Imagining the 5G Wireless Future

Apps · Devices
Networks · Spectrum

BRET SWANSON

EXECUTIVE SUMMARY

- The Internet's first few chapters transformed entertainment, news, telephony, and finance—in other words, the existing electronic industries. Going forward, however, the wireless Internet will increasingly reach out to the rest of the economy and transform every industry, from transportation to education to health care.

- To drive and accommodate this cascading wireless boom, we will need wireless connections that are faster, greater in number, and more robust, widespread, diverse, and flexible. We will need a new fifth generation, or 5G, wireless infrastructure. 5G will be the foundation of not just the digital economy but increasingly of the physical economy as well.

- Two big waves are driving the need for more wireless capacity—mobile video and the Internet of Things (IoT).

- Video, which demands far more capacity than previous mobile applications, is changing the ***nature*** of wireless data traffic. Younger generations especially are consuming far more entertainment on mobile devices, while also generating floods of social video and two-way video communications.

- Meanwhile, we are connecting many new types of devices to the Internet—cars, toys, packages, medical devices, remote cameras, appliances, industrial machines, wearable computers, sensors, drones, and much more. This immersive Internet, where everything is connected, is radically boosting the ***number*** of devices generating mobile traffic. Over the next decade, tens of billions of new devices will require new wireless connections.

- 5G will be a diverse but integrated network serving a multitude of varied devices, applications, and services. It will enhance mobile and residential broadband capacity; connect a wide array of billions of IoT devices; and serve as the key link for mission critical applications like autonomous cars and trucks.

- The capacity and coverage needs of mobile video and the immersive Internet will demand more commercial wireless spectrum than is available today. Today, total deployed mobile spectrum in the U.S. is around 544 MHz. 5G will make use of newly opened high frequency

bands, which could each provide 200 MHz, and up to 500 MHz, or nearly as much as all existing mobile spectrum.

- Existing and new spectrum bands will take advantage of millions of newly deployed "small cells," which are smaller than cell towers but more robust than Wi-Fi routers, and which can economically expand capacity and coverage.

- These small cells will be attached to utility poles, buildings, and even homes. Connecting these small cells back to the network will require deployment of new fiber optic links to building tops, neighborhoods, public spaces, and office parks. Cooperation and encouragement from state and local entities to speed permitting of fiber and small cell deployment will thus be a key economic development priority.

- 5G will also open up a huge number of new business models on the Web, in entertainment, for vehicles, industrial services, and much more. Experimentation and flexibility in developing these new technology and business models is imperative. "Free data" is one such innovative model that should be encouraged.

- Other government actions and policies can speed the arrival, and enhance the benefits, of 5G. Here are the fundamentals of a pro-active 5G policy:

- Successfully complete the 600 MHz incentive auction.

- Expand the 5 gigahertz (GHz) unlicensed band.

- Open the high bands at 28, 37, 39, and 64-71 GHz, using primarily flexible-use licenses and possibly allowing for some unlicensed spectrum at the higher frequencies.

- Promote flexible secondary spectrum markets. The ability to buy and sell spectrum is crucial if existing mobile carriers and upstarts are to build the types of complex networks needed to deliver 5G services.

- Pursue flexible and cooperative strategies at the state and local levels to encourage rapid build out of wired networks and siting of small cells.

- Reverse the attempt to regulate the broadband Internet, including mobile, as a telephone utility. Instead, adopt a forward-looking policy that encourages innovation and investment.

- Encourage experimentation in technology deployments and business models, such as free data, which can encourage a virtuous circle of investment and innovation across this huge and diverse new wireless economy.

Imagining the 5G Wireless Future

BRET SWANSON > November 2016

As we walk the avenues of downtown Chicago, my daughters wonder why their smartphones seem so much slower than usual. Snapchat isn't so snappy. FaceTime is halting. And why does the battery run down so quickly?

"Spectrum," I answer.

The one-word answer doesn't satisfy them, and so I launch into a gripping explanation:

"Where we live in the suburbs of Indianapolis, we have a good amount of wireless capacity but not a super dense population. Each person gets a good chunk of the available spectrum—a large slice of pie. Our connections are fast. Here on the streets of a big city, however, there are many more people competing for similar spectrum resources. Each person gets a smaller slice of the pie. Your phone also has to work harder to find that slice, so the battery runs down."

"Wow, Dad," they reply. "Fascinating."

Mobile Internet technologies have been the world's chief source of innovation over the last decade. This success, however, is not the end of the line. The hunger for new wireless products and services is not slowing. The mobile Internet economy is instead opening new windows of invention, breeding additional possibilities, spreading to unfamiliar industries, and creating the need for far more wireless coverage and capacity than exists today.

During its first few chapters the Internet transformed entertainment, news, telephony, and finance—in other words, the existing electronic industries. But the majority of the economy was left relatively untouched. In recent years, however, we've begun to see how the wireless Internet will reach out to the rest of the economy and transform every industry, from transportation to education to health care.

To drive and accommodate this cascading wireless boom, we will need wireless connections that are faster, greater in number, and more robust, widespread, diverse, and flexible. We will need a new fifth generation, or 5G, wireless infrastructure.

Apps, Devices, Networks, Spectrum

In this report, we address the varied ***applications*** 5G will enable and the ***devices*** it will connect. We also describe the new 5G ***network*** architectures and infrastructure needed to serve these applications and devices. We show the need for a substantial expansion of commercial wireless ***spectrum***. And finally, we address several important questions of ***public policy*** that will help determine the success of 5G.

To understand why we need a new wireless network and more spectrum, we begin with the forces behind the ongoing explosion in wireless usage.

Two Big Waves

Two big waves in the wireless world are driving the need for more capacity, and thus for spectrum, the electromagnetic frequencies that carry data to our phones, tablets, and other mobile devices.

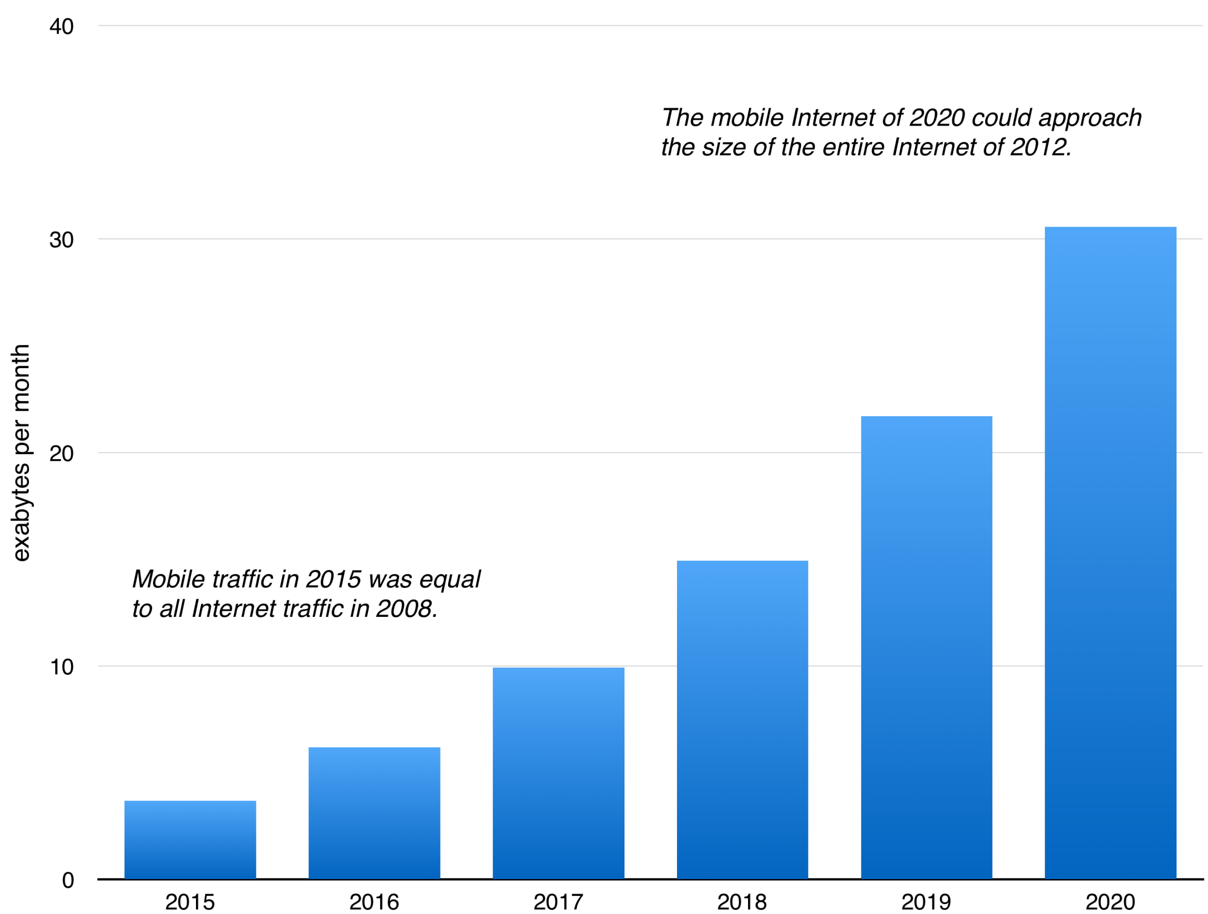
First, the boom in mobile video, which demands far more capacity than previous mobile applications, is changing the ***nature*** of wireless data traffic.

The millennial and post-millennial generations are consuming far more entertainment on mobile devices than their TV- and PC-bound elders. They video chat on FaceTime and Skype and share video clips on Snapchat, Instagram, and Musical.-ly. Netflix already accounts for more than one-third of Internet traffic at peak hours, and a growing fraction of its videos are watched on mobile devices.[1] Researchers at Google report that "for YouTube alone, users upload over 400 hours of video every minute, which at one gigabyte per hour requires a petabyte (1M GB) of new storage *every day*." YouTube video "continues to grow exponentially, with a 10x increase every five years."[2]

Cable and telco providers, meanwhile, are making available their TV channel lineups to broadband mobile devices. But a move away from pay TV altogether by some cohorts toward wireless-only households is also driving wireless video consumption.

Facebook's new auto-roll video clips now begin playing without a click from the user, turning your newsfeed into a cascading video feed. Facebook is also experimenting with live video and, along with Snapchat and Twitter, is trying to become a primary video platform. Coming soon are virtual reality, augmented reality, and a new generation of "app streaming," where inexpensive thin clients at the edge of the network exploit abundant bandwidth to run powerful software and virtual environments based in the cloud. These real-time interactive video platforms will demand much higher network performance in terms of capacity, latency, and jitter.

Figure 1: Mobile data will grow 400% by 2020



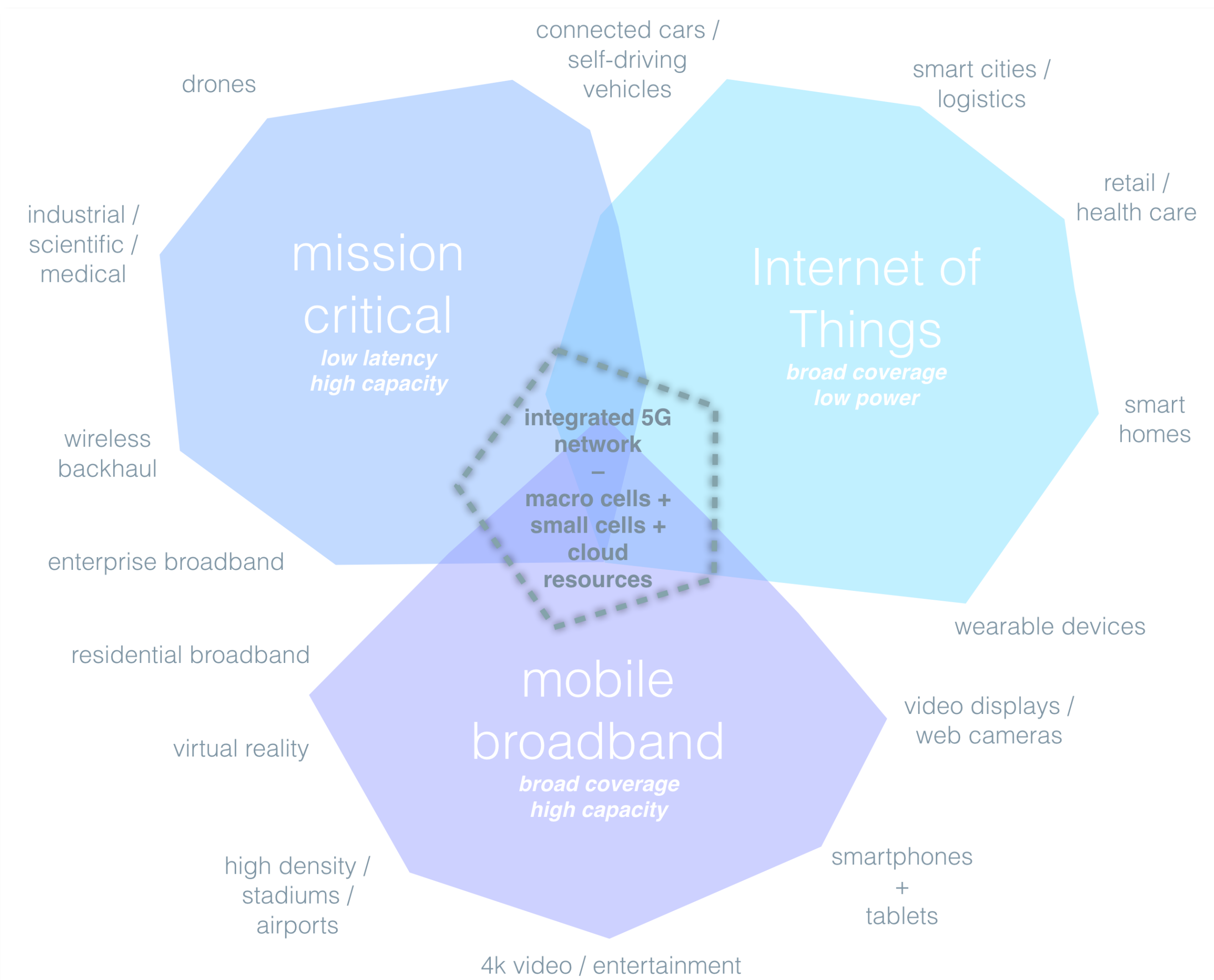
Source: Cisco VNI, Feb. 2016

Meanwhile, the emerging Internet of Things (IoT) —what I call the immersive Internet—is driving an acceleration in the ***number*** of connected devices. The idea that most people on earth now have mobile phones is staggering. These billions of mobile computers now far outnumber PCs, the connected devices of the earlier Internet era. As the world becomes saturated with 7 billion or so mobile phones, however, the immersive Internet will multiply even that total several times over. In the next decade, we will connect some 50 billion devices to the Internet—every car, truck, watch, boat, bot, shoe, package, display, shipping container, remote sensor, medical device, vending machine, appliance, industrial tool, camera, drone, you name it.

The exploding number of devices and the changing nature of traffic will require far more wireless capacity and coverage than is available today. Cisco estimates that by 2020, just four years from now, mobile data traffic will grow 400% to more than 30 exabytes per month. (See Figure 1 on page 4.) If my daughters think the network is crowded now, wait until they are competing with billions of additional devices.

An expansion of commercially accessible wireless spectrum is thus essential. But it is not enough. We will also need to build millions of new wireless access points to serve varied users and communities. These wireless nodes will be connected by new wired fiber optic networks and powered by

Figure 2: Integrated 5G network, serving dozens of end-points, devices, applications, and industries



cloud resources to accommodate the growing diversity of content, applications, devices, and users. We call this sprawling and immersive wireless future 5G.

Applications and Devices

5G will serve not only today's familiar mobile devices and mobile data and voice plans but also an array of emerging, non-traditional services and industries. This comprehensive network will connect people, machines, vehicles, computers, sensors, and objects.

A non-exhaustive list might be divided into three rough categories. As you can see in Figure 2 on page 5, these application categories are not rigid but in fact bleed into one another.

- *Mobile Broadband* — smartphones, tablets, laptops, smart glasses, Web cameras, video displays, high-density public areas, including stadiums and airports, telemedicine, virtual/augmented reality.
- *Internet of Things* — remote sensors, logistics and supply chains, appliances, smart homes, smart cities, wearable and implantable devices, retail and health care, connected vehicles.
- *Mission Critical* — connected cars, autonomous vehicles, drones, wireless backhaul and point-to-point connectivity, scientific, medical, and industrial tools and sensors, enterprise broadband, residential broadband and TV.

These devices and applications will require distinct and diverse wireless services. Mobile broadband, for example, will require both broad coverage and high capacity to deliver video content and other rich media to people on the move. Tiny sensors, meanwhile, might require broad coverage but not high capacity because they transmit small amounts of data. On the other hand, they may need to be very power-efficient. Some mission critical services might be either high or low capacity but will require absolute reliability. Many automated medical and transportation services, for example, may require five nines (99.999%) or more of guaranteed uptime and very low latency, or delay, of packet delivery.

The variety of applications and devices will be matched by a variety of network capabilities, wireless services, and business models. And yet the idea behind 5G is to serve nearly all of these markets with an integrated core network that can apportion resources and accommodate changing usage scenarios on the fly and serve a multitude of cell-types and spectrum bands.

5G will enable a proliferation of business models beyond traditional mobile phones for personal and business use. Retailers, manufacturers, utilities, and logistics firms will rely on the new network for supply-chain, remote monitoring, and industrial maintenance services. Fleets of cars, trucks, and perhaps drones will connect to the network for both navigation and entertainment. Health care, education, and entertainment firms could develop special products relying on the new network. And in many geographies, 5G could even offer residential and small business broadband that will compete with cable and telecom providers of wired broadband. In addition, the 5G network will be designed to be a truly general purpose platform that can accommodate all kinds of "plug-and-play" devices and services not yet conceived.

Many providers of content and services will deliver their products to consumers in the traditional manner—through the Web or apps. The growing array of services and business models, however, will enable more varied payment relationships. One new model, for example, is known as sponsored data, in which content providers help pay for the data consumed when people use their products. Already we are seeing content firms (such as Spotify, Pandora, Netflix, Facebook, and ESPN) partner with mobile carriers (T-Mobile, Verizon, and AT&T). In one form of sponsored data, called zero rating, data from a select content provider is not counted against a consumer's data allowance. Entertainment firms have been the most aggressive early users of sponsored data, but one can imagine that many other types of firms will make use of this model. Providers of health care, educational, and workforce training apps, for instance, may include the data consumed by their services as part of their offerings.

The proliferation of devices, apps, services, content, and business models suggests an environment of widespread experimentation with technologies and product offerings.

The 5G Departure

5G is distinct from previous generations of wireless technology. The steps between 1G, 2G, 3G, and 4G were mostly increments of greater voice and data capacity, based on faster air-interface technologies, enabled by Moore's law of exponential microchip technology. (The "air-interface" is the set of complex digital encoding/decoding protocols, and radio transmission, of information through the air.) Each generation basically worked within the original cellular network architecture in which cell towers each serve geographic areas of several square kilometers or miles.

The first four generations of wireless, moreover, served essentially one type of device—the mobile phone. The third and fourth generations began adding a few more devices—smartphones, laptops, and tablets, etc. 3G and 4G also moved beyond voice toward data. But because 5G will have to deliver more variable data to more varied devices, it will in some ways require a bigger jump from the previous generation.

5G will build upon 4G's basic LTE air-interface technology known as orthogonal frequency division multiplexing (OFDM). Over the next two to three years, moreover, "5G" will in large part mean overlaying high-capacity point-to-point links on top of the existing (and constantly improving) 4G network. In this way, 5G is evolutionary.

But in other ways, 5G is a departure. The 5G network will serve many more types of devices and more business use-cases. Compared to today's cellular network based mostly on cell towers, it will consist of more wireless access nodes, such as small cells, point-to-point links, and self-configuring mesh networks. It will operate in more spectrum bands, including the leap to up-spectrum (high frequency) millimeter wave bands and a more sophisticated use and integration of unlicensed bands. It will also operate more like the flexible, multipurpose Internet than a single-purpose cellular phone network. In fact, it will be not just an extension of the Internet but in many ways the Internet's new foundation.

The Blurring of Wired and Wireless

By 2015, mobile devices capable of consuming digital entertainment–mostly smartphones and tablets—already outnumbered TVs and PCs by a factor of three.[3] The mobile boom is thus transforming media consumption patterns in profound ways. With personal devices, we can each spend far more time consuming (and creating) content.

The categories of wired and wireless are blurring, however. About half the content viewed on mobile devices actually takes place in homes and offices and traverses not cellular networks but wired broadband links to the building and then Wi-Fi in or near the building. Cisco estimates that 51% of mobile data traffic in 2015 was "offloaded" to Wi-Fi.[4] TVs and PCs, meanwhile, will increasingly be wireless devices themselves, connected over the last few feet not by wires but by Wi-Fi or other short-range wireless signals.

Nearly all mobile, portable, and fixed devices will thus soon be "wireless." And yet they all rely on a wired infrastructure, which, depending the circumstance, may begin a few feet, or a few kilometers, away. In fact, the wired component of 5G may be more important than for any previous generation of wireless.

An expansion of fiber-optic networks will thus be a key component of the new wireless infrastructure. Likewise, a chief duty of residential broadband networks will be to serve wireless small cells in neighborhoods. Traditional cell towers may thus serve connected cars and trucks and IoT applications, while small cells fill the coverage gaps between cell towers and Wi-Fi nodes.

Small Cells

Today's cellular infrastructure in the U.S. consists of around 307,000 cell towers and sites.[5] Millions of Wi-Fi nodes are an important complement to the cellular infrastructure. But 5G calls for the addition of millions of small cells, which are much smaller than cell towers but more robust and powerful than Wi-Fi routers. They will use both existing licensed and unlicensed spectrum and also will be key to leveraging the prospective high frequency bands in the 20-80 gigahertz (GHz) range.

> *Extending information technology to the physical industries will boost economic output over the next few decades by many trillions of dollars.*

These millions of small cells will be placed on buildings, lamp posts, utility poles, in public spaces, and in neighborhoods. New cell towers often encounter some resistance from local permitting and zoning boards, although not so much that the U.S. couldn't ascend to world mobile leadership.

Because of their numbers and locations, siting and permitting for small cells may likewise be a challenge. Small cells will be placed in strategic locations and will often be connected with new fiber optic links. Connecting such large numbers of wireless access nodes to the Internet is why 5G will be as much a wired infrastructure project as a wireless one. Wireless operators will therefore actively seek the cooperation of state and local officials to find constructive ways to quickly deploy new small cells with minimal disruption to communities.

One key consideration is ensuring that small cells can be placed on public rights of way (ROW), such as utility and light poles, as well as other non-ROW public structures. These are often perfect locations for the small, light devices. Not all states and localities, however, guarantee ROW access to wireless carriers. In addition, some states and localities may be tempted to impose higher fees on small cells, or exact tribute in return for permits, especially because of the numbers that will be deployed. But delaying the deployment of small cells via high fees, cumbersome permitting, or denied access to rights of way will also delay the enormous benefits of 5G.

States and localities that wish to lead the way in 5G can take action. Some states and municipalities have already adopted policies streamline the small cell permitting process. Others are considering similar laws and ordinances. These policies include:

- inclusion of small cells and associated networks as approved devices on all ROW and other public structures;
- inclusion of wireless carriers as approved users of ROW;
- prohibiting discriminatory fees and conditions that would treat small cells differently than other ROW or public structure attachments;
- keeping fees low for both ROW and non-ROW deployments;

- encouraging single permits for a number of small cells, instead of requiring a separate permit for each cell; and
- using "shot-clocks" to ensure states and municipalities answer permit requests within reasonable time periods.

Streamlining the path to 5G through these and other policies will also speed the way for innovation across the economy—in health care, transportation, education, energy, the IoT, and of course in existing digital content and services. Extending information technology to the physical industries will contribute many trillions of dollars to economic output over the next few decades.[6] These 5G policy ideas are thus some of the most of the most important state and local economic development tools of the next decade.

The New Network

The 5G story will build on the most powerful recent advances in networking technology. Just as cloud computing created massive efficiencies by pooling commodity computing and data storage resources in centralized data centers, so too are networking functions being virtualized on general purpose computing platforms in the cloud. Software defined networking (SDN) and network function virtualization (NFV) will abstract many of the traditional telecom and data networking jobs into code.

So instead of purpose-built "telecom" equipment, much of the new communications network will be based on the same machines that form the rest of the Internet. The "telecom" components will be software code, which is far more flexible and future-proof than hardware.

5G will make special use of these cloud-based resources. For example, instead of requiring a full cellular base-station at each small cell site, a small cell can essentially be an antenna connected to a more centrally located base station that serves numerous types of cells—macro cells, micro cells, distributed antenna arrays (DAS), etc. This will allow small cells to be smaller and more efficient.

Cells of all types will also be more flexible. Because the new network is built with general purpose computing resources and defined primary through software, new services can be rolled out on the fly. The network can be modified in real-time to accommodate shifting usage patterns. And new network elements can be added or subtracted in a plug-and-play manner, where new elements notify the network and other elements of their presence and the network self-configures.

SDN and NFV therefore will make our wireless networks more like the Internet—a general purpose data network—and even less like a single-purpose telephone network.

The Spectrum Imperative

The 5G future will not happen without the commercial availability of more wireless spectrum. The electromagnetic spectrum is the range of frequencies (or wavelengths) of radiative energy, running from super-high frequency gamma rays, with wavelengths the size of atoms, to the extremely low frequencies, where wavelengths are measured in thousands of kilometers. In between these extremes are visible light, infrared light, microwaves, and radio waves. The radio waves that carry today's wireless signals for television, satellite, and mobile are primarily situated between 400 megahertz (MHz) and 6 gigahertz (GHz), with wavelengths measured in centimeters.

Modern radio technologies send (and receive) signals by modulating (and reading) the waves in particular frequency bands. The amount of information that can be transmitted is a function of bandwidth, noise, and transmission power. Bandwidth, as the term suggests, is the width of the frequency band. Think of it as a road or a water pipe—the wider the path, the more traffic, water, or information can be transmitted per unit time. Electromagnetic energy, however, travels far faster than cars or water. It travels at near the speed of light, depending on the medium through which it is moving.

Managing this spectrum is the job of the Commerce Department's National Telecommunications and Information Agency (NTIA), the steward of U.S. radio waves, and of the Federal Communications Commission (FCC), which conducts spectrum auctions and certifies radio equipment. Early last century, the government handed out spectrum for exclusive use to broadcasters of radio and then television. In the 1980s and 1990s, however, as the mobile revolution was approaching from the horizon, the U.S. and much of the world began moving toward a property-rights approach to spectrum.[7] Within limits, the government would allow firms to buy and sell spectrum slices and would auction off additional government-owned spectrum for private use.

Today, the U.S. spectrum map is a mix of mostly government-owned spectrum for scientific, military, navigational, and other uses; the old command-and-control broadcast licenses; and the newer, more flexible, property-based airwaves used by the mobile industry.

Figure 3: Active U.S. Mobile Spectrum

2015	MHz licensed	MHz deployed
Cellular	50	50
PCS	140	130
SMR	14	14
700 MHz	70	46
AWS	90	90
EBS	194	194
WCS	20	20
AWS-3	65	
1670 MHz	5	
MSS	40	
600 MHz	(up to 126)	
Total MHz	**688**	**544**

Sources: Recon Analytics, FCC

The mobile industry, however, is a victim of its own success. It has produced a technological revolution using relatively small slices of spectrum. To keep growing, it needs much more. Most spectrum, however, remains in the hands of gov-

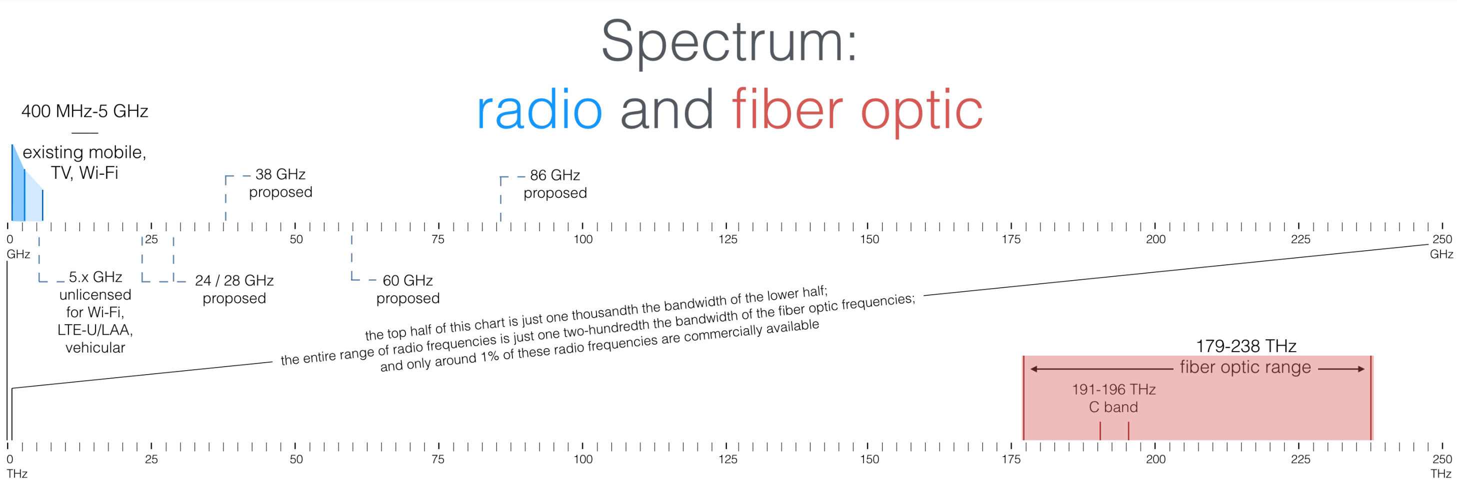


Figure 4: The lower half of this chart depicts the electromagnetic spectrum from 0 to 250 terahertz (THz), or trillions of cycles per second. The lasers of fiber optic communication operate in the upper portion of this range, the near-infrared spectrum, seen in red. The chart's upper half shows the radio spectrum between 0 and 250 gigahertz (GHz), which is just a tiny sliver — one one-thousandth — of the lower half. The blue slices of spectrum at top left contain nearly all existing broadcast TV, satellite TV, mobile, and unlicensed wireless (e.g. bluetooth, Wi-Fi) and are just a tiny sliver of all radio spectrum. A carrier of 4G mobile signals, which is typically 5 MHz wide, has just one millionth the bandwidth of the optical C band, which is 5 THz wide and is the most commonly used fiber optic range.

ernment agencies or previous broadcast licensees, and it is severely underutilized. By many estimates, the U.S. government still controls 60-80% of the best spectrum. In all, the U.S. has licensed around 688 MHz for mobile use (see Figure 3). But it takes years for licensed spectrum to show up in the marketplace as usable, deployed spectrum. Total active, deployed mobile spectrum in the U.S. is thus closer to 544 MHz.

How much is 544 MHz? Think of it this way: The coaxial cable running into your home that delivers cable TV and broadband has a bandwidth of nearly 1 GHz, or nearly twice all the deployed licensed mobile spectrum in the U.S.

We have learned how to multiply that 544 MHz of mobile spectrum many times over across the nation. Carefully limit the transmission power and the direction of a signal within a particular spectrum slice, and we can use that spectrum slice over and over, even within relatively small spaces.

A typical range of signals for a conventional cell tower is several kilometers. In theory we could build infinitely many cell towers transmitting at near zero power, and we could achieve nearly infinite capacity without more spectrum. And yet in reality, there are limits to spectrum reuse. We can only build so many cell towers closer and closer together, transmitting at the same frequency, before the economics and technology break down. There is an optimal balance of physics and finance. At some point, we simply need more spectrum in additional frequency bands.

How much spectrum do we need?

To see how little wireless spectrum is available today, compare wireless to fiber optics, the super-pure threads of glass that carry data via laser beams across the country and around the world. The relative vastness of the spectrum used for optical communication, which makes up the core of the Internet, can be seen in Figure 4 on page 10.

Fiber optics uses near-infrared light with wavelengths around 1,500 nanometers (nm), or frequencies near 200 terahertz (THz). Where a typical carrier of a 4G wireless signal is 5 MHz wide, the most commonly used spectrum window for fiber optics, the C band between 1530 and 1565 nm, has a bandwidth of 5 THz—*or a million times wider*. If we wrap dozens of optical fibers in a ca-

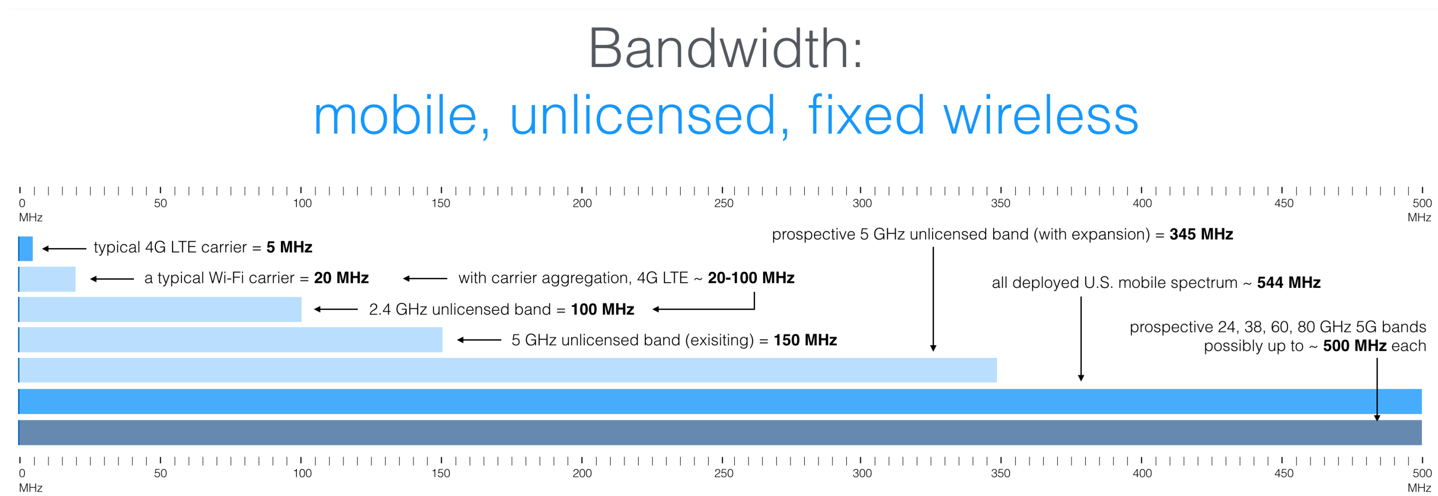


Figure 5: Bandwidth is the defining constraint on information transmission. The wider the band, the more information can be transmitted. Unlike Figure 4, which shows both the bandwidth and the "location" on the electromagnetic spectrum of the various bands, the blue bars here represent not the frequency locations but the size of the bands — the bandwidth. All deployed licensed mobile spctrum in the U.S. today totals 544 MHz. A typical carrier of a particular 4G mobile signal is 5 MHz wide (and potentially as large as 20 MHz). Combining these 5-20 MHz carriers using a technique called carrier aggregation can yield wider carriers of between 20 and 100 MHz. Some of the prospective up-spectrum 5G bands could each be 500 MHz, or a hundred times wider than the typical 4G carrier.

ble, moreover, we multiply the bandwidth by the number of threads.

The entire range of fiber optic technologies utilizes a window between 1260 and 1675 nm, for a total bandwidth of around 60 THz. By comparison, nearly all of today's wireless communications—TV, satellite, mobile, Wi-Fi, etc.—fit in a tiny slice of spectrum between 400 MHz and 6 GHz. That slice, seen in blue in Figure 4, is (generously) less than 5 GHz wide. The fiber optic bands are therefore 12,000 times larger than all the spectrum available today for TV, satellite TV, mobile, and unlicensed broadband.

The abundant capacity of fiber optics made the Internet revolution possible. And yet to fully exploit the marvel of optics, we must expand the capacity and reach of our wireless networks. Wired and wireless, optical and radio, each have strengths and weaknesses. Fiber optic links are high capacity but expensive and fixed geographically. Wireless radio has less capacity but enjoys mobility and less expensive hardware. The two complement and feed one another and, as mentioned above, are meshing into one unified network.

600 MHz Incentive Auction

In 2010, the Administration set a goal of making commercial 500 MHz of additional wireless spectrum. In March of 2016, a Senate committee approved the Mobile Now Act to codify this goal and direct government agencies to help make it happen. In May of 2016, the FCC announced that the first step of the broadcast TV (600 MHz) incentive auction had produced a substantial 126 MHz of spectrum to be auctioned off in step two. This total is at the high end of estimates of how much spectrum would be made available to bidders. If the auction is successful, much of the "beachfront" spectrum mobile operators have been coveting for decades will have been relicensed for modern uses. These are positive developments. And yet that 500 MHz of additional spectrum, should we meet it, is still just one ten-thousandth the bandwidth found in the C band used in a typical optical fiber.

Up Spectrum / High Band

The frontier of spectrum policy, therefore, now turns to higher frequencies. To date, mobile wireless has been confined to the beachfront spectrum between 400 MHz and 6 GHz. These bands offered the best mix of attributes. Signals in these ranges travel substantial distances, penetrate obstacles (such as buildings), and offer enough bandwidth to transmit decent amounts of information. In addition, and crucially, inexpensive silicon electronic components can perform most of the transceiver and baseband functions of mobile devices.

Higher frequency bands were always known to provide more bandwidth potential, and thus higher capacity. And yet these high bands were much more difficult to harness. Higher frequency signals don't travel as far or penetrate obstacles as well (or at all). And they required more sophisticated

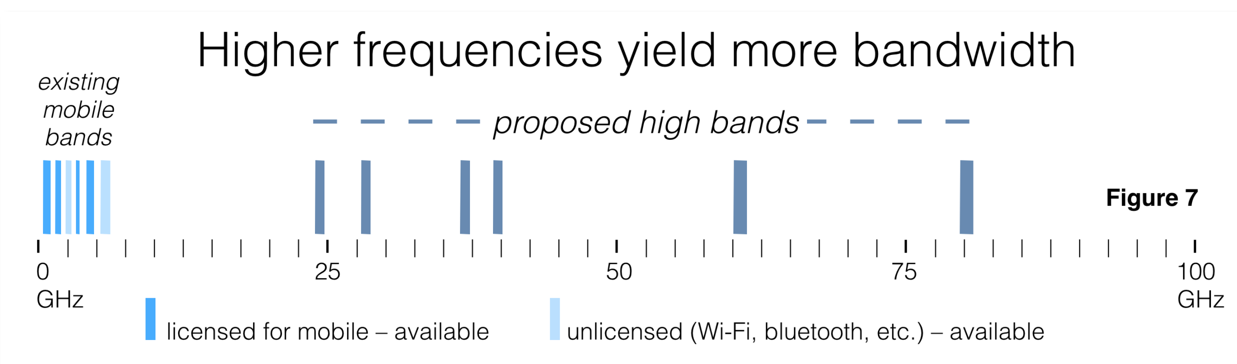


Figure 7

and expensive radio frequency (RF) components, often consisting of exotic materials, such as gallium arsenide (GaAS), instead of the typical silicon. Today, however, technologists have figured ways to exploit these higher frequencies and incorporate them into economical networks and devices. The FCC is, in turn, studying the feasibility of up-spectrum technology, availability, and rules of the road.[8] If authorized for commercial use, these high bands will be a central component of 5G networks, dramatically expanding wireless capacity and thus enabling the next several generations of Internet innovation.

These bands, located between 20 and 80 GHz, offer far more bandwidth than today's commercial spectrum does (see Figure 7). For example, the two unlicensed ISM bands used for Wi-Fi and bluetooth (located at 2.4 GHz and 5 GHz) today consist of a total of around 250 MHz of spectrum. All deployed licensed spectrum for mobile in the U.S. is, as previously noted, 544 MHz. And yet some of the prospective high bands could offer usable bandwidth of between 200 and 500 MHz *each* (see Figure 8). Compared to today's 4G mobile connections, 5G high band links will thus provide data throughput 10 times higher (or more) —up to 1 gigabit per second (Gbps).

There are tradeoffs, of course. Higher frequencies don't travel as far or penetrate walls as well as traditional mobile signals. But these up spectrum links will be be well suited to the new network of small cells positioned on city corners, in neighborhoods, in offices, or on campuses.

Unlicensed

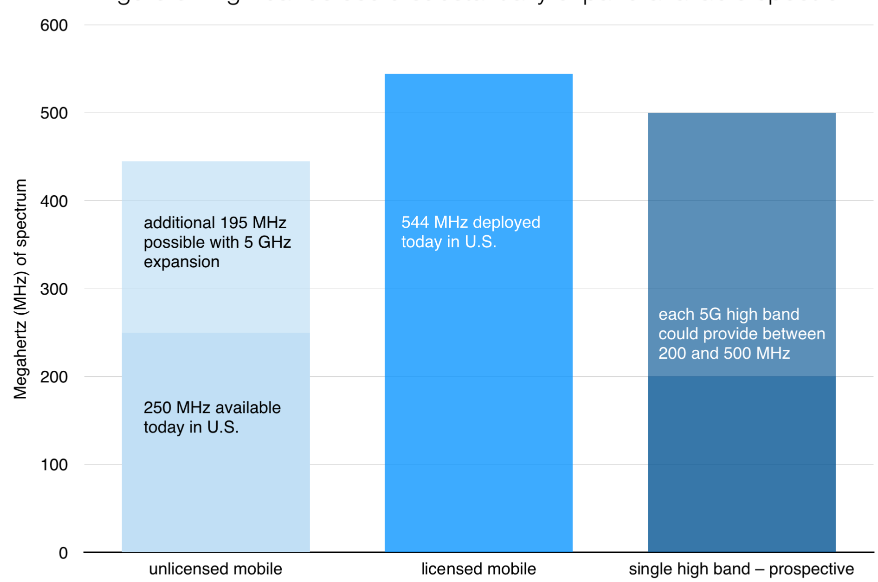
Unlicensed spectrum—or spectrum that is available for anyone or any device to use, so long as it operates below certain power levels and does not interfere with others—will continue to be a central component of wireless innovation. Expansion of the 5 GHz band is one of the most important near-term actions the FCC could take on unlicensed spectrum.

Today, the 5 GHz unlicensed band consists of 150 MHz of usable spectrum, but the FCC is contemplating more than doubling that figure to 345 MHz. This would help ensure that Wi-Fi, bluetooth, and other unlicensed devices continue to grow.

One such newer protocol developed for the unlicensed ISM bands is known as LTE-U, or LTE-LAA. These technologies are similar to Wi-Fi but are based on the LTE technologies used in the mobile carriers' *licensed* mobile networks. LTE-U/LAA are improvements on Wi-Fi and should operate alongside Wi-Fi networks, perhaps even improving the performance of Wi-Fi devices.

The 70-80 GHz high band may also be useful as unlicensed territory, providing extremely high capacity short links for connecting all kinds of computers and media devices in homes, offices, and industrial settings.

Figure 8: High bands could substantially expand available spectrum



Policy for 5G Networks and Spectrum

Here are the fundamentals of a successful 5G policy:

- Successfully complete the 600 MHz incentive auction.
- Expand the 5 GHz unlicensed band.
- Open the high bands at 28, 37, 39, and 64-71 GHz, using primarily flexible-use licenses and possibly allowing for some unlicensed spectrum at the higher frequencies.
- Promote flexible secondary spectrum markets. The ability to buy and sell spectrum is crucial if existing mobile carriers and upstarts are to build the types of complex networks needed to deliver 5G services.
- Pursue a flexible and cooperative strategy at the state and local levels to encourage rapid build out of wired networks and siting of small cells.
- Reverse the attempt to regulate the broadband Internet, including mobile, as a telephone utility (see below). Instead, adopt a forward-looking policy that encourages innovation and investment.

Internet Policy

Achieving the 5G future will require risky technological and business experiments and large financial investments. The mobile Internet revolution succeeded in the U.S. in large part because of a bipartisan consensus policy of entrepreneurial innovation, not regulation. That policy, however, is now at risk of coming unglued. With it, the 5G future is at risk.

For three decades, U.S. policy affirmed that enhanced data services and, later, information services (Internet and broadband) were not subject to the old rules governing monopoly telephones. Perhaps not surprisingly, most of the investment (totaling $1.5 trillion) and innovation flowed to this arena of information services, and the old, highly regulated telephone network withered away.

Now, however, the FCC has reclassified the broadband Internet, including mobile, as a Title II telephone network and plans to regulate it as such. This is a dramatic reversal of a successful policy, and it could impede the flexibility, energy, and investment that will be needed to explore and build the next 30 years' worth of innovations.

The Internet is not, as the new regulations presume, a stagnant utility. It is a growing, dynamic ecosystem. It doesn't transport undifferentiated molecules of water or electrons but highly differentiated bits of information, which are connected to a wildly diverse and growing array of apps, content, and services spread across many industries.

An example of a regulation that could impede 5G is the new suspicion of sponsored or free data. Free data is already a useful tool by which content firms, such as music streaming companies, help pay for the data consumed while subscribers use their products. In the future free data will be a key component of health care apps and connected car services, among many other new offerings.

But the FCC is considering banning, or curtailing, use of such strategies, under the conviction that it violates the "net neutrality" principles embedded in its new Internet regulations. Such prohibitions on new business arrangements, which are win-win-win for consumers, mobile ISPs, and content firms, could disrupt rational economic arrangements and thus block innovative new services, and therefore discourage new infrastructure and spectrum investment.

The FCC's new assertion of authority over Internet technologies and business arrangements is broad and deep. Treating new 5G networks and services like the old telephone network would increase the chances that it produces telephone levels of innovation—in other words, very little.

Conclusion

5G networks will be a foundation for innovation across the economy. They consist of advances in high band spectrum, cloud computing, and the adoption of wireless Internet services across a much broader set of firms and industries. Rich media content and the immersive Internet, consisting of billions of new devices joining the network, continue to drive rapid growth of data traffic. Such growth can only be encouraged and accommodated with expansion of networks, via small cells and other similar wireless access points, and by opening up far more wireless spectrum than is available commercially today. EE

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