencies to be used face challenges with propagation.

    Use cases: eMBB and FWA will help enable smart homes, video everywhere, and VR and AR experiences.
- **Mission Critical**
  - Mission critical applications require high security standards, nearly universal coverage, and a signal that supports ultra-reliable, low latency communications (URLLC). These are applications where a network failure could lead to potentially disastrous consequences.

    Use cases: Among others, mission critical applications will include developments such as autonomous cars, remote medical surgery, robots and drones, and industrial automation.
- **Massive IoT**
  - Massive IoT is characterized by huge numbers of connected devices typically transmitting data that is not delay sensitive in the same ways that mission critical applications are. Massive IoT requires deep coverage and density to support connected devices that have long battery life and send low rates of data via machine type communications (MTC).

    Use cases: Applications could include sensors that support smart buildings, smart agriculture, smart cities, and smart logistics, among others.



What the technical definition means as 5G launches and continues to develop

There's a lot of technical information to unpack within the official 5G definition and its requirements. And that's part of the problem: 5G is a technology standard, but it's not always easy to translate technical specifications into what they mean for an everyday user experience or into a clear interpretation of marketing claims.

Breaking the various technical aspects of 5G into more manageable pieces, however, helps show just why 5G is so important to the future of our connected lives and how different variations of 5G can lead to vastly different experiences for end users.

> Different implementations of 5G can lead to vastly different experiences for end users.

First steps and where we're currently at

Even though 5G includes provisions for ultra-reliable, low-latency and machine type communications, initial launches are focused on the features necessary to support eMBB and FWA. In other words, initial 5G launches are not expected to include capabilities that are to specifically or uniquely support Mission Critical and Massive IoT requirements.

That being said, this does not mean that these features are not also needed in mission critical or massive IoT applications. In fact, some early capabilities (such as those features that support AR/VR and high speed video streaming) have use cases for industrial, non-consumer applications as well. We do, however, envision a race by mobile network operators (MNOs) to meet the following minimum KPI requirements that the ITU has established for 2020:

> Bringing together market intelligence data with survey results from key industry influencers, our new Digital Orbit Intelligence Service looks at both the overall readiness and potential impact of key transformative technologies. While the anticipated impact of 5G scored incredibly high, readiness results indicate that the influence of 5G might not be felt immediately.
>
> **Learn more at https://technology.ihs.com/610403**

- A minimum sustained user experienced data rate of 100 Mbps downlink and 50 Mbps uplink (although we expect the leading mobile network operators to be well above this range very quickly, likely at launch)
- Peak achieved data rates of 20 Gbps downlink and 10 Gbps uplink
- 4 milliseconds (ms) user plane latency
- Control plane latency of at least 20 ms or less
- 99.9999% reliability

How closely MNOs meet or surpass these performance metrics will be the primary measures of comparison that we will use to benchmark performance of the various 5G networks.

Implementation varies by operator and makes a big difference

In addition to the confusion created by 5G needing to act as a unifying network architecture for three very different use cases, early implementations of 5G vary and can lead to wildly different experiences for end users. These implementation differences are first and foremost tied to what spectrum holdings different operators have available.

Spectrum, frequency, and bandwidth

Spectrum is the range of electromagnetic radio frequencies used to transmit sound and data through the air. When consumers use their cell phones, these 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.

6 GHz and mmWave are the critical tipping points

References to mmWave in 5G discussions are prevalent, but what does mmWave really mean? To help simplify this, 6 GHz can be seen as the dividing line for mmWave: while not technically accurate, practically speaking, above 6 GHz is mmWave, while below 6 GHz is not mmWave.

> 6 GHz is the tipping point, with potentially wildly different experiences available for 5G at higher frequencies compared to lower frequencies.

This shorthand matters because, when it comes to the 5G experience, 6 GHz is the tipping point, with potentially wildly different experiences available for 5G at higher frequencies compared to lower frequencies. Technically, 5G can and will operate at frequencies below 6 GHz. While this sub-6 GHz implementation of 5G will be faster than current LTE, the difference in these spectrum ranges won't be as drastic. On the other hand, the 5G experience with mmWave (aka above 6 GHz) will be markedly different.

The reason for this divergence comes back to the characteristics of spectrum itself. Remember the idea of pipes delivering information? Spectrum is crowded at the lower, sub-6 GHz frequency bands most often used for cellular communication as well as other communications networks today. At those 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 there's more real estate and the chance to utilize bigger pipes for carrying cellular information.

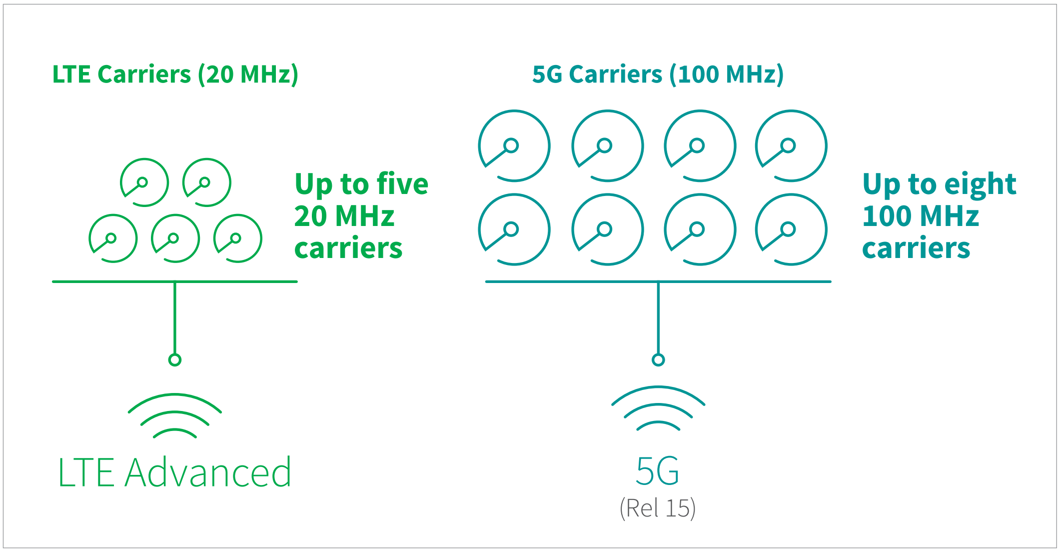
As we noted earlier, one of the key technical characteristics of 5G calls for "component carrier bandwidths up to 100 MHz in sub-6 GHz spectrum and up to 400 MHz component carrier bandwidths in spectrum above 6 GHz." This idea of pipes helps explain how that requirement can contribute to differences in 5G performance: in sub-6 GHz spectrum, the largest individual 5G pipe will be four times smaller than the largest individual pipe possible in mmWave.

Different channels mean opportunities for carrier aggregation

Operators can also create bigger "pipes" by combining two frequency channels together. Known as carrier aggregation, binding channels together like this enables faster data speeds than could otherwise be achieved with just a single channel.

In 4G LTE, channels are typically configured in sizes of 5, 10, 15, or 20 MHz. With LTE, we're currently seeing aggregation max out with four or five channels. It's technically possible, then, for carrier aggregation with LTE to combine five different 20 MHz channels to create one much larger 100 MHz pathway. From a network perspective, however, binding this many channels together is complicated by many MNOs not having enough 20 MHz channels available for such a large aggregation.

With 5G, however, networks operating at greater than 6 GHZ spectrum will have up to 400 MHz component channels ("component" in this example simply means there can be up to 400 MHz of channel available without any aggregation necessary). Moreover, 5G will allow for additional carrier aggregation from that already generous starting point, with the potential in Rel 15 to combine different bands up to an 800 MHz channel and in Rel 16 all the way up to an enormous 1.2 GHz channel. In other words, "pipe" size and capacity with mmWave 5G has the potential to be eight to twelve times greater than what is available under today's LTE configurations.



Propagation will impact 5G coverage

The greater room at higher frequencies does however come at a cost, thanks to what's known as propagation. Propagation is a measure of how far a signal at a given frequency can travel and how well it can penetrate solid objects. Propagation varies significantly between low and high frequencies, with a lower frequency able to travel farther and penetrate solids better than a higher frequency.

This difference in propagation has an impact on 5G coverage as well. The higher the frequency band, the smaller the area that each base station is able to cover. This means that 5G implemented at the lower frequencies found in sub-6 GHz spectrum will have wider coverage than what is seen with mmWave 5G. Networks that want to deliver the bigger channels and faster speeds possible above 6 GHz will therefore need to have more base stations.

The device matters too

Even if the operator offers 5G, it doesn't mean that there will automatically be any difference in performance. A device capable of accessing that technology and network infrastructure is also needed.

Keep in mind as well that at launch 5G networks will be Non-Standalone (NSA) and make use of existing 4G LTE infrastructure for non-data tasks. In simple terms, this means you won't always be utilizing 5G even if it's available in your coverage area; regardless of what mode of operation the phone reports in idle mode, 5G will only be used for large, resource-draining data tasks. Voice calls, and potentially smaller data tasks such as light messaging, will still be supported by 4G LTE or potentially 3G for some MNOs. Some MNOs may choose to show a 5G symbol while the device is in idle mode if there is a 5G carrier available, but while in idle mode, technically the phone will be operating on an LTE control channel.

Massive MIMO offers great potential moving forward

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. LTE currently makes use of either 2x2 or 4x4 MIMO. In a 2x2 system, there are two antennas on both the tower and device. As you might expect, in a 4x4 system, there are four antennas on both the tower and device.

Taking advantage of mmWave frequency bands, 5G will eventually benefit from the growth of massive MIMO and its enormous number of potential antenna configurations (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 the higher frequencies of mmWave. 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. As you reach the higher frequencies of mmWave, however, the size of antennas shrinks considerably and allows for a dramatic expansion of MIMO.

Initial mmWave 5G infrastructure and devices won't be ready to such massive antenna configurations, but the pathway will exist to grow in this direction due to the much smaller antenna sizes possible at higher frequencies.

IHS Markit anticipates early 5G devices accessing spectrum over 1 GHz will initially support 4X4 MIMO. We plan a full teardown and cost analysis of the new Samsung 10 Plus 5G and LG V50 in the near future.

Beamforming

mmWave and massive MIMO also set the stage for operators to make the most of beamforming. Current cellular networks are built using a spread-spectrum configuration that sends a signal across the entire frequency channel. The downside to spread spectrum is that the more people that utilize a given frequency, the greater the noise; and the more noise there is, the more capacity and prospective user experience are negatively impacted.

Beamforming addresses this issue of interference by following each user individually with a unique radio beam. Because signals are directed individually rather than spread across the entire coverage area of the antenna, there is much less possibility for signals to interfere with one another. This enhances spectral efficiency and is like turning cell service from a generic, blanketed approach into a smart, targeted, and individualized beam. The result is less noise and greater capacity.

Beamforming is technically possible below 6 GHz, but mmWave is where beamforming will become much more useful. Remember that mmWave will allow for the development of massive MIMO, with configurations of hundreds of antenna elements. With beamforming, the more antennas that are available, the more an MNO will be able to direct signals to prevent noise and interference. As mmWave 5G grows, beamforming will become more and more important to help handle traffic in the most efficient manner possible.

Putting it all together

The path to 5G isn't a straight line. Despite the flurry of 5G excitement and ever-increasing number of 5G marketing campaigns, what 5G means for the end user can vary dramatically based on the interrelated factors above. Different 5G flavors mean wildly different 5G experiences, with one line of demarcation falling at 6 GHz.

Above 6 GHz = greater potential but smaller coverage

Implementations of 5G that make use of frequencies in the mmWave range are when those truly transformative technologies and experiences can begin to develop.

With channels starting at 100 MHz, vast room for carrier aggregation, the possibility of massive MIMO, and the help from increased beamforming, 5G at these frequencies will look much different from what end-users experience with 5G at lower frequencies. The downside is that low propagation at these frequencies means that coverage will be more expensive to deploy.

Below 6 GHz = better coverage but a less transformative experience

Implementations of 5G that make use of frequencies below 6Ghz will certainly be better than your current LTE experience, but the difference likely won't be dramatic.

In fact, we anticipate about a 25% improvement for 5G networks implemented in frequency bands below 6 GHz. On the other hand, thanks to better propagation at this frequency range, 5G coverage at this part of the spectrum should be less capital intensive to cover a similar area or indoors compared to 5G implemented at mmWave.

The 5G (r)evolution

So, is 5G going to help transform existing business models and how we interact with the world and potentially even with each other? Yes, but it depends on which "5G" you're talking about.

Implementations below 6 GHz point toward more of an orderly evolution, with 5G extending many of the same use cases that LTE and LTE-Advanced have started. Implementations above 6 GHz are where the truly revolutionary potential of 5G will begin.

Benchmarking the 5G landscape

From market share information to teardowns of 5G-enabled devices to performance benchmarking of 5G networks, IHS Markit provides a comprehensive, silicon-to-subscriber view into the changing 5G landscape.

Offering both scientific test results and crowdsourced data, our information helps the industry evaluate current performance and look for optimization opportunities that will create a seamless 5G experience during our increasingly always-on and connected daily lives.

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