Smarter and More Efficient:

How America's Wireless Industry Maximizes Its Spectrum

1 Executive Summary

The wireless industry is always looking for more spectrum to meet the growing demand for mobile data, power the connectivity that creates jobs and grows the economy, and sustain the networks that hundreds of millions of Americans rely upon every day.

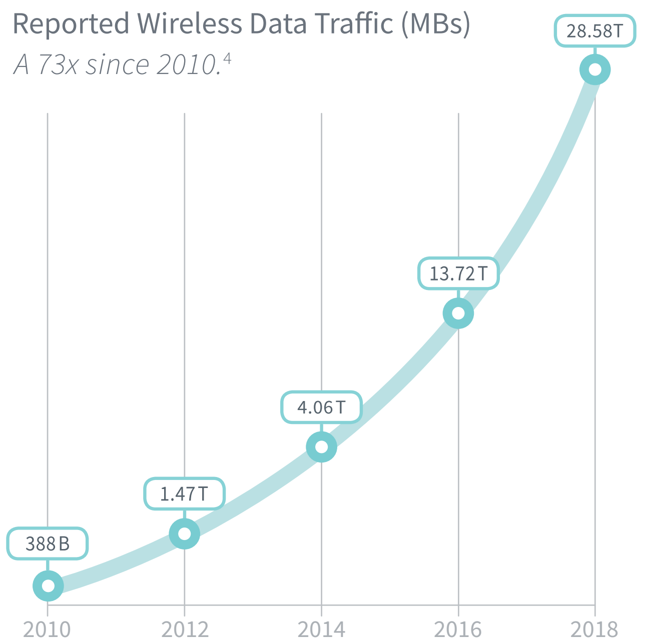
But as the industry works with policymakers and federal agencies to find new spectrum to bring to market, wireless providers are also investing heavily to make more efficient use of the spectrum holdings they have today.

Spectral efficiency is not an academic exercise for U.S. wireless providers. It's essential. Facing a hockey stick increase of mobile data growth, wireless providers must look at all strategies to increase network capacity—incorporating new, more efficient wireless technologies into their networks and deploying densified infrastructure.

In the past five years, the number of wireless subscribers has increased more than 25 percent. Subscribers are using more mobile data: the average smartphone user now exceeds 6.5 GBs a month, up from 1.1 GBs five years ago.[1]

Reported Wireless Data Traffic (MBs)

A 73x since 2010.[4]



As 5G is deployed, the demands on wireless networks are only going to increase. 5G will enable a massive increase in the number of wirelessly-connected devices, and the significant increase in 5G network speeds will drive further increases in data across wireless networks.

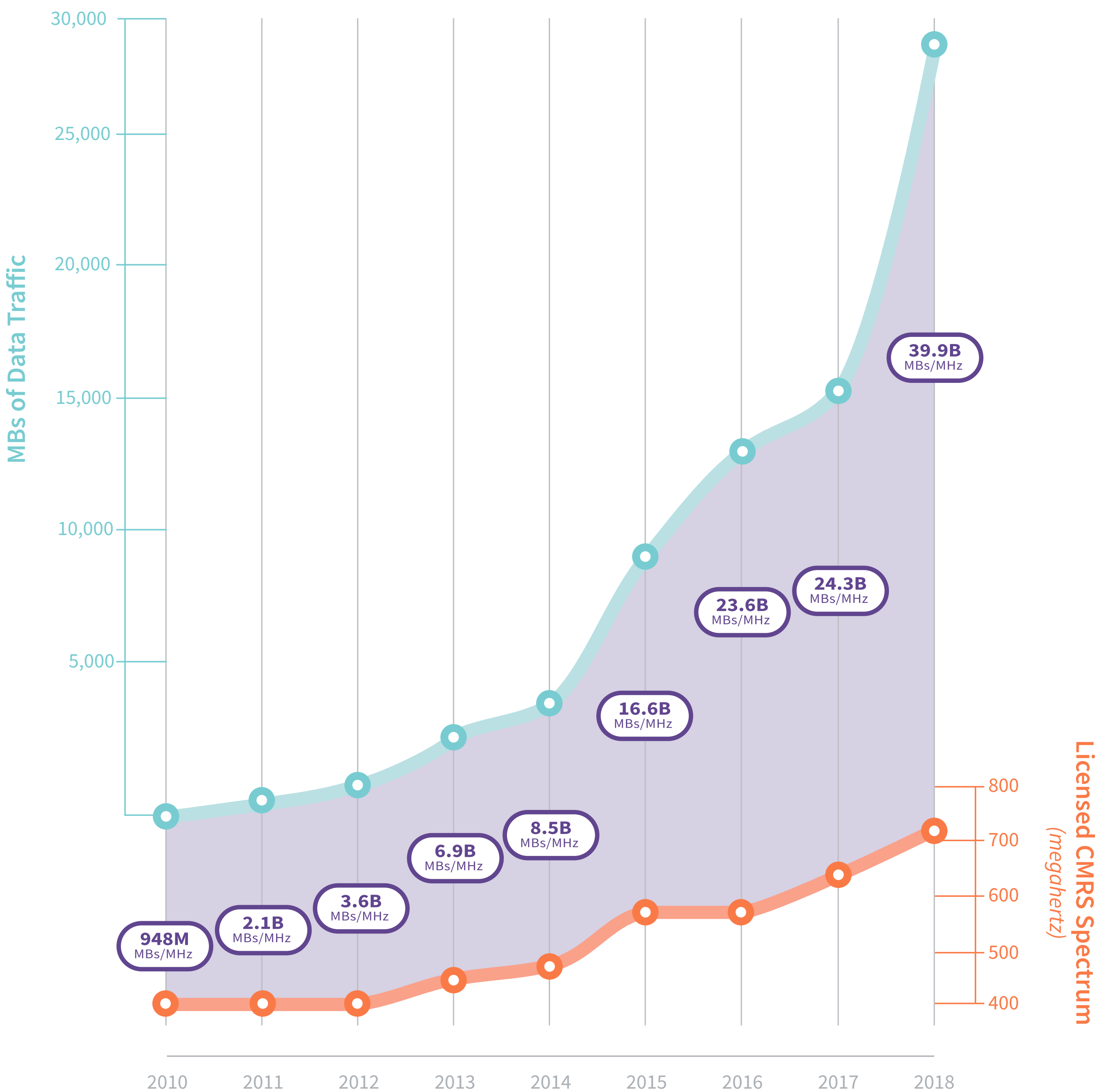
Facing this explosion in mobile data traffic, wireless providers have taken aggressive efforts to maximize their limited spectrum resources. As Verizon CEO Hans Vestberg said, "[T]here are billions of dollars going into spectrum efficiency every day."[2] The reason is simple: efficient use of industry's spectrum resources is critical to consumers' mobile experience.

Spectrum efficiency has also been a hallmark of the U.S. focus on flexible, exclusive-use licensing—a framework that has driven America's wireless leadership. The FCC has recognized that exclusive-use licensed bands are often the most intensively used and serve as a "runway" for the launch of innovation services.[3] Indeed, it was on exclusively-licensed spectrum that the industry migrated to digital mobile, evolved from 2G to 3G service, and produced global leadership by the U.S. in 4G—and now is leading the world in 5G.

Just recently, President Trump set a goal that the U.S. should "have more 5G spectrum than any other country in the world" by 2020. While we work with policymakers to answer that call, the industry continues to take steps to be smarter and more efficient with our spectrum holdings. Specifically, the industry is working to refarm existing spectrum, quickly deploy new spectrum assets, and upgrade to new generations of wireless networks, all while deploying denser wireless infrastructure and other techniques that enhance spectral efficiency.

Wireless providers will continue to make efficient use of spectrum assets in order to ensure they deliver the wireless experience that consumers demand—and help ensure we continue the lead the world in 5G. Going forward, all spectrum users will need to increase their own efforts to be good stewards of this limited natural resource.

Increasingly Efficient: Handling More Wireless Traffic with Commercial Spectrum Assets



On a MBs/MHz basis, U.S. wireless providers have increased their spectrum efficiency by a factor of 42 since 2010. The purple bubbles represent the amount of wireless data handled by wireless providers divided by the amount of licensed spectrum wireless providers have had access to over the last eight years.

2 Making Efficient Use of Commercial Spectrum Assets

Two major ways that the wireless industry achieves greater efficiency from its spectrum assets is by 1) actively refarming existing spectrum holdings and 2) quickly putting new spectrum to use.

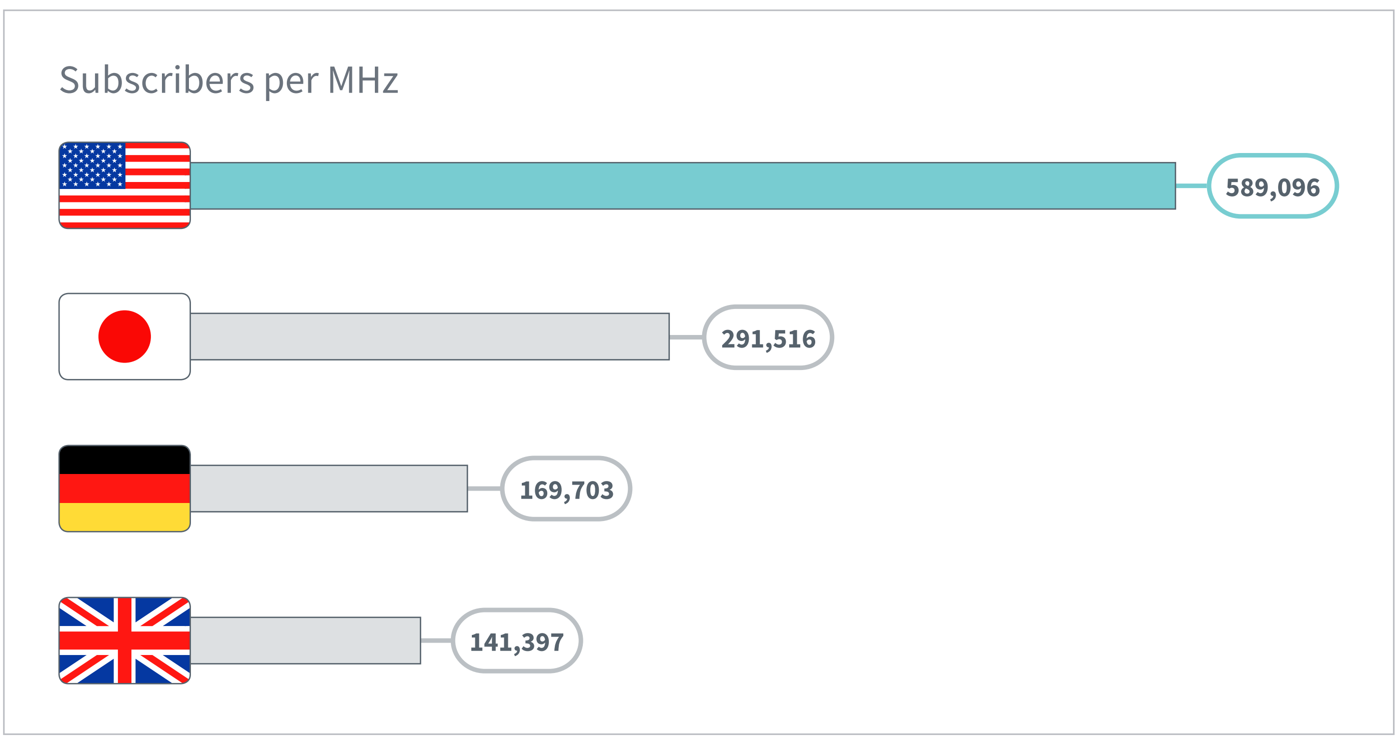
Refarming

Refarming involves investing to repurpose spectrum bands from one generation of wireless technologies to newer, more efficient generations of wireless. Refarming is a time-intensive, highly coordinated, and complex networking effort, with spectrum re-farmed block-by-block and carefully executed to avoid any impact on consumers' wireless experience. Refarming requires multi-mode mobile devices that include both the current and new technology. By shifting usage to the new technology, the operator is able to free up spectrum from the old technology and repurpose it to the new, more efficient technology.

Wireless providers refarm to serve more subscribers with limited spectrum assets—in other words, refarming enables wireless to do more with less. That's exactly what U.S. providers are doing.

With an average spectrum depth of 719 megahertz and over 421 million subscribers, the U.S. has the fifth most subs per megahertz in the world. U.S. wireless providers serve over 589,000 subscribers for each megahertz of spectrum, more than twice that of Japan, three and a half times that of Germany, and four times that of the U.K.[5]

To put it another way, many other countries have provided wireless providers with more bandwidth to serve their subscribers. To work around that and to better serve their customers, U.S. wireless providers continually invest to refarm their airwaves to more spectrally efficient technologies.



A Track Record of Refarming

Let's look back at wireless providers' refarming efforts over the past decade. AT&T completed refarming its 2G network in 2017, putting that spectrum to use for its 4G network.[6] Just recently, the company announced plans to refarm its 850 MHz spectrum for 5G.[7] When U.S. Cellular wanted to launch the iPhone on its network in 2013, the regional provider increased its capital spending to refarm its 850 MHz holdings for 4G, with much of that spending going to new 4G-capable base stations.[8]

After refarming spectrum used for its 2G network by the end of this year, Verizon has already begun refarming its 3G spectrum—a project that the provider is "working every day" on and that will be completed by 2020.[9] Sprint refarmed 2G spectrum for enhanced 3G and 4G;[10] T-Mobile did the same.[11]

When wireless providers make acquisitions, one of the driving factors is often access to airwaves, which is then refarmed: T-Mobile refarmed CDMA spectrum acquired from MetroPCS,[12] and AT&T refarmed spectrum from its Leap purchase.[13]

> We're refarming our spectrum very rapidly...Why is that important? It allows us to free up legacy technology-bound spectrum... [M]ore refarming allows us to really strengthen [our] capacity position.
>
> —NEVILLE RAY, CTO, T-MOBILE [14]

Quickly Deploying New Spectrum

When wireless providers acquire new spectrum, they move quickly to deploy those airwaves in their networks. As the price for acquiring new spectrum can range from hundreds of millions to billions of dollars, economic sense dictates providers promptly put new spectrum to use.

This process can often take years—wireless providers first must install new radios and antennas on their wireless towers and infrastructure that use the new spectrum. In addition, wireless providers must work with handset manufacturers to ensure that new devices are capable of supporting the new airwaves.

As case studies from recent FCC auctions illustrate, wireless providers go to great lengths to quickly deploy new spectrum licenses.

600 MHz

Following the completion of the 600 MHz incentive auction in April 2017, T-Mobile moved rapidly—at "breakneck pace"[15] —to deploy the spectrum it won, starting just four months later.[16]

T-Mobile worked quickly with infrastructure providers, chipset makers, and device manufacturers, as well as the FCC and the broadcasters who were relinquishing the spectrum, to deploy this spectrum in record time.[17] In fact, to speed up access to these airwaves, the company struck a deal to voluntarily cover the cost to relocate some broadcasters' low-power facilities following the auction.[18]

T-Mobile's 600 MHz spectrum is now available in over 2,700 communities across 43 states and Puerto Rico, and as broadcasters continue to clear operations, the company will continue to deploy its 600 MHz spectrum.[19]

U.S. Cellular will launch 5G—including in rural areas—later this year using its 600 MHz spectrum.[20]

AWS-3

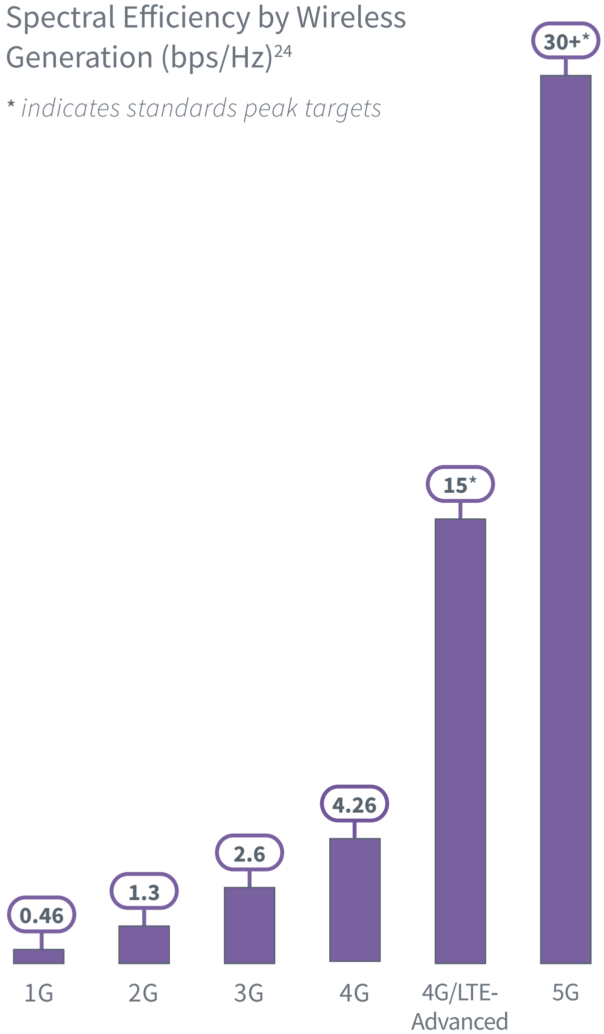
The FCC's 2015 auction of 65 megahertz of AWS-3 spectrum came in at a record $44.9 billion in gross winning bids.[21] Even as the Department of Defense needed time to clear those airwaves, by the end of 2016, wireless providers had begun turning on mobile service leveraging AWS-3 spectrum.[22] Within two years, AT&T, T-Mobile, and Verizon all had begun deploying their AWS-3 spectrum.[23]

3 Every Wireless Generation Yields Greater Spectrum Efficiencies

Another way that the wireless industry achieves more efficiencies with its spectrum is by upgrading to new generations of wireless networks. Each progression to newer generations of wireless increases spectral efficiency (see chart below). Wireless providers invest billions to advance to newer generations of wireless, and billions more to enhance capacity even within a generation of wireless. This investment unlocks better spectrum efficiency.

Spectral Efficiency by Wireless Generation (bps/Hz)[24]

** indicates standards peak targets*



Continued 4G Efficiency Gains

Even as the focus turns to 5G, the wireless industry continues to improve the 4G wireless experience, and that includes continued enhancements to spectral efficiency.

4G MIMO

Multiple-input and multiple-output ("MIMO") groups multiple antennas at the transmitter and receiver to provide better throughput and spectral efficiency. This 5G-precursor technology expands the capacity of existing 4G networks by increasing the amount of data paths between cell sites and mobile devices, thus enabling greater efficiency from providers' spectrum.

LTE-Advanced

Following the release of new standards, many wireless providers introduced LTE-Advanced, which enhances spectral efficiency. LTE-Advanced combines multiple different technologies: carrier aggregation, which aggregates the bandwidth of multiple LTE frequencies in the same or different bands to achieve faster speeds and MIMO, which uses more antenna elements to generate additional capacity.

LTE-Licensed Assisted Access (LAA)

These technologies leverage unlicensed spectrum[25] with licensed network technology to increase spectral efficiency as well as to improve coverage, speed, mobility, and security. LAA technologies look for vacant unlicensed channels, operate on that unlicensed spectrum, and then vacate when the spectrum is no longer needed.

VoLTE

The initial 4G networks supported mobile data only, with voice enabled by 3G or 2G technology. Following advances in the 4G standards process, deployment of voice over LTE—basically data packet-switched voice services—has accelerated significantly in the past two years, with many wireless providers now offering VoLTE across the entirety of their LTE networks.[26] By moving voice traffic to its own data channel, VoLTE improves

> To further enhance spectral efficiency… AT&T has been "re-inventing its own wireless network, re-farming spectrum and transitioning to newer air interfaces; implementing carrier aggregation, MIMO and other intra-generational network enhancements; densifying its network and adding distributed antenna systems and pico-cells; and deploying technologies like… LAA to leverage unlicensed spectrum with licensed networks.[27]

voice quality and makes more efficient use of spectrum than prior voice service offerings. In doing so, wireless providers can then refarm voice-dedicated spectrum for other uses.

5G Will Further Increase Spectral Efficiency

Today, wireless providers are investing billions to deploy 5G networks. This transition to the next generation of wireless will make industry's use of spectrum even more efficient—and also speed the spectrum refarming process.

Indeed, it is clear that 5G "is a spectrally efficient technology that creates a massive increase of capacity."[28] Here's why 5G will generate spectral efficiencies:

Larger Spectrum Blocks

Large blocks of spectrum will allow for wide channelization that enables key 5G attributes: speeds up to 100 times faster than 4G networks and single-digit latency. Large spectrum blocks allocated for 5G will enhance spectral efficiency: in adopting 100 megahertz channels in high-band spectrum, the FCC found that "this size would be consistent with developing industry standards that maximize spectral efficiency."[29]

Massive MIMO/Beamforming

Massive MIMO's larger number of transmitters enables beamforming, which allows the signal to be aimed towards the mobile unit using accurate and narrow beams—and is capable of delivering data to multiple subscribers simultaneously. Nokia has noted, this "spatial reuse of frequencies enables high spectral efficiency, resulting in greatly increased system capacity."[30]

Dynamic Spectrum Sharing

Dynamic Spectrum Sharing (DSS) is also poised to further increase spectral efficiencies gained from refarming and transitioning to newer generations of wireless. Ericsson describes DSS as the ability to dynamically share spectrum between 4G and 5G to enable the "best utilization of spectrum band assets."[31] In essence, DSS will accelerate the transition to 5G by enabling 4G and 5G to use the same blocks of licensed spectrum.

So in lieu of manually re-farming spectrum, DSS will allow wireless providers "to dynamically allocate some of their existing 4G LTE spectrum to 5G and use existing (5G NR-capable radios) to deliver 5G services" with just a software upgrade.[32] This will dramatically speed up the refarming process.

5G Will Drive Even Greater Spectral Efficiencies In Key Bands[33]

19%

increase in low-band spectral efficiency.

52%

increase in mid-band spectral efficiency.

4 Enhancing Spectral Efficiency with Equipment, Techniques and Services

The capacity of spectrum can also be increased by investing in infrastructure to enhance spectrum re-use. In the highly competitive wireless marketplace, providers—with billions of dollars in network investments—are constantly deploying new infrastructure technologies and techniques to meet consumer demand and gain a competitive edge.

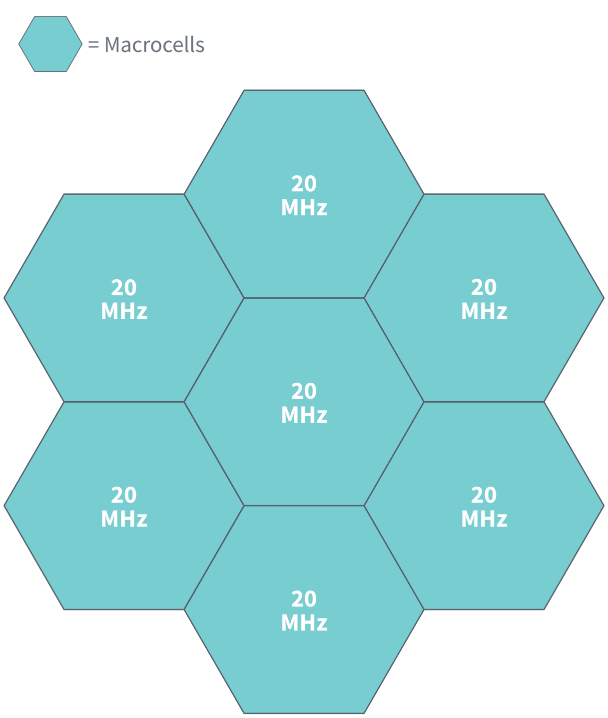
Network densification

While wireless networks for years were built with 200-foot towers, providers are increasingly deploying small cells—wireless radios the size of pizza boxes—in order to unlock the full potential of 5G networks and augment 4G networks. Providers are projected to deploy nearly 800,000 small cells by 2026.[34]

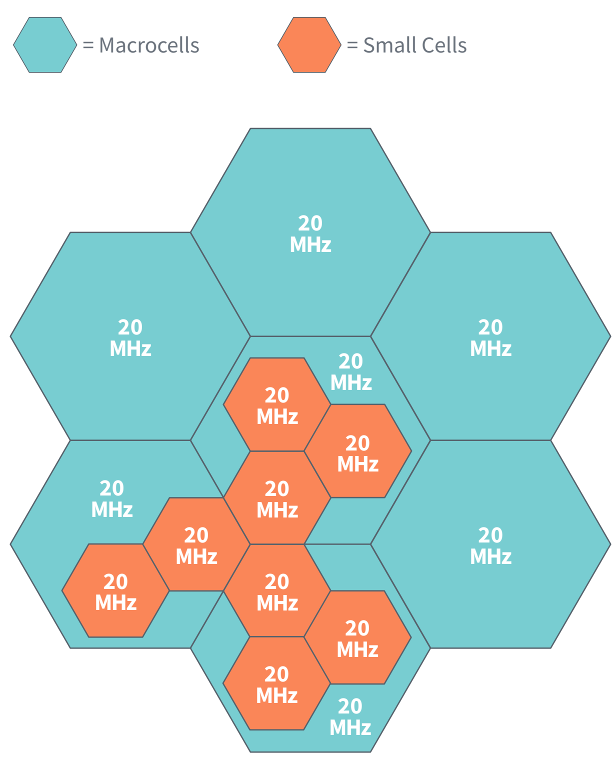
When wireless providers densify their networks—deploying, for instance, tens of thousands of small cells with smaller coverage areas—they reuse their spectrum at a greater rate. As Qualcomm has noted, “5G Small Cells equate to more reliable coverage, better spectral efficiency and improved overall network performance & capacity, creating an opportunity to lower cost-per-bit.”[35]

Another way to use spectrum more efficiently is to use very small cells known as picocells. About ten years ago, wireless providers began deploying these low power, short-range base stations that users connect to

Spectrum use in traditional macro tower cell network.



By densifying their networks, wireless providers are able to reuse spectrum, increasing the efficiency of their spectrum assets.



an existing broadband connection, typically to expand coverage within a home or office. The licensed spectrum is reused again, customers receive better coverage, and the macrocell network's capacity becomes available for other customers. More users can use the same spectrum in the same area, thus improving spectral efficiency.

Cell splitting and antenna sectorization

Cell splitting is a way of increasing the capacity of a wireless network. By subdividing one cell into two or more smaller cells, network operators can reuse spectrum frequencies more often over a given area. The smaller the cell, the more wireless providers can reuse spectrum frequencies. For example, a single cell with 40 megahertz of bandwidth can be split into say, five cells, covering the same area leading to a 5 times improvement in capacity as the five cells can now each access that 40 megahertz of bandwidth separately.

Similarly, sectorized antennas allow operators to transmit signals in specific directions within a cell, allowing reuse of the same spectrum frequencies within a single cell to serve customers located in different areas.

Both cell splitting and sectorization are often capital-intensive efforts that require modifying existing cell sites or adding new sites. Deploying a three sector cell in lieu of an omni-directional cell, for example, requires installing triple the number of transmitters and receivers on a tower. Not only may the tower not support this type of weight loading, these changes may require renegotiating leases with the tower owner and may require revisiting tower authorizations. More importantly, in the case of adding new towers, a host of new approvals is often required. The wireless industry makes these investments—in time, resources, and money—to wring increased efficiencies out of its spectrum assets.

LTE-M/NB-IoT networks

Many wireless providers are deploying new offerings called LTE-M or NarrowBand-Internet of Things, also known as NB-IoT. These technologies support low-power, lower-cost, and longer-battery-life devices on LTE networks.

LTE-M and NB-IoT will significantly enhance spectrum efficiency for IoT devices that require less bandwidth. These technologies are particularly good at providing better coverage for IoT deployments such as smart cities (e.g., parking garages) and in providing extended coverage in rural areas.

What Tom Hazlett and Matthew Spitzer said fifteen years ago remains true today: "The pressure to increase spectral efficiency is relentless."[36] America's wireless providers invest billions to make the most efficient use of their spectrum assets—the lifeblood of wireless service. As mobile data demand continues to increase and 5G networks proliferate, the wireless industry will carry on its efforts to be smarter and more efficient with this limited natural resource.

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