5G and Advanced Networks Briefing Booklet

March 2019

The Future of Mobile Networks and 5G

What is 5G?

5th generation mobile networks, abbreviated 5G, are the next generation of wireless telecommunications.. Carriers are marketing 5G for its provision of higher speeds, greater capacity, seamless connectivity, and lower latency, offering 1 gigabit per second or faster for greater numbers of users. 5G technology, according to available descriptions, combines fiber deployment with wireless connections to end-users, with the fiber needing to be within about 1,000 feet of the end user.

What will 5G do?

5G uses significantly smaller cells than traditional wireless network buildouts. At a minimum, 5G small cells provide a means to increase capacity in existing networks. Carriers suggest that 5G will support billions of connected devices, enabling the "Internet of Things," driverless cars, virtual and merged reality, smart agriculture, and other technologies that require heightened network capacity, communication, and data transfer. Verizon says "fixed wireless" (home Internet) will be its first 5G application. AT&T has talked about using 5G to replace its old DSL offerings, enabling the company to deliver a quad play of DirecTV service, 5G home Internet, wireless phone, and home phone.

When will 5G arrive?

Carriers have been announcing 5G's imminence for several years. AT&T, Verizon, and other carriers have announced plans to pilot and field-test 5G in several U.S. locations and have begun to deploy in limited markets. Most industry analysts note that 5G will not be widely implemented until 2020 or perhaps much later. And, then, it will be largely available in population dense, high-income, and fiber-rich areas. For example, it appears that none of the 3 companies (AT&T, Frontier, and Consolidated) accepting $590 million FCC Connect America Fund 2 (CAF2) funds in California will be deploying 5G technology to upgrade or reach 231,825 underserved and undeserved locations, although AT&T will be constructing fixed wireless infrastructure.

Why is 5G important?

A Qualcomm-led study claims that by 2023, when 5G is fully realized across the globe, the technology could produce up to $12.3 trillion worth of goods and services enabled by 5G. The same reports claims the "5G value chain" will generate up to $3.5 trillion in revenue in 2035 and could support 22 million jobs. Other studies question whether 5G services will find a sufficiently sizable market to support 5G's costs.

What will consumers need for 5G?

Existing devices currently won't work on 5G networks and 5G standards haven't been established. Consumer-ready, 5G-compatible devices will need to be developed, manufactured and distributed for public consumption. 5G likely will benefit hardware firms that can produce a new generation of must-have devices.

Is 5G a substitute for wireline broadband?
5G advocates intend 5G to be a substitute for wireline infrastructure to end users. However, every wireless communication ends up as a wireline transmission for backhaul or to the backbone. A January 2017 Vantage Point paper states: *"wireless technologies should be viewed as a complement—a tool in a toolkit—rather than a viable widespread substitute for wireline broadband networks. In fact, newer wireless technologies will rely more heavily than any predecessor wireless technology upon far deeper penetration of wireline facilities. Undoubtedly, 5G wireless technologies will result in better broadband performance than 4G wireless technologies and will offer much promise as a mobile complement to fixed services, but they still will not be the right choice for delivering the rapidly increasing broadband demanded by thousands or millions of households and businesses across America."* It also is generally recognized that 5G will not be a solution for reaching rural unserved communities and more remote areas, such as Tribal Lands, in the foreseeable future.

How will 5G affect rural broadband?
Industry experts caution that both 4G and 5G rely heavily on the wireline network and thus do not, in themselves, solve limitations on rural broadband infrastructure. This reliance on in-the-ground, expensive fiber infrastructure only will increase with 5G because only a small portion of the last-mile customer connection (the "local loop") will use wireless technologies. In other words, 5G networks are predominantly wireline deep fiber networks, with only a small portion of their network using a wireless technology—the connection to the end-user.

Will 5G work in rural areas?
Other than traditional licensed mobile spectrum held by existing carriers, the only spectrum available for use by 5G is so high in frequency that the propagation loss and environmental impacts are extremely significant in rural areas with diverse terrain. These high frequencies also have poor penetration capabilities. To overcome these shortcomings, the 5G wireless cells must be placed very close to the customer (often within 300 to 500 feet or at the most 1,000-1,500 feet), which make 5G deployment more problematic for many rural communities.

What are carriers doing to prepare for 5G?
While technology companies (such as Google and Facebook) have scaled back their fiber-to-the-premises (FTTP) plans, broadband providers—wired and wireless—are seeking to increase the amount of fiber in their network in preparation for 5G. Landline providers are replacing copper cable with fiber, cable operators are replacing coax cable with fiber, and even wireless providers are replacing wireless networks with fiber by placing their towers (or small cells) closer to the customer.

What will be the effect of 5G on the Digital Divide?
The Digital Divide—particularly between rural and urban areas—could widen as 5G rolls out, because there is little economic incentive to provide 5G in areas that are not population dense and fiber rich. Also, given that 5G will require a new generation of 5G-ready devices, low-income consumers will have difficulty paying for the likely higher costs for both computer hardware and wireless and wireline service fees. Thus, as technology evolves, additional effort will be needed to ensure that there is not a widening divide between low-income communities and the rest of California.

TELECOMMUNICATIONS POLICY REVIEW
Washington, D.C.
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MODERN REGULATORY PRACTICES SERIES MEMORANDUM

Re: "5G" Cellular: Some Points.

Introduction

"5G" is the term used for the next generation of cellular mobile radio service. And, Wikipedia probably has all the information on this technology that you need to know. Worth remembering is that 5G frequencies are far higher than those used these days ca. 6 GHz, 24 GHz. So one thing needed is a lot more "transceivers" -- base stations. So setting these networks up could get really expensive (regulation -- Federal and local -- has pushed the cost of 4G base stations to the $800,000 range).

By the Numbers

Now, cellphone companies -- and, even broadcasters -- say 5G service will just be wonderful (or, as Lawrence Welk said, "wunnerful, wunnerful"). Both industry and Government personages have also declared that it's important the United States "maintain its technological leadership," and all that. But is that really true?

The first thing to remember is the U.S.-based cellphone companies -- Verizon, AT&T, and Sprint -- are much smaller than the leading companies in the world. Much. The biggest cellphone company is (1) China Mobile, with 922 million customers. They're followed by (2) India's Airtel (aka. Bharti Airtel)(436M), (3) Vodafone Idea (421M), (4) Telefonica (357.5), (5) Axiata (350M)(Malaysia), (6) Vodafone (313M), (7) China Unicom (310); (8) China Telecom (294M), (9) America Movil (279M), and (10) Reliance Jio (272M).

France Telecom, now Orange, is No. 13, with 199M customers. Then, there's (15) Telenor (172M)(Norway), and (16) Deutsche Telekom (170M). You don't hit Verizon until No. 19 -- 154M customers. AT&T Mobility is No. 20 (150M), and Sprint is No. 30 (53.6M). In a world where global cellphone elephants are dancing, the U.S.-based companies are very much the chickens -- which, of course, means they're also likely takeover targets. Just as Japan's Softbank bought Sprint, we could see one of the monster Chinese companies buying Verizon, say, or even AT&T.

During the immediate post-Bell System breakup period, the Bell companies expanded aggressively overseas. But no American cellphone company today is a significant "world market" player -- and, our companies are just far smaller than anyone else's. So how exactly are we going to "maintain" leadership?

"Just Say No" to Manufacturing

In the 1980s, the United States had three world-class cellular equipment manufacturers -- AT&T's Lucent, Motorola, and Nortel (a company both Canada and the United States were proud to call their own). But U.S. Government policy hurt these companies badly. Spectrum auctions siphoned away resources that equipment vendors might have used to finance research, etc. The United States also sanctioned several different technical standards.

Today. our cellphone manufacturers are all out-of-business. China's Huawei is the world's leading telecommunications equipment vendor, with revenues of $93 billion a year. Cisco is ranked second at $48 billion -- but that's chiefly computer servers. Fujitsu is third, at $39B, followed by (4) Nokia ($28B), (5) Ericsson ($24B), (6) NEC ($24B), (7) Qualcomm ($23B), (8) ZTE ($17B), (9) Corning ($10.12, and (10) Motorola Solutions ($6.38B).

Remember, Qualcomm is chiefly semiconductors and Corning, fiber cable. And, Motorola Solutions sells chiefly to the "authority market" (law enforcement). We don't even have any cellular handset manufacturing here (Apple has Foxconn make its gear in China).

Greed Getting the Better Of It

The United States does have one of the leading handset providers -- Apple. Even though virtually all of its manufacturing is overseas.

The biggest problem with Apple, however, is unremitting corporate greed. As experts including radio's Rush Limbaugh have noted, there's not a lot of difference between the latest iPhone offerings and the iPhone 7, for instance. Or, the iPhone 5 -- which is what they're selling in India. The big difference, however, is price.

Apple pushed the handset price well over $1,000 -- and, then was surprised when sales dropped off. At the same time Apple is pushing its prices higher and higher, Chinese companies such as Xaomi or Huawei are going in the opposite direction. Much more "feature rich" handsets for lower and lower prices. What's proven to be a winning combination in much of Asia and Africa.

Still No. 1

One sector where U.S.-based companies are maintaining their leadership is microprocessors and other semiconductors. Intel is the biggest in the world with $56 billion in sales. Samsung is second, at $44B, followed by (3) Taiwan Semiconductor ($23B), (4) Qualcomm ($15.44B), (5) Broadcom ($15.3B), (6) SK Hynix ($14.23B), (7) Micron technology ($13B), (8) Texas Instruments ($12B), (9) Toshiba ($11B), and (10) NXP ($9.5B).

The leading designer and producer of microprocessors for cellphones, by the way, is UK-based ARM Holdings, now controlled by Sprint's parent, Softbank.

What Could Be Done?

Now, there are steps which the FCC could take that would improve our global situation. We could require the equipment used to prove 5G services be assembled in the United States with a minimum U.S. content. We could even suggest that any foreign-based carrier which wants to do business here must use American products in their networks and facilities overseas. The FCC, remember, is dispensing valuable assets. It's not required to just "lie back and enjoy it," as Senator Ernest F. ("Fritz") Hollings might say.

Right now, the FCC is very flexible when it comes to the "type acceptance" of equipment. If a certified facility overseas says the device won't cause interference, the FCC generally goes along with that finding. But we could require another test here, with American engineers. And, as the FCC

has done in connection with the ongoing U.S. vs. Huawei & ZTE, the FCC could even ban certain products from our market.

Conclusion

Years ago, nobody in Washington could imagine a truck and automobile business where Mercedes-Benz and Volvo dominated the "Class 7/8" over-the-road truck market. Nobody in Washington had heard of Toyota, Hyundai, and Kia. The only people familiar with Audi, BMW, even VW were those who'd served overseas. Now, of course, the American car companies have fallen far behind and, in 10 years, we'll probably be like Britain. That is, where all the car and truck companies are foreign.

Right now, the third-largest cellphone company (T-Mobile) is controlled by the German Government, and the fourth-largest (Sprint) is Japanese. The fifth biggest -- America Movile's TracFone and other brands -- is Mexican, of course. And, for heaven's sake, Verizon Wireless's new CEO is actually Swedish.

If the U.S. Government (and, the FCC) don't start paying more attention to "America First," in ten years foreign-based companies will control our cellphone business -- as they currently control our wireline telephone equipment business. And, that should be the primary concern today. Not fanciful stories about "maintaining our [nonexistent] global leadership."

* * *

5G will be the next revolution in global communications, but the U.S. may be left behind

Michael Hiltzik

Telecom expert Susan Crawford warns that the U.S. isn't prepared to take the lead in the next generation of internet technology (scrawford.net)

In late 2017, Susan Crawford was visiting Seoul, South Korea, about six months before it hosted the 2018 Winter Olympics.

Although she's an expert in telecommunications policy, Crawford was stunned at what she witnessed in Korea, which she describes as "the most wired nation on the planet" — flawless cellphone coverage even in rural areas, real-time data transmission, driverless buses using the latest communications technology to smoothly avoid pedestrians and evade obstructions.

"I've never been embarrassed to be American before," Crawford told me recently. "But when Korean people tell you that going to America is like taking a rural vacation, it really makes you stop and worry about what we're up to."

Crawford, who teaches at Harvard Law School, has assembled her concerns, along with suggestions for how to alleviate them, in a new book published this week entitled "Fiber: The Coming Tech Revolution — and Why America Might Miss It." It's a follow-up to her 2013 book "Captive Audience," which warned that the nation's global leadership in internet technology was being frittered away by placing tech policy in the hands of profit-seeking companies with no incentive to keep the U.S. on the leading edge.

It may sound paradoxical, but the future of advanced wireless services depends completely on how much fiber is in place.

Susan Crawford

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"Fiber" describes how that trend has intensified. The risk is even greater today, Crawford writes, because the data-carrying capacity of the next generation of fiber optics, known as "5G" (as the fifth generation of wireless

telecommunications technology), will give countries that invest in those advanced networks a huge advantage over those that don't. It's 100 times faster than the existing 4G technology and far more capacious, allowing simultaneous connections of billions of devices.

Which countries are investing in the technology? For one, China, which is planning to cover 80% of its residences and businesses with 5G connectivity by 2025. "While the leaders of the USA and China rant and rave at one another, Western companies continue to work closely with those in China, aware that 5G will be a global platform," observed tech analysts at ReThink Research last month. "In the run-up to 5G, it has been China's operators, especially China Mobile, which have been a driving force."

As Crawford reports, America's experience with trying to bring fiber to its homes and businesses isn't auspicious. Only about 10% of the nation's 119 million households subscribe to high-speed fiber services, and 75% of census blocks have no access to residential fiber at all. Households with fiber connections tend to be located in the most densely developed and richest parts of the country — America's "digital divide" has turned into a chasm.

This has happened, Crawford writes, because the U.S. hasn't turned the building of its optical fiber infrastructure into a national imperative — that is, government-supervised — as it did its highways, airports, dams and bridges. She draws comparisons to the government initiative to bring electrification to rural communities in the 1920s and 1930s.

Electrification, she writes, "followed a set pattern: municipal buildings and businesses first, wealthy urban dwellers next, then poorer urban dwellers, and last of all, rural homes and farms." That commercial model resulted in 90% of farmers in the 1930s lacking electric power and even poorer sections of thriving cities lacking applicances we take for granted — refrigerators, electric cooking and heating. One result was the rise of public power systems, just as one result of the spotty rollout of fiber connectivity today is the emergence of municipal broadband.

By ceding telecommunications infrastructure to big, monopolistic carriers such as Comcast, Verizon and AT&T, the U.S. government has effectively given up its role in information technology policy, Crawford says. The Federal Communications Commission — under President Obama as well as President Trump — allowed the companies to develop vertically integrated systems in which they own the distribution systems as well as the content moving over those systems; Comcast owns NBC Universal, AT&T owns Time Warner properties including CNN and Warner Bros., and Verizon owns Huffington Post, Yahoo, and other former AOL properties.

"These guys' plans will be to have islands of exclusive content," Crawford told me. "You will join the Comcast world when you're born, or the AT&T world."

That control removes the incentive for the internet carriers to spend much to upgrade their distribution networks to fiber, she argues. "They're looking for ways to make more money out of the same physical infrastructure, not for ways to expand that infrastructure. They feel they've reached the number of people they want to serve, and now they're just looking for how to make more money from them."

That's a critical problem, because although 5G networks serve wireless devices, they still need extensive land-based fiber systems —in fact, much more extensive systems than the existing 4G technology. "It may sound paradoxical," Crawford writes, "but the future of advanced wireless services depends completely on how much fiber is in place." At the moment, there's not enough of it in the U.S. to meet the needs of 5G, and the big private companies will not and can not raise the private capital needed to build more, at least not from investors looking for a quick return on their money. Basic infrastructure "requires patient capital," Crawford observes.

The answer is to bring in the only entities willing to make long-term, patient investments: cities, states and the federal government, the same entities that built dams, roads and bridges — indeed, the internet itself — before it was clear how any of that infrastructure could be exploited by private companies for profit.

Cities and localities can guarantee bonds to provide low-cost financing for fiber networks; the federal government can exploit its own rock-bottom borrowing costs. All have the incentive to bring the networks to residents and businesses shunned by the commercial internet carriers because they don't look sufficiently profitable.

But the incumbent internet firms are standing in the way, Crawford reports. The companies have been pushing state legislation and federal regulations that would give them more power to decide how to deploy 5G equipment in their own interest by cutting local and state authorities out of the process. California Gov. Jerry

Brown vetoed one such bill in 2017, in a decision regarded as a blow to the major wireless internet carriers.

Crawford believes it's pointless to expect any leadership on this issue from the current FCC or its Republican chairman, Ajit Pai. "Today's FCC is the equivalent of a loading dock up to which the incumbents' trucks are backing to take out as much cash as they can. There's no thought of genuine oversight of the current market."

The solution may be to track what happened with electrification a century ago — start small. "There are 700 communities and cooperatives across the country, many of them in Republican areas, that deeply understand this issue and are pragmatically working on building fiber networks. Just as with electricity, you start on the local level and gradually shame the feds into doing something."

The problem, however, is that people without genuine high-speed connections don't know what they're missing, so they aren't clamoring for improvement — yet. "There's a little bit of internet access in a lot of places, and a lot of confusion over what it would mean to have a world-class connection. In America, people just don't know."

Pulitzer Prize-winning journalist Michael Hiltzik writes a daily blog appearing on latimes.com. His business column appears in print every Sunday, and occasionally on other days. As a member of the Los Angeles Times staff, he has been a financial and technology writer and a foreign correspondent. He is the author of six books, including "Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age" and "The New Deal: A Modern History." Hiltzik and colleague Chuck Philips shared the 1999 Pulitzer Prize for articles exposing corruption in the entertainment industry.

Introducing 10G: The Next Great Leap for Broadband | NCTA — The Internet & Television Association

Global cable industry plans massive advancement in network capacity and speed with platform that will keep ahead of consumer demand and innovation curve

LAS VEGAS — January 7, 2019 — Today at the Consumer Electronics Show (CES), NCTA – The Internet & Television Association, CableLabs and Cable Europe introduced the cable industry's vision for delivering 10 gigabit networks, or 10G™ – a powerful, capital-efficient technology platform that will ramp up from the 1 gigabit offerings of today to speeds of 10 gigabits per second and beyond – to consumers in the United States and across the globe in the coming years. To support the rollout, Intel will deliver 10 gigabit ready technology from the network infrastructure to home gateways.

Cable operators in the U.S., whose networks currently pass 85 percent of U.S. homes, including Comcast, Charter, Cox, Mediacom, Midco and others – plus international operators, including Rogers, Shaw Communications, Vodafone, Taiwan Broadband Communications, Telecom Argentina, Liberty Global and more, are implementing the new 10G initiative, with lab trials already underway, and field trials beginning in 2020.

"With groundbreaking, scalable capacity and speeds, the 10G platform is the wired network of the future that will power the digital experiences and imaginations of consumers for years to come," said NCTA President and CEO Michael Powell. "As an industry, we are dedicated to delivering an exceptional national infrastructure that will power digital advancement and propel our innovation economy into the future."

A Great Leap, Already in Motion

The foundation of 10G is already proven with cable networks offering 1 gigabit service today across 80 percent of the U.S., up from just five percent in 2016. Similar gigabit services are available by cable operators across the world. Ultimately, 10G will deliver symmetrical speeds that are up to 10 times faster than today's fastest networks.

Built using a capital-efficient approach and leveraging the expansive cable networks already deployed throughout much of North America, Europe and Asia, the 10G network will seamlessly support a wide variety of immersive digital services and applications. On the path to accomplishing 10G, internet providers will continue to upgrade their networks with a combination of technologies that currently exist alongside the ongoing advancements of new hardware, software and techniques that are being developed and tested by technologists and vendors.

Redefining Experiences and Opportunities

10G's promise of faster speeds, more capacity, lower latency and greater security will enable and help fully realize a wide variety of new services and applications that will change the way millions of consumers, educators, businesses and innovators interact with the world.

"CableLabs creates the technology that supports the deployment of high-capacity broadband networks and gigabit services at scale for the industry," said CableLabs President and CEO Phil McKinney. "With the 10G platform, CableLabs will help ensure the broadband infrastructure will be in place globally with the capacity and performance needed in the future to fuel new innovations and emerging technologies that will transform and enhance the way we live."

Through the 10G platform, new innovations will transform consumer experiences in homes, businesses and wherever people connect. It creates new possibilities for smart cities, healthcare, connected gaming, video streaming, virtual and augmented reality, education and businesses of all sizes.

Simply put, the 10G platform promises improved security, seamless connectivity, reliability, increased capacity and, as the name would imply, up to 10 gigabit per second speeds.

CES media attendees can learn more about the 10G platform by attending "The Future of the Broadband Network" conversation at The Four Seasons on Wednesday, January 9 at 9:00 a.m. PT. Industry leaders from NCTA, CableLabs and member companies will participate.

For more information on the cable industry's 10G platform, please visit https://www.10Gplatform.com.

All other products and/or services referenced are trademarks of their respective companies.

About NCTA:

NCTA – The Internet & Television Association represents network innovators and content creators that connect, entertain, inform and inspire consumers every day. NCTA's members have invested $290 billion in private capital to build the world's most powerful technology platform, reaching 93 percent of American homes and serving 66 million customers. More than 200 programming networks are creating imaginative, popular and award-winning television content. Our industry supports 2.9 million American jobs and employs at least 300 people in every congressional district.

About CableLabs:

As the leading innovation and R&D lab for the cable industry, CableLabs creates global impact through its member companies around the world and its subsidiaries, Kyrio and UpRamp. With a state-of-the art research and innovation facility and collaborative ecosystem with thousands of vendors, CableLabs delivers impactful network technologies for the entire industry. For more information, please visit https://www.cablelabs.com/.

About Cable Europe:

Cable Europe is the trade association that connects leading broadband cable TV operators and their national trade associations throughout the European Union. The regulatory and public policy activities of Cable Europe aim to promote and defend the industry's policies and business interests at European and international level. The European cable industry provides high speed broadband internet, TV services, and telephony to more than 65.8 million homes in the European Union. www.cable-europe.eu

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Supporting Quotes

ARRIS

"ARRIS has been developing the building blocks that are the foundation for 10G for several years, providing the ability to gracefully evolve today's networks to support multi-gig symmetrical services. Early technology trials have been very promising and will mature very quickly this year," said Bruce McClelland, ARRIS CEO.

Charter

"We are entering a new age of digital innovation that will require networks that can deliver high speed, massive capacity and low latency," said Tom Rutledge, Chairman and CEO of Charter Communications. "The cable industry's 10G platform will be the platform of choice for the innovators and developers of the future technologies and applications that will create and inspire the way we work, live, educate and entertain."

Comcast

"This initiative demonstrates our continued leadership in broadband, where today we provide the fastest speeds,the most advanced Wi-Fi,and the broadest deployment of gigabit Internet service, now available to tens of millions of homes," said Dave Watson, President and CEO of Comcast Cable. "10 gigabit technologies will open the doors to an almost unimaginable future of innovation paving the way for an entirely new generation of exciting applications and experiences."

Cox

"There's no better place to introduce the 10G initiative than CES – the world's largest showcase of current and future technologies," said Pat Esser, President of Cox Communications. "Many of the innovative visions being discussed here will require the kind of exceptional technology platform that our industry will deliver with 10G."

Liberty Global

"While the world is talking about 5G, we're proud to be part of this extraordinary movement to 10G. We're already launching entire Gigicities and that's just the start," commented Mike Fries, CEO and Vice Chairman of Liberty Global. "We're building a network that leverages the strategic advantage that DOCSIS 3.1 brings, and we're excited to utilize this world-class platform to provide a 1G to 10G playbook that will fuel innovation and the economy of the future."

Rogers Communications

"The industry is at the cusp of a technological transformation as we move beyond super high speeds, to introduce ultra-high capacity and ultra-low latency that will open up a whole new world of possibilities for consumers and businesses," said Jorge Fernandes, CTIO, Rogers Communications. "10G broadband is an instrumental technology for 5G as it will be the critical, unified backbone that connects our wireless, broadband and enterprise networks."

SCTE•ISBE

"The introduction of 10G positions our industry as the foundation for innovations that will transform the lives of consumers and businesses," said Mark Dzuban, President and CEO of SCTE•ISBE. "As the industry's applied science arm, SCTE•ISBE is working in concert with NCTA and CableLabs to develop training, standards and operational practices that optimize time-to-market and performance, and to fuel SCTE•ISBE Cable-Tec Expo's role as the pivotal venue for 10G thought leadership."

Shaw Communications

"We are pleased to be part of the 10G journey with CableLabs and its members to enable the fast broadband speeds that will be critical to how our customers live and how our economy grows," said Zoran Stakic, COO and CTO, Shaw Communications. "Connectivity fuels the lives of our customers, businesses, and communities, and leveraging CableLabs' research and innovation has already allowed us to efficiently double the speeds of our fastest plans to more than 4 million homes across 94 percent of our footprint. We will continue to work with CableLabs as we push to make faster broadband speeds economically feasible and broadly available across Western Canada."

Taiwan Broadband Communications

"As one of the leading cable operators in Asia and one of the first to enable gigabit technology, we are excited to be a part of the next big step for broadband in delivering wide scale deployment of gigabit broadband across Taiwan where TBC operates," said Jimmy Chen, CEO of TBC. "Moving forward, in line with global trends, we are of the view that 10G is the innovative solution and path forward for surpassing our customers' demands for next-generation content delivery and connectivity."

Telecom Argentina

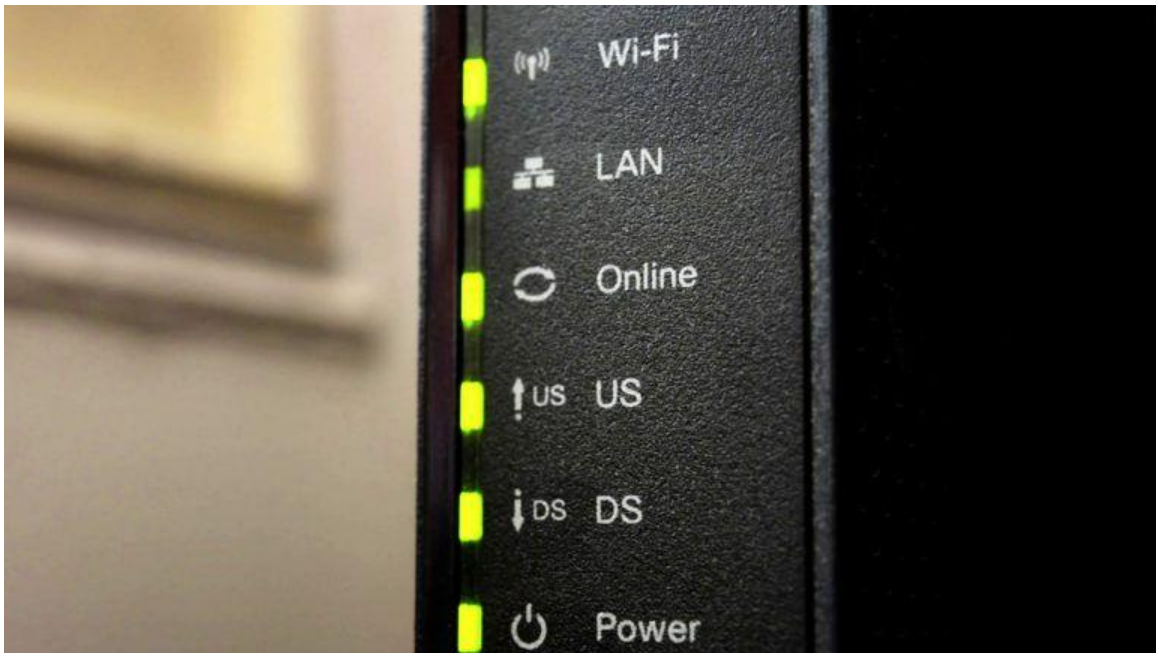
"10G represents a tremendous commitment to furthering broadband innovation by the global industry, and one we are proud to be a part of," said Carlos Moltini, CEO of Telecom Argentina. "As we continue on the path of evolving broadband services across Argentina, we are looking forward to enabling both new experiences and the development of new products and services with technologies that will enable the convergence of our fixed and mobile networks. As a mobile operator, Telecom will rely on 10G as we deploy our own next-generation networks through close integration with 10G fixed networks to enable our new wireless infrastructure."

Vodafone Germany

"We are thrilled to support the vision and development of 10G as we roll out gigabit broadband services across Germany and we are already offering gigabit service to more than 6 million homes in Germany by year-end and nearly all of our 13 million homes by the end of 2020," said Manuel Cubero, CCO, Vodafone Germany. "As technologies within the cable industry progress, we look forward to paving the way for multi-gigabit broadband and unparalleled content experiences in Germany."

BEYOND SPEED: BUILDING THE ULTRA-CONNECTED FUTURE WITH 10 GIGABIT TECHNOLOGY

Written by WK Tan | January 7, 2019



By 2022, it is estimated that each person in North America will have 13 or more connected devices[1] [#_ftn1] and those will generate large amounts of data.

The immense increase in devices and data requires intelligent networks with a new level of speed and capacity. While there may be no single device that needs a multigigabit connection today, or even three years from now, homes with 50-100 connected devices will drive unprecedented demand. At the

the living room, delivering amazing experiences, and those also demand significant new speed, lower latency and higher capacity.

10 GIGABIT NETWORKS: BIGGER CAPACITY, FASTER SPEEDS, MORE RESPONSIVE

To address this need, we're working with some of the world's leading Internet service providers, technology companies, industry organizations and standards bodies to take the next big step forward to evolve the access network—10 Gigabit networks.

10 Gigabit access networks leverage several next-generation technologies to provide low latency, multi-gigabit performance with up to 10 Gbps speed, capacity and symmetrical link rates that bring a major boost to uploads. This can all be done over modern hybrid fiber coaxial networks that deliver the

worldwide.

These speeds and capabilities may seem extreme, but only a few years ago, 100 Mbps seemed extreme and today 100 Mbps-and-faster connections are mainstream service tiers. At Intel, we have always designed our technology with tomorrow in mind and this is no different.

That's the world we're designing for—one in which everything is connected and Internet users expect to have access to the best of all experiences instantly from the comfort of their homes.

GLOBAL STANDARD, GLOBAL REACH

At Intel, we work closely with Internet service providers on the transformation of the network across the connected home, access network and data center. We're involved with every aspect of the 10 Gigabit transformation, from the network infrastructure, all the way out to the home network that will power the experience in customers' homes. We are seeing tremendous results with these technologies in lab settings today, and are working with operators to start trialing them in customer homes as early as spring 2020.

At the center of this technology transformation is a new, fully-developed technological standard called 10 Gigabit Full Duplex DOCSIS (also referred to as 10g FDX). This standard makes it possible to deliver multi-gigabit upload and download speeds over the connections already present in hundreds of millions of homes.

construction—to deliver real value to customers at scale. Much like the recent large-scale Gigabit deployments by companies like Comcast, Cox, and Charter—three of our early partners in 10 Gigabit—the technology will be rapidly scalable from the moment it is deployed.

Intel will deliver 10 Gigabit ready technology from the network infrastructure to home gateways to support the rollout. This is all part of our commitment to the transformation of the network to power tomorrow's ultra-connected homes and experiences. Our U.S. network partners, including Charter, Comcast and Cox—three of the nation's largest broadband providers—are working actively to test that technology in their networks. We are also working with MaxLinear on a new family of 10 Gigabit ready gateway platforms [http://www.maxlinear.com/maxlinear-collaborates-with-intel-and-the-cable-industry-to-enable-10-gigabit-technology-for-new-home-experiences/] for the home. In addition, NCTA—The Internet and Television Association—and CableLabs are actively working to advance 10 Gigabit technology [http://www.ncta.com/media/media-room/introducing-10g] , including creating a global certification program. You can learn more about those efforts at www.10Gplatform.com [http://www.10Gplatform.com] .

The 10 Gigabit future is coming fast, and we're excited about the new experiences it will make possible.

---

[1] [#_ftnref1] Source: Cisco VNI, 2018. https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html [https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html] .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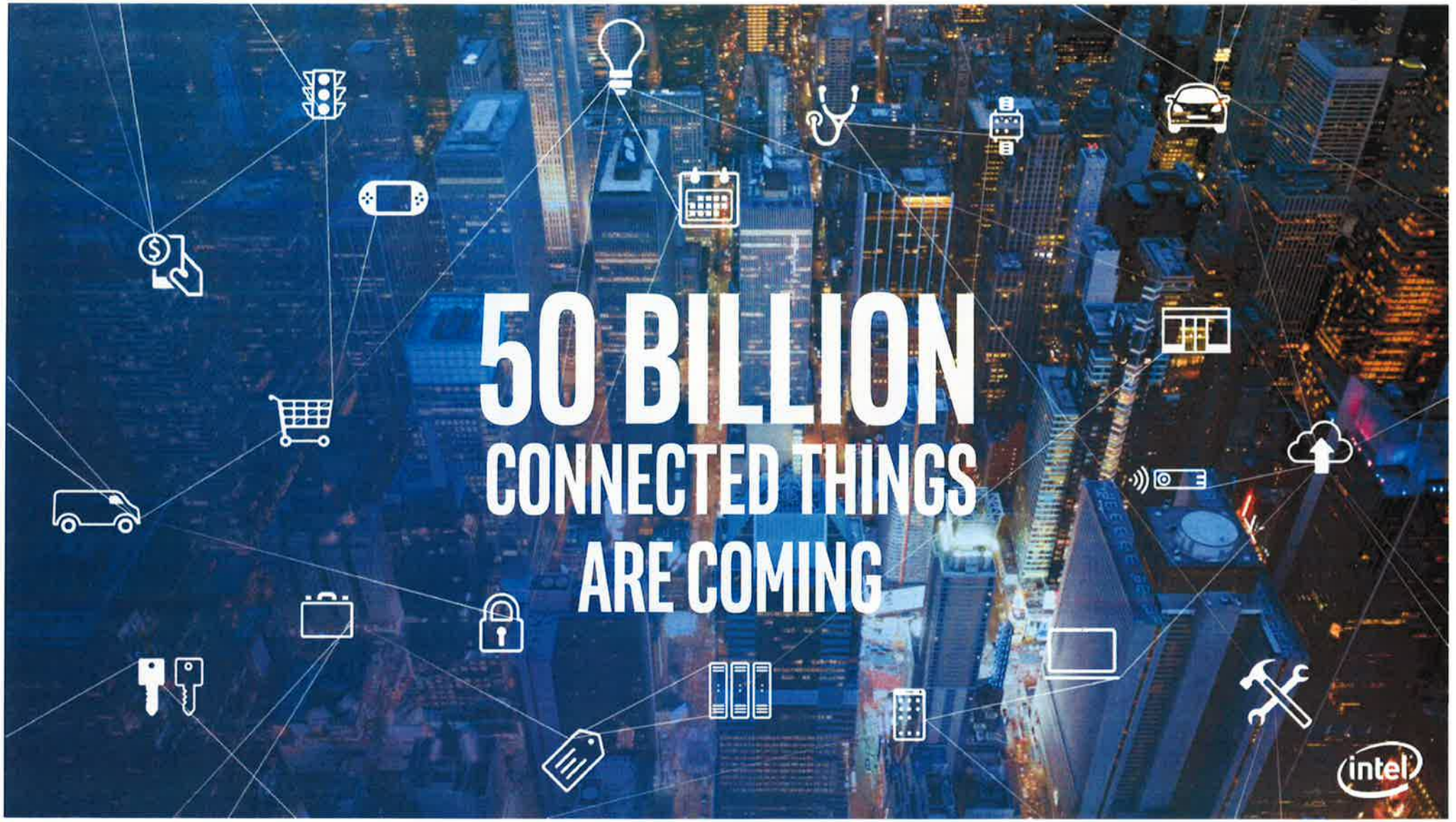
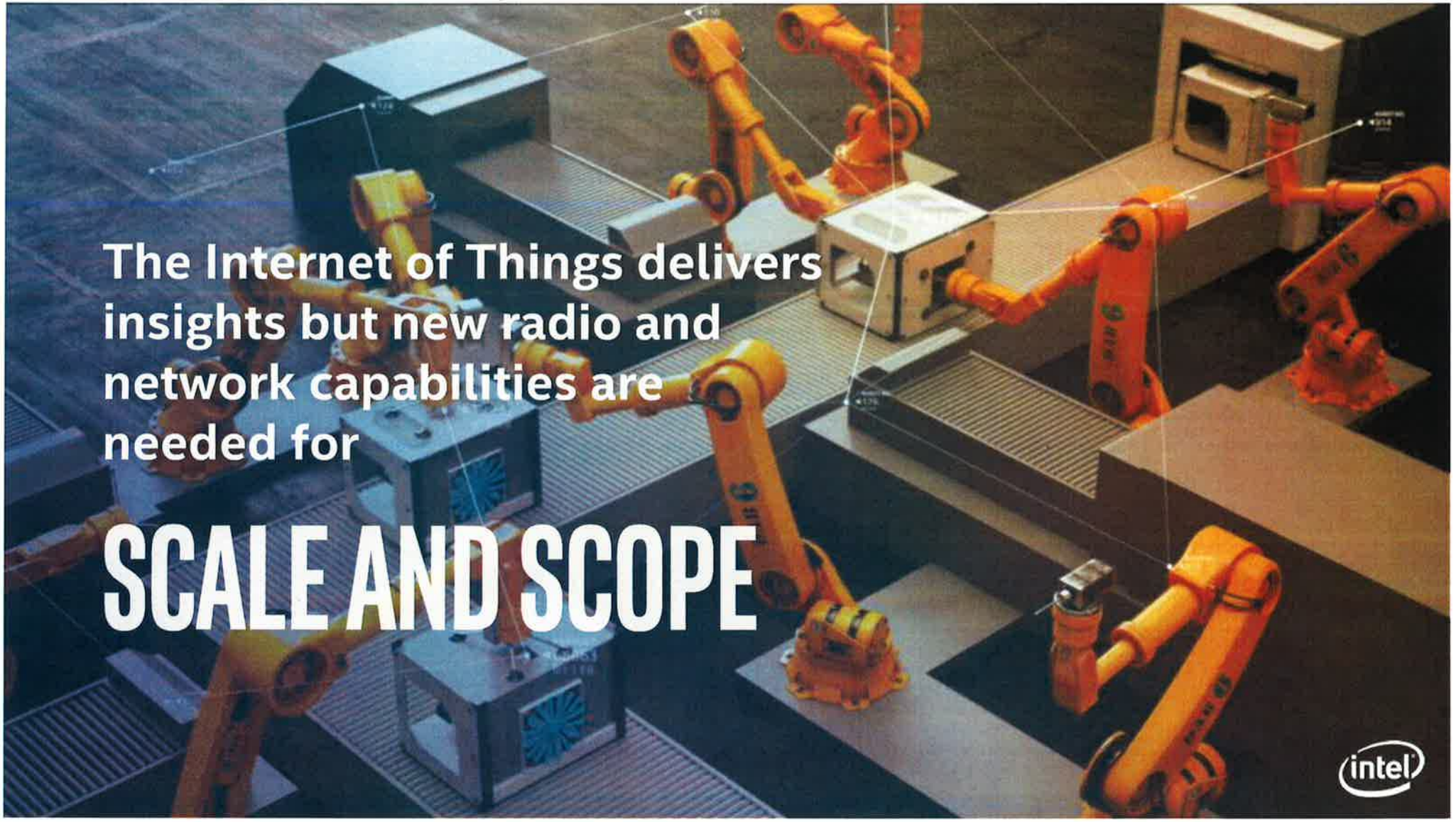
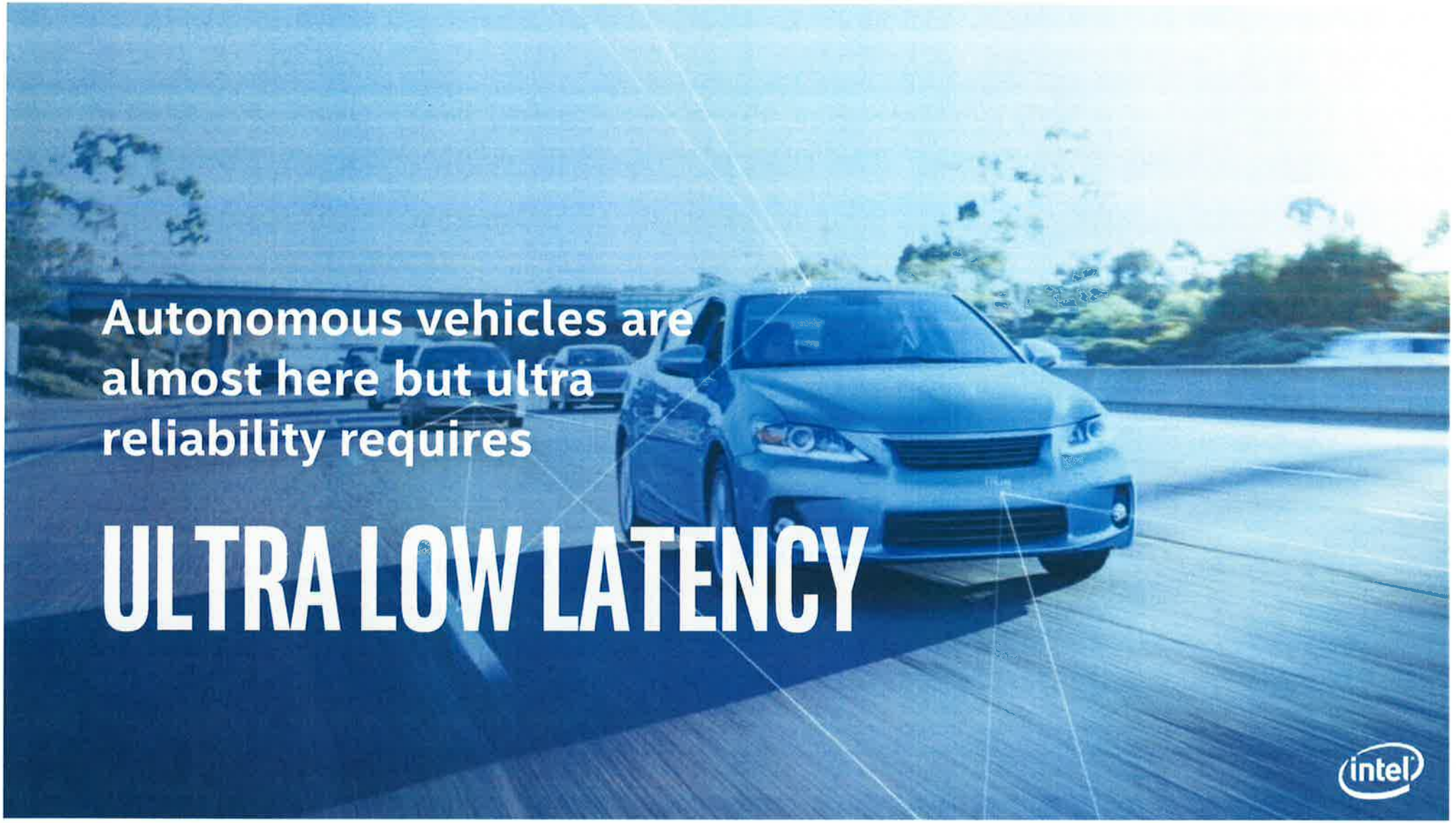
INTEL'S VISION FOR 5G


50 BILLION
CONNECTED THINGS
ARE COMING
intel


The Internet of Things delivers insights but new radio and network capabilities are needed for
SCALE AND SCOPE
intel


The visual cloud will alter how we perceive reality but immersive experiences will require
MORE BANDWIDTH
intel

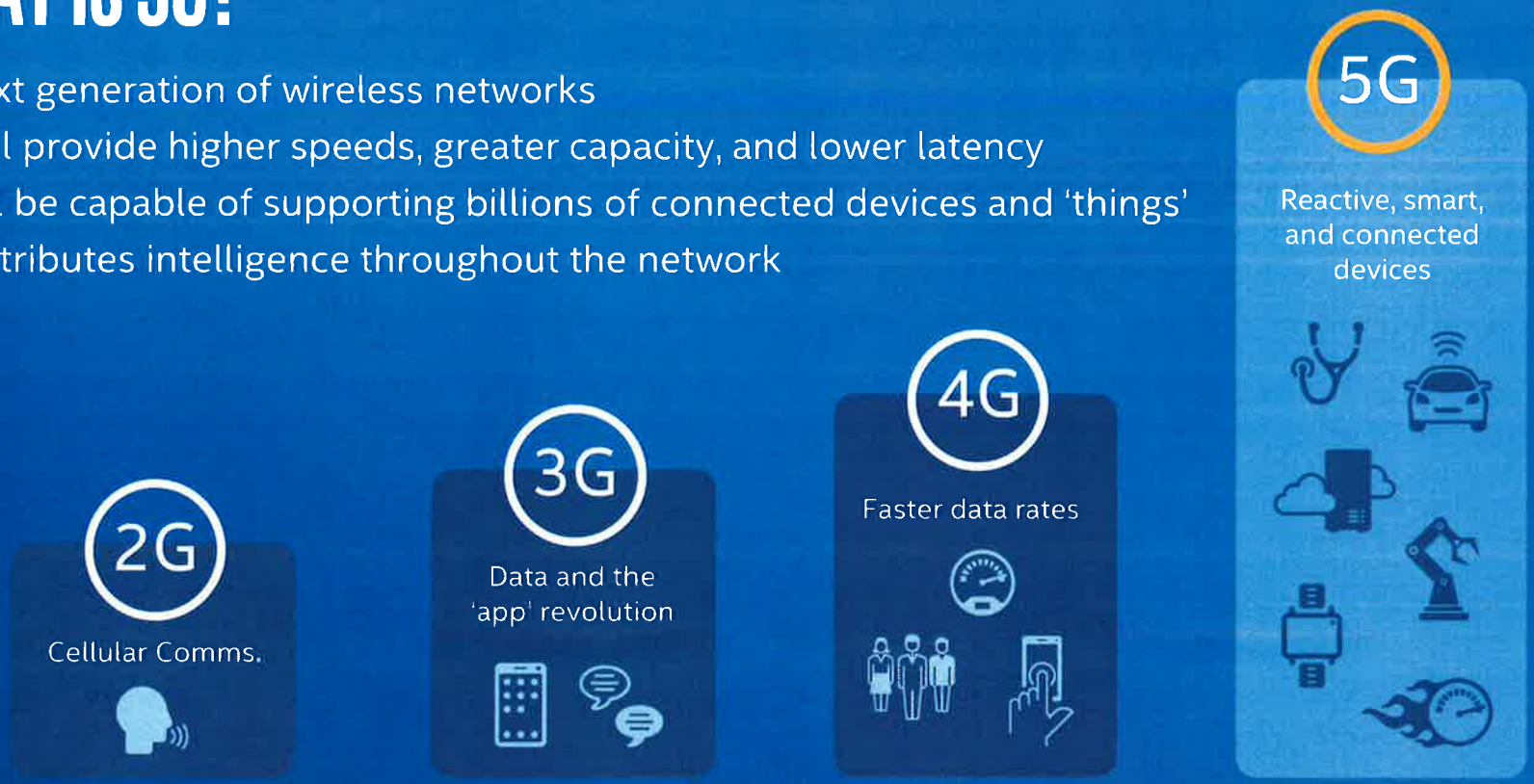

Autonomous vehicles are almost here but ultra reliability requires
ULTRA LOW LATENCY
intel


A NEW GENERATION OF
NETWORKS IS NEEDED
intel


5G
intel

WHAT IS 5G?

- Next generation of wireless networks
- Will provide higher speeds, greater capacity, and lower latency
- Will be capable of supporting billions of connected devices and 'things'
- Distributes intelligence throughout the network



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5G IN ACTION
intel

5G ENHANCEMENTS WILL TRANSFORM LIVES

Ultra Reliability and Low Latency

Massive M2M Connectivity

Enhanced Mobile Broadband

intel

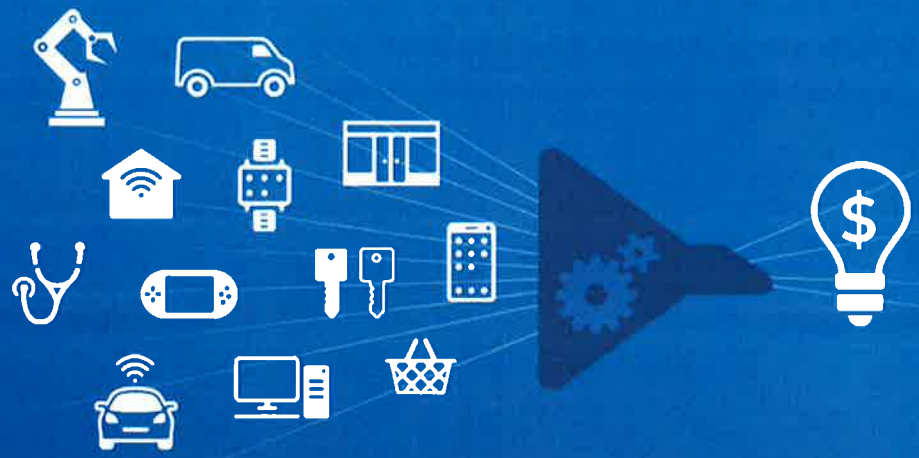
5G IS A CRITICAL ELEMENT OF THE NEW DATA ECONOMY

Connecting billions of devices will generate a massive wave of data. Only 5G has the scale and scope to enable new insights, drive business efficiencies, and create data monetization.

Autonomous Driving
1 GB/second

Smart Hospital
4000 GB/day

Connected Factory
1 million GB/day

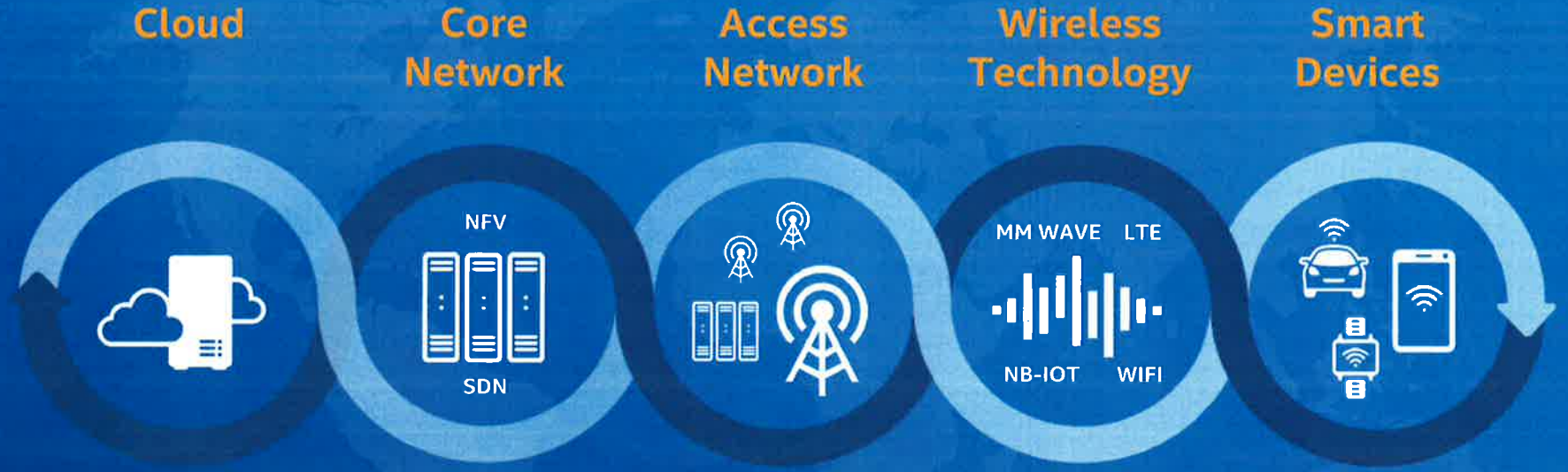


intel


Intel powers every segment of
the smart, connected world,
from the cloud to the network
to the device. This makes us the
PARTNER OF CHOICE FOR 5G
intel

INTEL POWERS 5G END-TO-END

Intel's Scale Meets 5G Scope



Intel Architecture, FPGAs, Software, Security

intel

INTEL IS ALREADY BUILDING 5G'S FUTURE

Collaborating to Accelerate 5G Technology, Standards, and Spectrum

"**BMW, Mobileye** and **Intel** are building a full self-driving car for 2021."

Tech Crunch 7/1/16

"**Intel, GE** Partner to make trains Mobile Data Centers"

eWeek 9/19/16

*Other names and brands may be claimed as the property of others.

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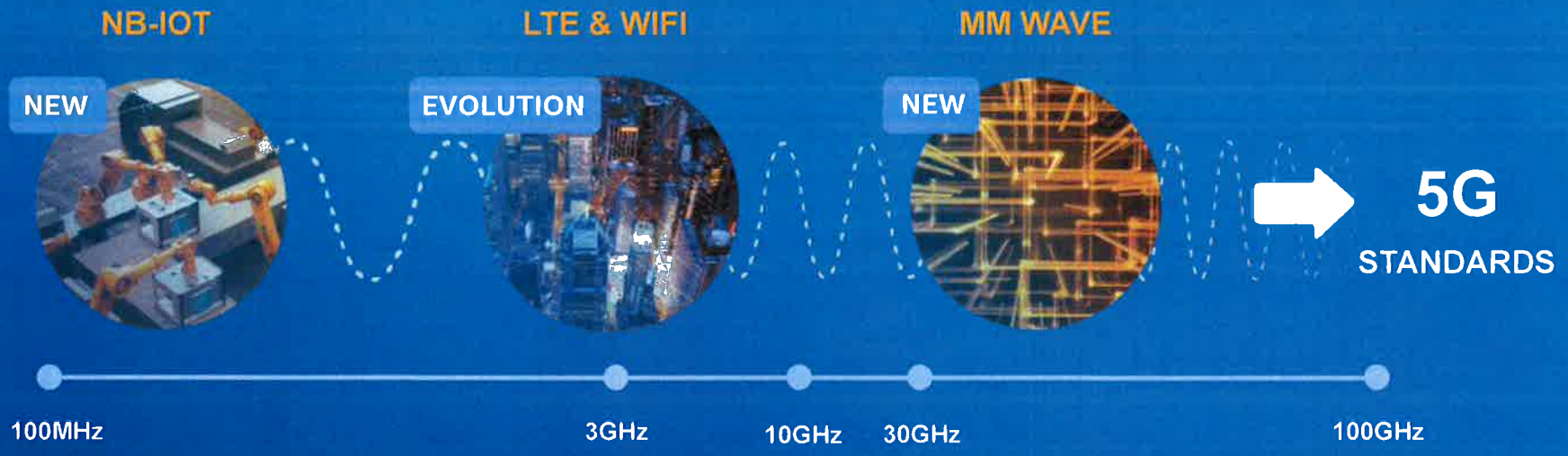
INTEL IS PREPARED FOR THE JOURNEY AHEAD


mmWave
Narrowband IoT
CRITICAL WIRELESS TECHNOLOGIES FOR 5G
Massive Antennae Arrays
LTE-WiFi Evolution
intel

INTEL DELIVERING SOLUTIONS FOR ALL 5G RADIOS



- 5G will be a heterogeneous network of many wireless technologies
- LTE, Wi-Fi, mmWave, NB-IOT, and the new 5G interface will work together seamlessly
- Intel delivering silicon for 4G and pre-5G solutions today

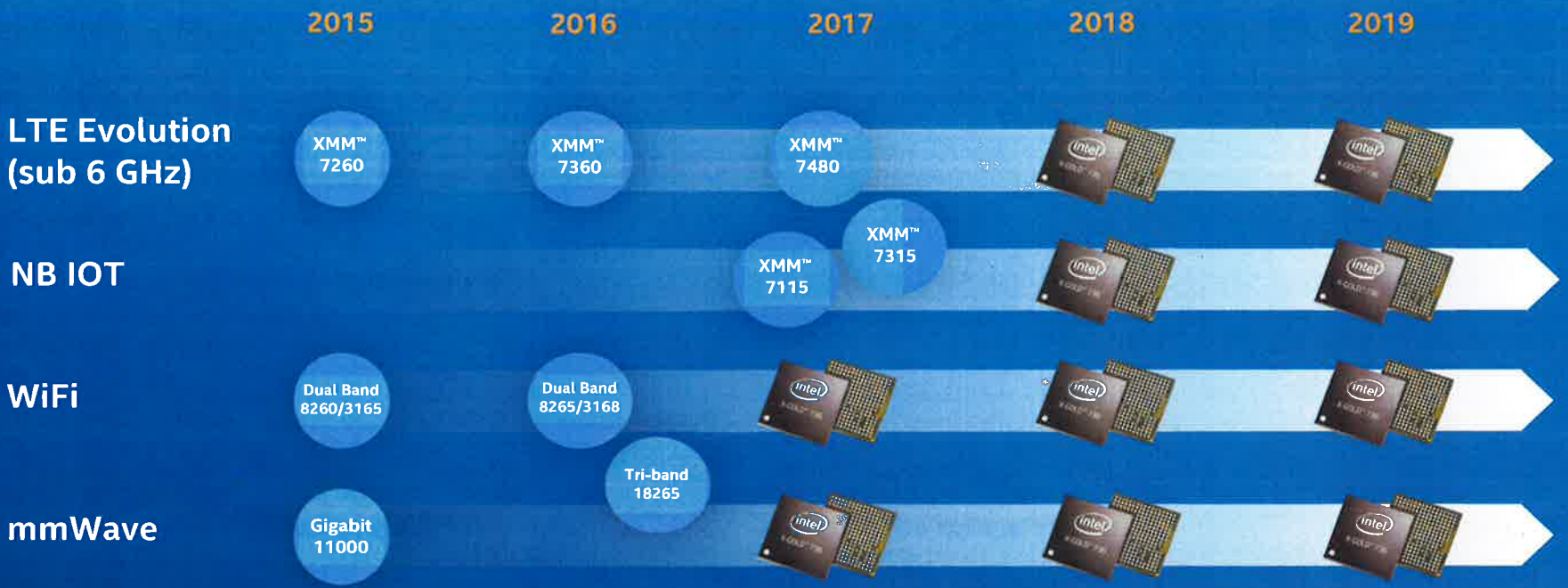
intel

INTEL'S MOBILE TRIAL PLATFORM USED TO TEST 5G END-TO-END

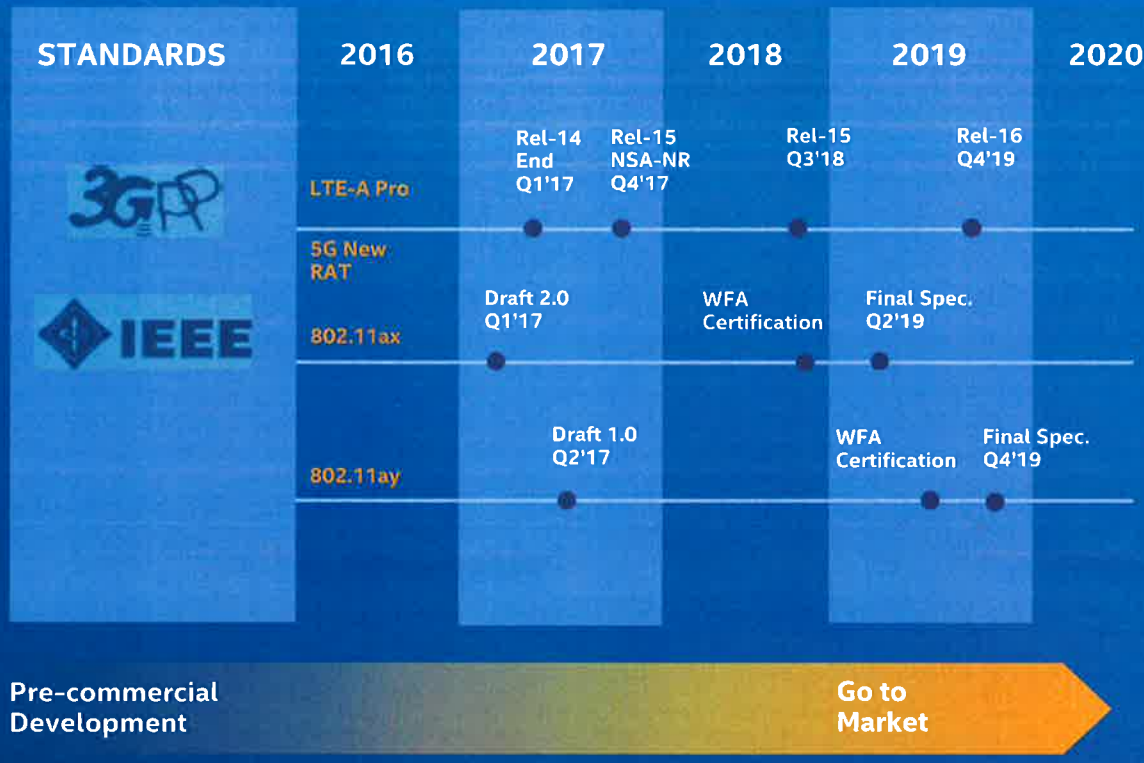
- Delivered industry's first trial platform in February 2016 supporting sub 6GHz and mmWave
- A second Gen Platform with integrated 4x4 MIMO launched in August 2016
- Fully-capable, small form factor, mobile solution allows for fast field and interoperability testing
- Tier-1 service providers are already using it for 5G network testing today

intel

INTEL DELIVERING PRODUCTS PAVING THE PATH TO 5G



INTEL DRIVING HIGH IMPACT IN 5G WIRELESS STANDARDS

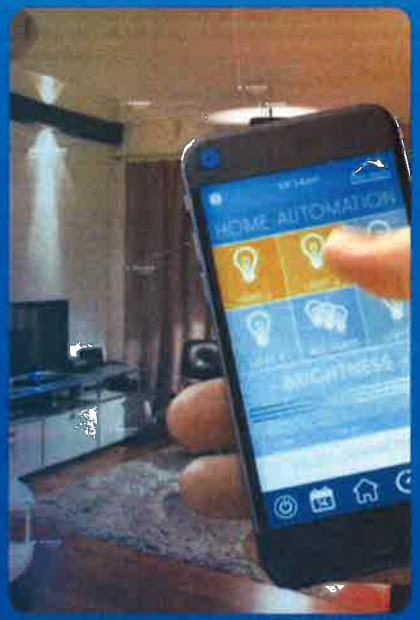


- Top contributor in work groups
- Multiple leadership positions in 3GPP and IEEE
- Thousands of researchers and engineers driving R&D behind the scenes

IOT AND 5G WILL GENERATE A 5G DATA EXPLOSION

Industrial IoT

Smart Homes & Buildings



Smart Cities

Autonomous Vehicles

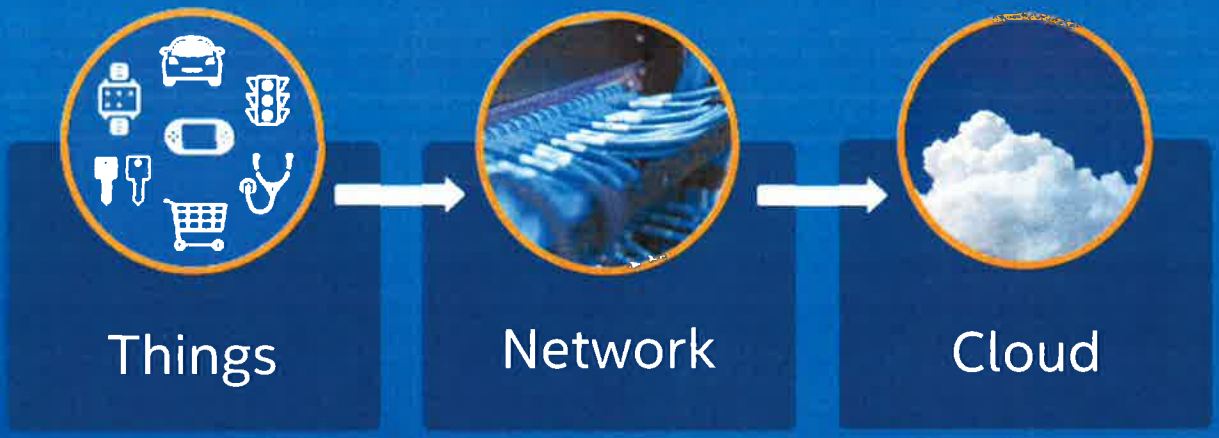
intel

INTEL'S IOT APPROACH: THINGS THROUGH CLOUD

5G delivers advanced technologies for IoT usages

The Intel® IOT Platform

Reference Architectures
Portfolio of Products



Our Approach: Create Vertical Solutions + Build on Horizontal Platform & Products + Build Strong Ecosystem

5G Technology Innovations

intel

DIVERSE 5G TECHNOLOGIES WILL FUEL IOT SUCCESS

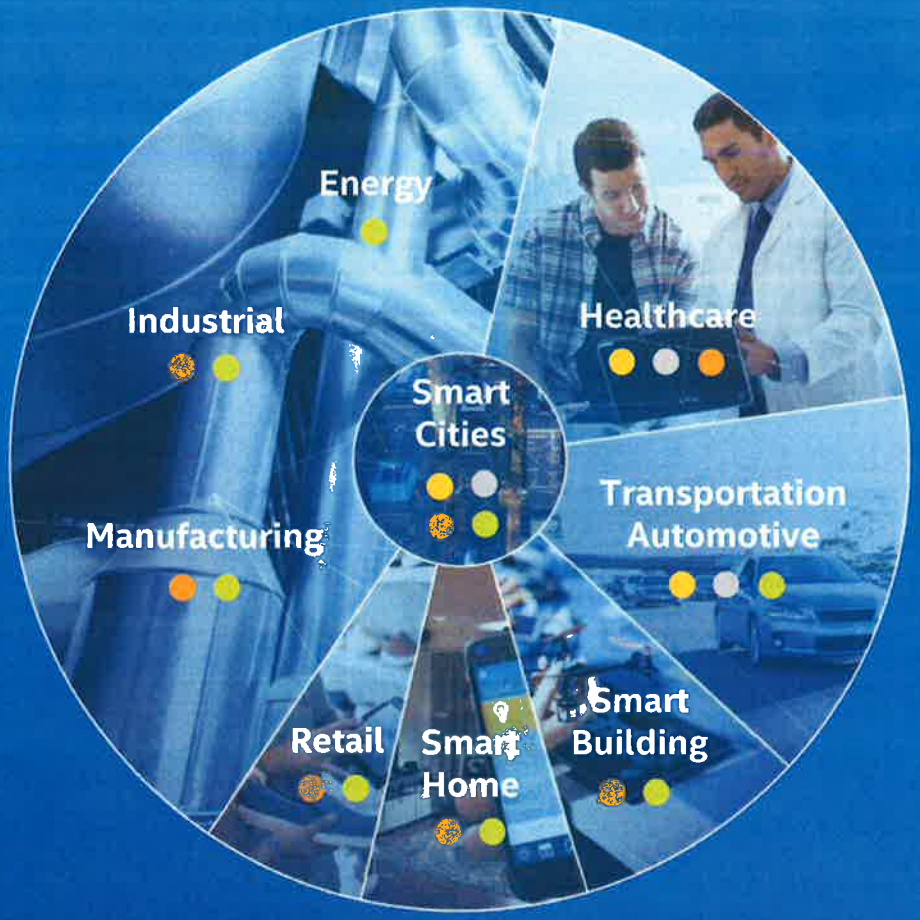
Intel 5G solutions will help grow IoT deployments by matching requirements to industry use cases

LTE ADVANCED PRO

NB-IOT

802.11AX

5G NEW RADIO



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PROMISE OF IOT DELIVERED THROUGH AI AND 5G

Intel investments in artificial intelligence will unleash new wave of opportunity

- 5G's billions of connected things will require AI and analytics for accurate insights and a path to monetization
- Intelligence to power AI will be embedded in devices, the edge, and the cloud
- Intel servers fuel analytics today, and we're investing in future technologies to make AI ubiquitous

intel

5G UNLEASHES THE FULL POTENTIAL OF THE CLOUD

Opens up new business opportunities for operators

Gives more granular control for workloads and usages

Creates whole new classes of cloud services

Enables the cloud to deliver deeper insights and more accurate analysis

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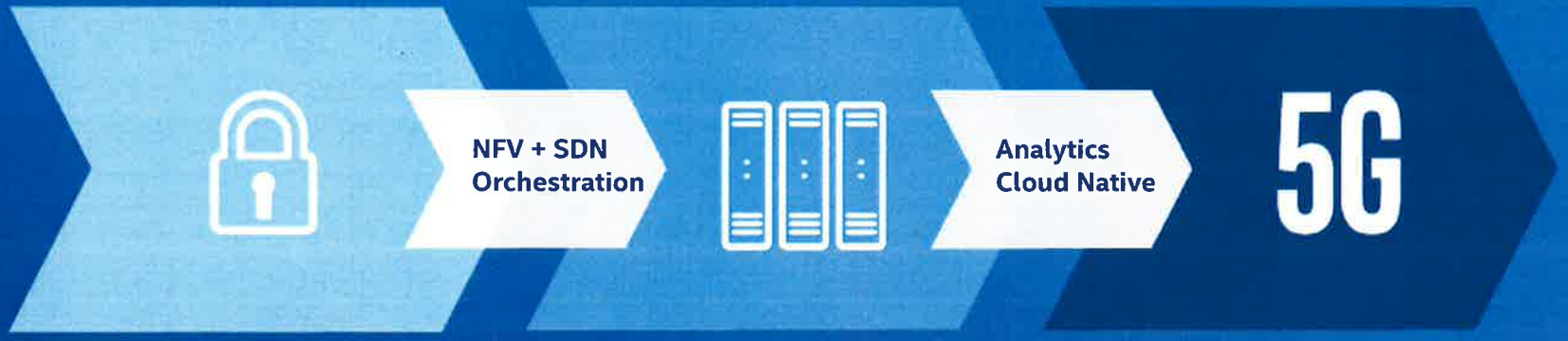
TRANSFORMING THE NETWORK FOR 5G READINESS

Taking Intel's expertise in cloud and applying it to the Network



Custom
Proprietary
Hardware Defined

Software Defined
Agile
Open

Network Slicing
Analytics Core to Edge
Visual Cloud

intel

5G READY: MODERN, SOFTWARE DEFINED INFRASTRUCTURE

Intel advancing SDI through open source, standards, and ecosystem to accelerate network transformation

Agile services delivery

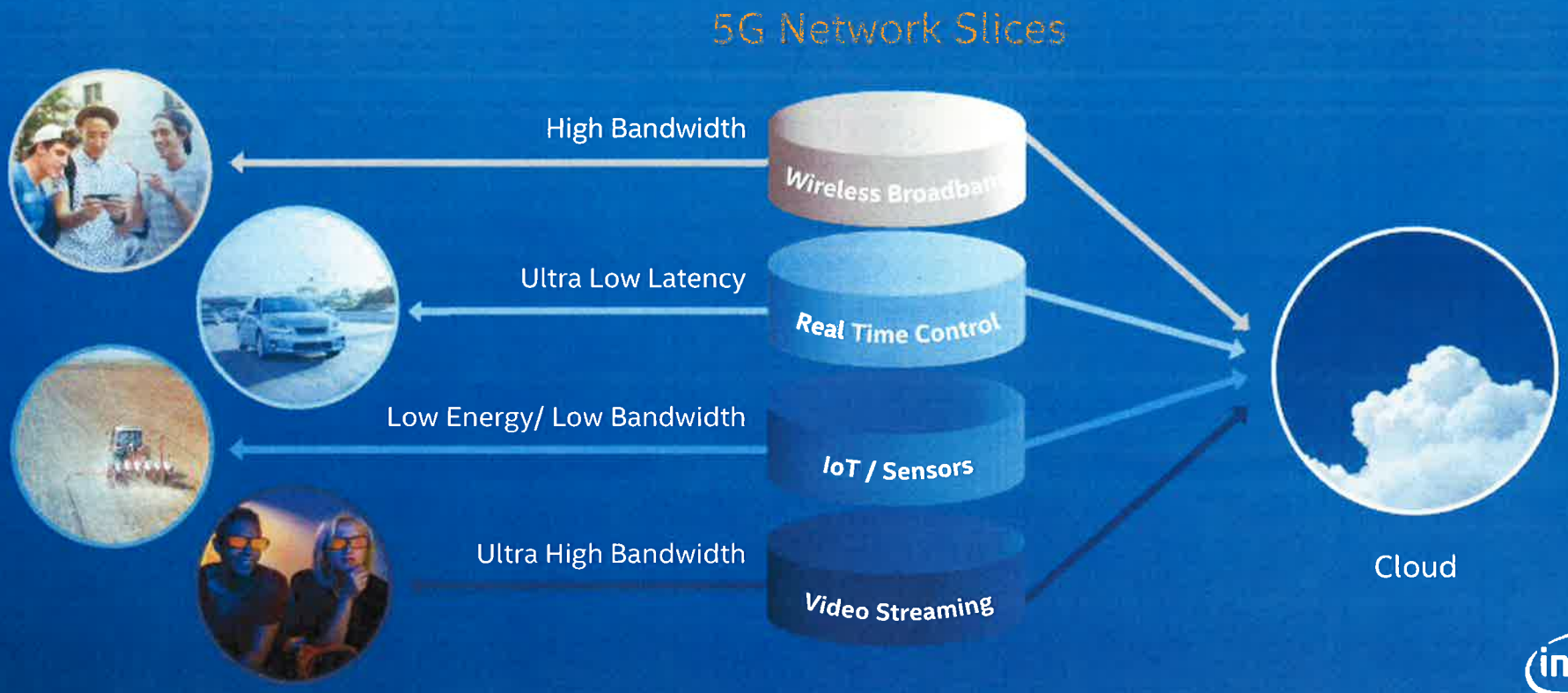
Next-Gen architectures
On high volume servers

Pooled resources of
Standardized solutions

intel

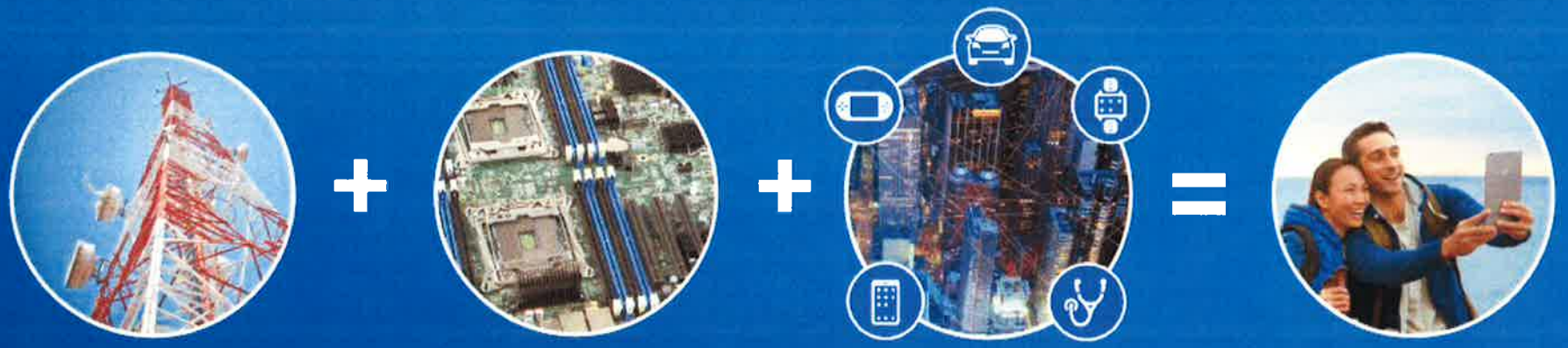
MATCHING CLOUD SERVICES TO DIVERSE DELIVERY NEEDS

Intel technology delivers the diverse processing requirements to power 5G network slicing



5G EXTENDS THE CLOUD TO THE MOBILE EDGE

High performance, Intel-powered analytics and services at the edge unlocks the network to new services



Radio

\+

Compute
Storage

\+

Healthcare
Connected Car
Positioning
Virtual Taps

Gaming
Virtual Apps
Smart City
Caching

=

Better User Experience
Lower Latency
Streamlined Approach

intel


PUTTING IT ALL TOGETHER
intel

PUTTING IT ALL TOGETHER: AUTONOMOUS DRIVING

Cloud

Powerful analytics required to make sense of massive data from moving vehicles

Core Network

Network will isolate vehicle data in a 'slice' separating it from other types of data

Access Network

Cloud computing at the mobile edge lowering latency

Wireless Technology

5G radios integrate 'vehicle to vehicle' and 'vehicle to everything' connectivity

Smart Devices

Vehicles will have intelligence to manage internal systems and connect to cloud

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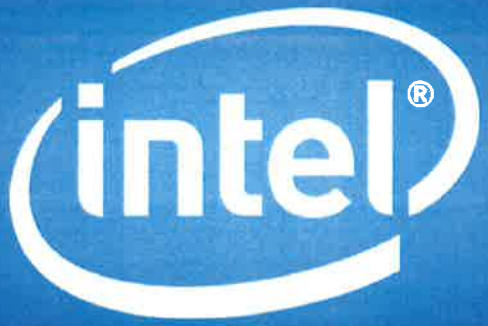
END-TO-END 5G
Powered by Intel®
Intel helps bring together the worlds of connectivity, computing,
and cloud, for a seamlessly connected, powerfully smart 5G future.



5G Summit Recap

Andrew Entwistle
andrew@newstreetresearch.com

Jonathan Chaplin
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Blair Levin
blair.levin@newstreetresearch.com

What Is 5G?

5G is a collection of technologies that will:

1) Increase wireless network capacity

2) Increase wireless network speed

3) Reduce latency

4) Increase the number of connected devices to a cell

Jonathan Chaplin | 212 921 9876 | jonathan.chaplin@newstreetresearch.com

The Most Important Benefits Are Increased Capacity & Speed

1) Capacity

2) Speed

} **Drives benefits for all wireless users**

3) Latency → **Only benefits certain, limited applications**

4) Connected devices → **May have benefits for IOT applications**

Jonathan Chaplin | 212 921 9876 | jonathan.chaplin@newstreetresearch.com

The increase in capacity and speed are both made possible by harnessing very high-frequency spectrum that was previously unusable for terrestrial mobile networks.

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Increased Capacity Is Driven By Two Factors

1) More Spectrum: harnessing millimeter wave frequencies (spectrum above 6GHz) should yield at least a ten-fold increase in spectrum deployable for terrestrial mobile use.

2) Spectrum Reuse: In 4G the capacity in a cell is shared by all the users the cell. With 5G, beam forming will be possible in a mobile environment. Beam forming allows all of the available capacity in a cell to be reused for every user in the cell.

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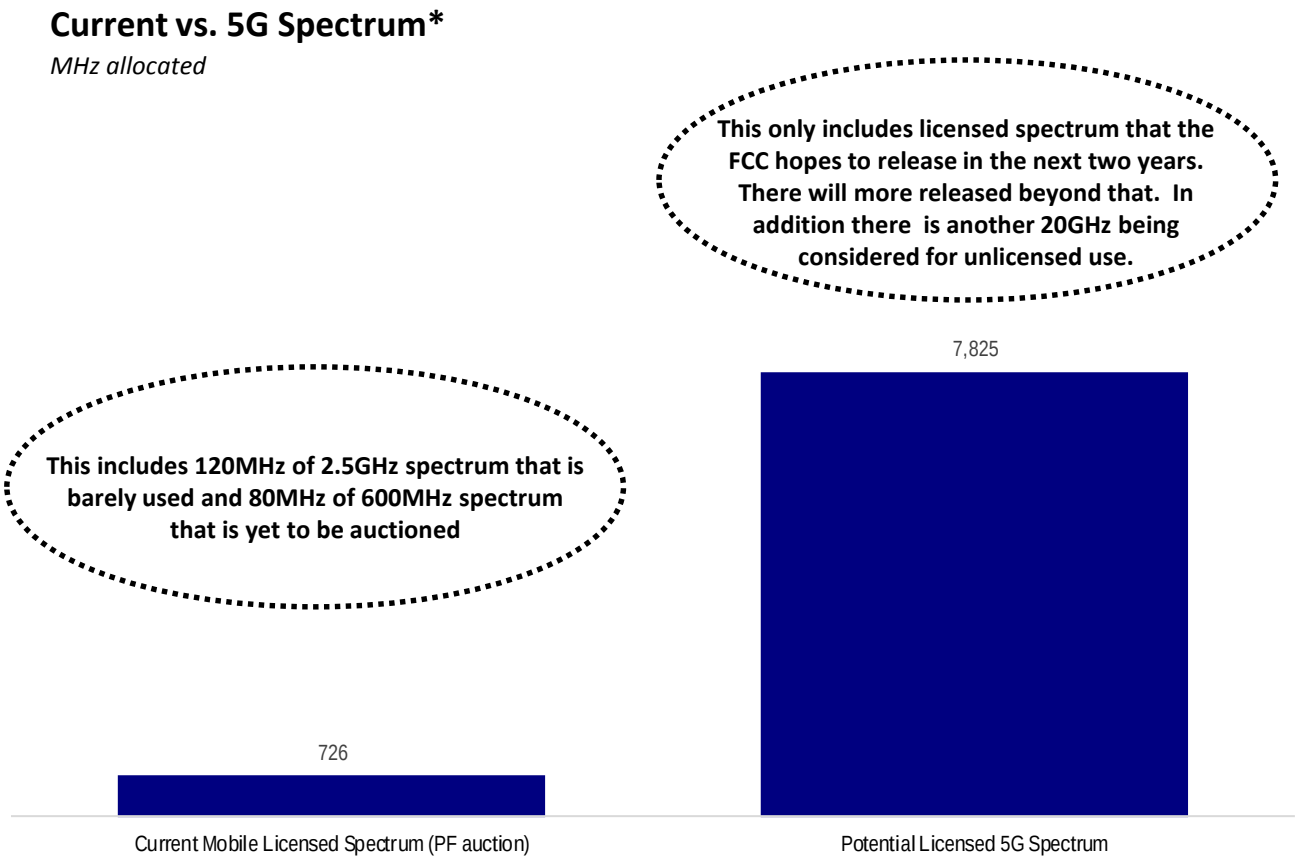
5G Will Unleash a 10x Increase In Useable Spectrum (At Least)



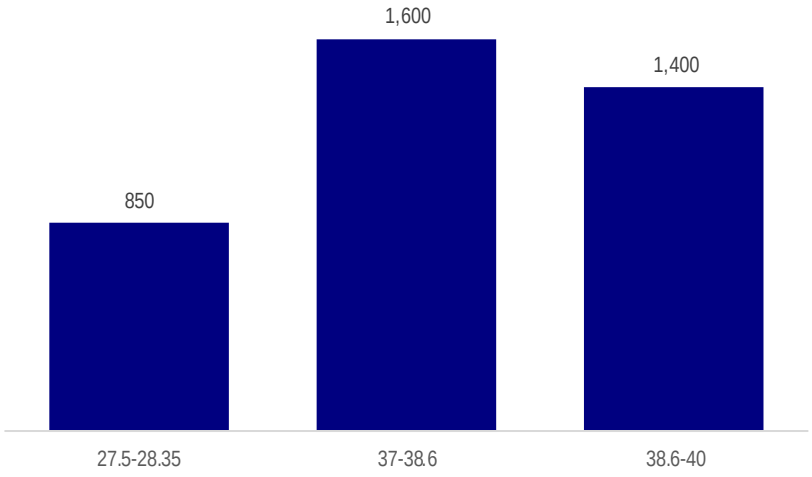
Source: Company data, New Street Research estimates

FCC Targeting ~4GHz In July; Another 3GHz In 2017/18

Wave 1 – July 2016

MHz Avail. (y-axis); Frequency in GHz (x-axis)

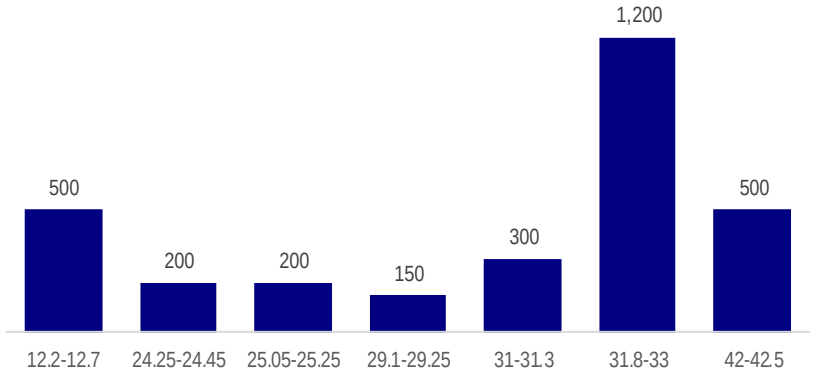
Total: 3.85GHz



Wave 2 Candidates – 2017/18

MHz Avail. (y-axis); Frequency in GHz (x-axis)

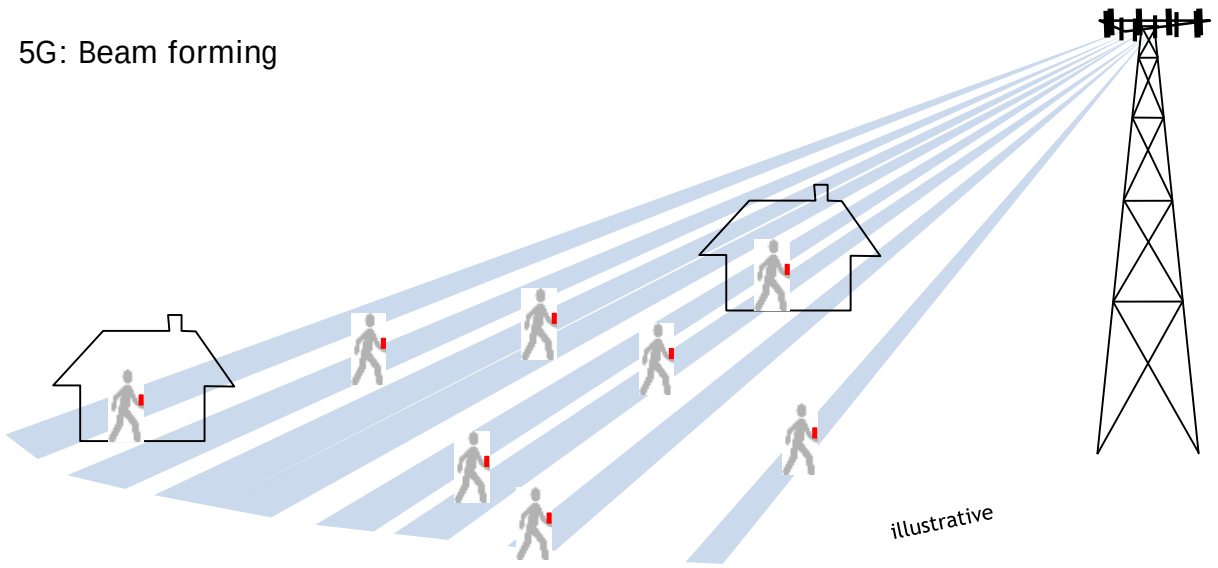
Total: 3.05GHz



Source: Company data, New Street Research estimates

Beamforming Significantly Increases Spectrum Re-Use

With beamforming, every device receives a discrete "beam" which leverages all of the available spectrum in a cell. This is only possible with very high frequencies.



Source: Company data, New Street Research estimates

Faster Speed Also Made Possible By New High Frequency Spectrum

5G will be able to deliver 1Gbps to multiple devices in a cell in the real world. There are two primary drivers of the increase in speed: the use of "higher order" MIMO and the use of much wider channels. Both higher order MIMO and the wider channels are made possible with high frequency spectrum.

Speed = bps/hz x Channel Width

4G LTE Speeds By Channel Width *

Channel Width (MHz)	bps/Hz	Mbps
5	1.5	7.5
10	1.5	15
20	1.5	30

5G Speeds By Channel Width *

Channel Width (MHz)	bps/Hz	Mbps
100	2	200
400	2	800
1,000	2	2,000

* NB: this is illustrative. It ignores MIMO and spatial multiplexing benefits for 4G and 5G.
Source: Company data, New Street Research estimates

High Frequency Spectrum Requires Line Of Sight

Two Big Implications:

1) 5G networks will exist alongside 4G networks; they won't work as standalone networks. In this regard, 5G is much more akin to WiFi than current mobile networks.

2) Wireless networks will become increasingly reliant on wireline networks. We heard estimates that range anywhere from a 5x increase to a 50x increase in network density.

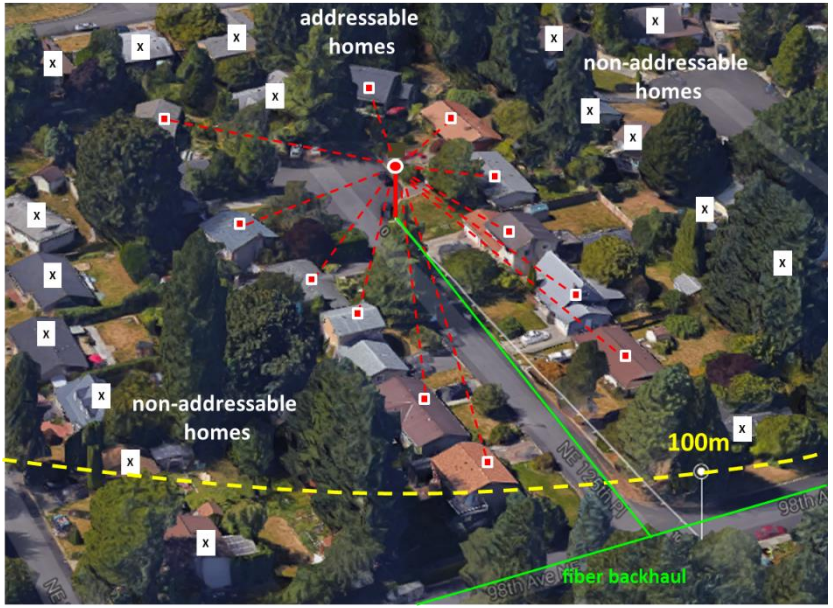
Line of sight can be direct or reflected

Fixed Wireless Is Not A Standalone Business

Carriers may deploy fixed wireless capabilities in 4G and 5G small cells to improve the economics of small cell deployments; however, to the addressable market is small and marketing the product will be challenging.

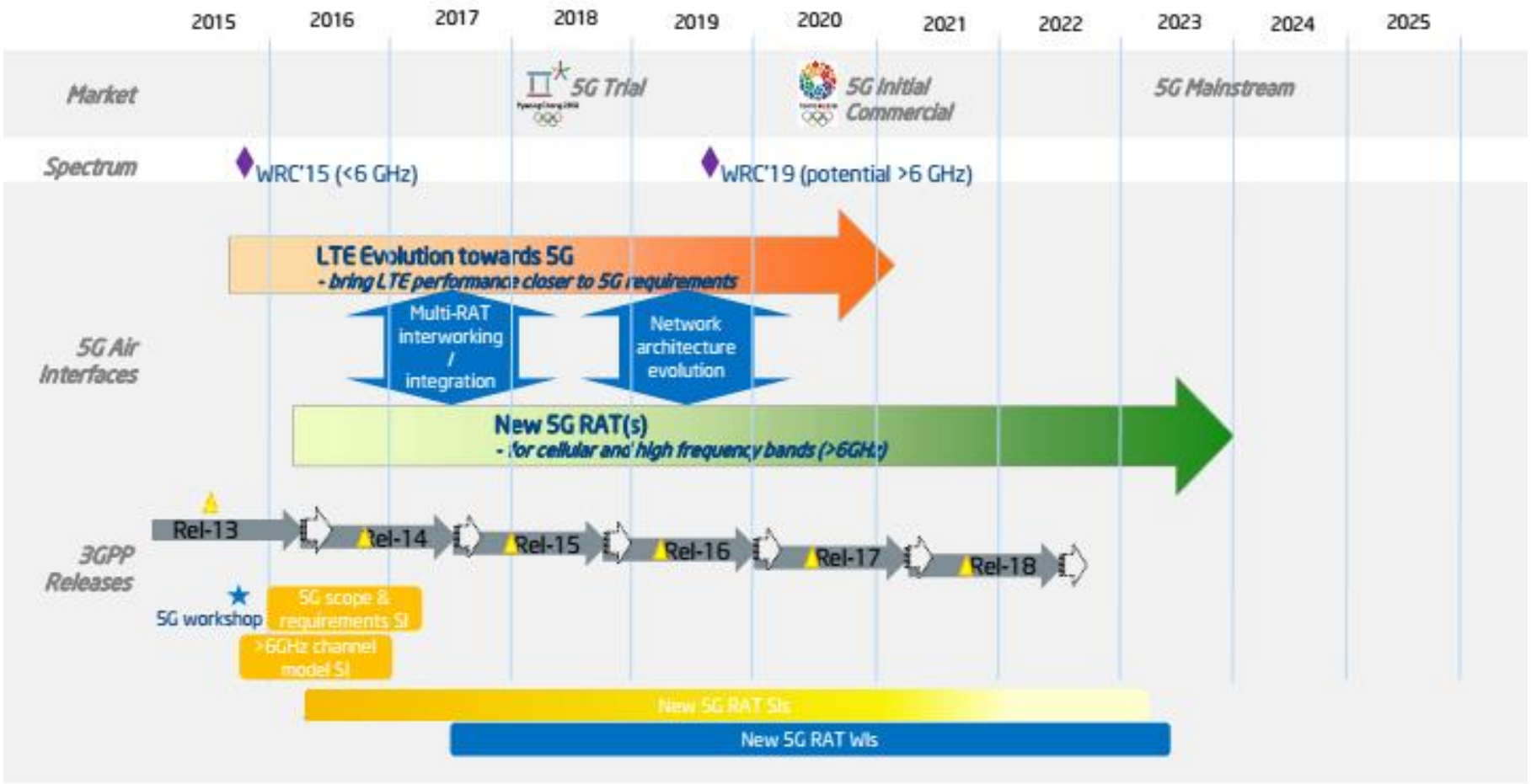
Small cells	Homes per small cell	Addressable Homes	Percent Of US Homes
40,000	12	480,000	0%
70,000	12	840,000	1%
160,000	12	1,920,000	2%
500,000	12	6,000,000	5%
1,000,000	12	12,000,000	10%
1,500,000	12	18,000,000	15%
2,500,000	12	30,000,000	26%

Practical deployment range



Source: New Street Research

Standard 5G Will Be Available In 2020 At Earliest



Source: Reed Hundt

Jonathan Chaplin | 212 921 9876 | jonathan.chaplin@newstreetresearch.com

Implications For The Communications Landscape

1) Wireless: most challenged

2) Spectrum: not impacted

3) Towers: some benefit

4) Cable / wireline: best positioned

TMUS: Most Exposed
But Also Best Positioned
For A Take-out

Disclosures

Regulatory Disclosures: This research is directed only at persons classified as Professional Clients under the rules of the ***Financial Conduct Authority ('FCA'), and must not be re****-distributed to Retail Clients as defined in the rules of the FCA.*

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nature

COMPUTING

The Bandwidth Bottleneck That Is Throttling the Internet

Researchers are scrambling to repair and expand data pipes worldwide—and to keep the information revolution from grinding to a halt

By Jeff Hecht, Nature magazine on August 10, 2016

Credit: JOHN LAMB Getty Images

On June 19, several hundred thousand US fans of the television drama Game of Thrones went online to watch an eagerly awaited episode—and triggered a partial failure in the channel's streaming service. Some 15,000 customers were left to rage at blank screens for more than an hour.

The channel, HBO, apologized and promised to avoid a repeat. But the incident was just one particularly public example of an increasingly urgent problem: with global Internet traffic growing by an estimated 22% per year, the demand for bandwidth is fast outstripping providers' best efforts to supply it.

Although huge progress has been made since the 1990s, when early web users had to use dial-up modems and endure 'the world wide wait', the Internet is still a global patchwork built on top of a century-old telephone system. The copper lines that originally formed the system's core have been replaced by fibre-optic cables carrying trillions of bits per second between massive data centres. But service levels are much lower on local links, and at the user end it can seem like the electronic equivalent of driving on dirt roads.

The resulting digital traffic jams threaten to throttle the information-technology revolution. Consumers can already feel those constraints when mobile-phone calls become garbled at busy times, data connections slow to a crawl in crowded convention centres and video streams stall during peak viewing hours. Internet companies are painfully aware that today's network is far from ready for the much-promised future of mobile high-definition video, autonomous vehicles, remote surgery, telepresence and interactive 3D virtual-reality gaming.

That is why they are spending billions of dollars to clear the traffic jams and rebuild the Internet on the fly—an effort that is widely considered to be as crucial for the digital revolution as the expansion of computer power. Google has partnered with 5 Asian telecommunication companies to lay an 11,600-kilometre, US$300-million fibre-optic cable between Oregon, Japan and Taiwan that started service in June. Microsoft and Facebook are laying another cable across the Atlantic, to start service next year. “Those companies are making that fundamental investment to support their businesses,” says Erik Kreifeldt, a submarine-cable expert at

telecommunications market-research firm TeleGeography in Washington DC. These firms can't afford bottlenecks.

Laying new high-speed cable is just one improvement. Researchers and engineers are also trying several other fixes, from speeding up mobile networks to turbo-charging the servers that relay data around the world.

THE FIFTH GENERATION

For the time being, at least, one part of the expansion problem is comparatively easy to solve. Many areas in Europe and North America are already full of 'dark fibre': networks of optical fibres that were laid down by over-optimistic investors during the Internet bubble that finally burst in 2000, and never used. Today, providers can often meet rising demand simply by starting to use some of this dark fibre.

But such hard-wired connections don't help with the host of mobile phones, fitness trackers, virtual-reality headsets and other gadgets now coming online. Data traffic from mobile devices is increasing by an estimated 53% per year—most of which will end up going through mobile-phone towers, or 'base stations', whose coverage is already spotty, and whose bandwidth has to be shared by thousands of users.

The quality is spotty, as well. First-generation mobile-phone networks, introduced in the 1980s, used analogue signals and are long gone. But second-generation (2G) networks, which added digital services such as texting in the early 1990s, still account for 75% of mobile subscriptions in Africa and the Middle East, and are only now being phased out elsewhere. As of last year, the majority of mobile-phone users in Western Europe were on 3G networks, which were launched in the late 1990s to allow for more sophisticated digital services such as Internet access.

The most advanced commercial networks are now on 4G, which was introduced in the late 2000s to provide smartphones with broadband speeds of up to 100 megabits per second, and is now spreading fast. But to meet demand expected by the 2020s, say industry experts, wireless providers will have to start deploying fifth-generation

(5G) technology that is at least 100 times faster, with top speeds measured in tens of billions of bits per second.

The 5G signals will also need to be shared much more widely than is currently feasible, says Rahim Tafazolli, head of the Institute for Communication Systems at the University of Surrey in Guildford, UK. “The target is how can we support a million devices per square kilometre,” he says—enough to accommodate a burgeoning 'Internet of Things' that will range from networked household appliances to energy-control and medical-monitoring systems, and autonomous vehicles.

The transition to 5G, like those to 3G and 4G before it, is being coordinated by an industry consortium that has retained the name Third Generation Partnership Project (3GPP). Tafazolli is working with this consortium to test a technique known as multiple-input, multiple-output (MIMO)—basically, a way to make each radio frequency carry many streams of data at once without letting them mix into gibberish. The idea is to put multiple antennas on both transmitter and receiver, creating many ways for signals to leave one and arrive at the other. Sophisticated signal processing can distinguish between the various paths, and extract independent data streams from each.

MIMO is already used in Wi-Fi and 4G networks. But the small size of smartphones currently limits them to no more than four antennas each, and the same number on base stations. So a key goal of 5G research is to squeeze more antennas onto both.

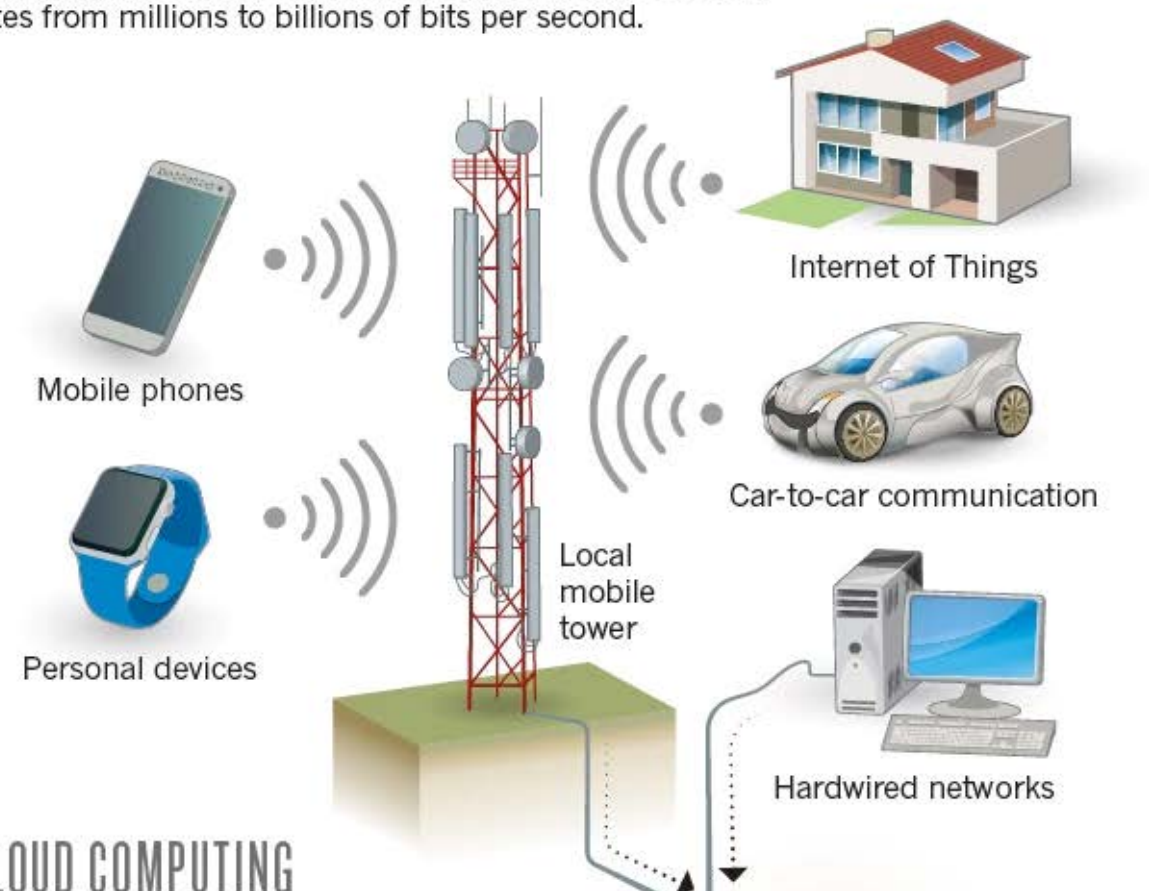
Big wireless companies have demonstrated MIMO with very high antenna counts in the lab and at trade shows. At the Mobile World Congress in Barcelona, Spain, in February, equipment-maker Ericsson ran live indoor demonstrations of a multiuser massive MIMO system, using a 512-element antenna to transmit 25 gigabits per second between a pair of terminals, one stationary and the other moving on rails. The system is one-quarter of the way to the 100-gigabit 5G target, and it transmits at 15 gigahertz, part of the high-frequency band planned for 5G. Japanese wireless operator NTT DoCoMo is working with Ericsson to test the equipment outdoors, and Korea Telecom is planning to demonstrate 5G services when South Korea hosts the next Winter Olympics, in 2018.

BOTTLENECK ENGINEERING

The Internet was built on a century-old telephone system, leaving many choke points that have to be eliminated to keep the bits flowing.

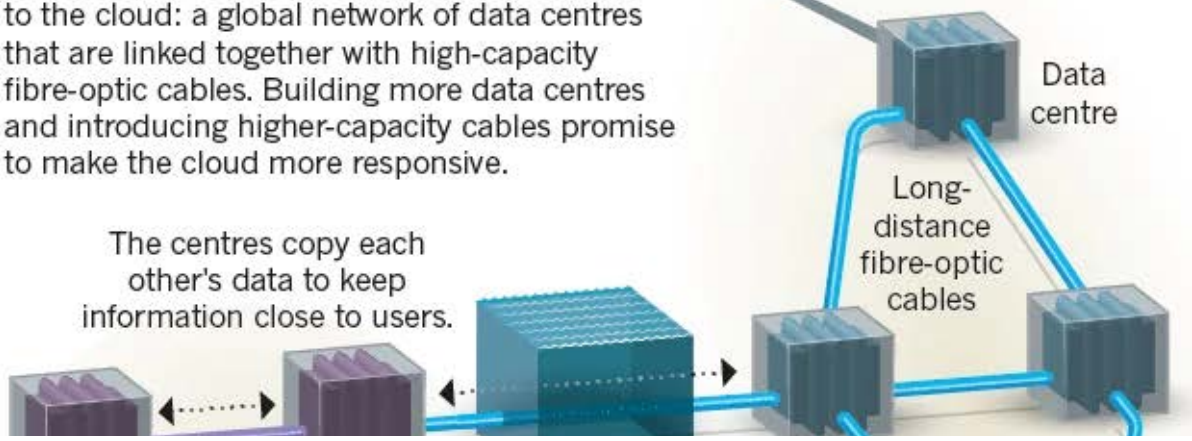
MOBILE EVERYTHING

Demand for wireless connections is exploding, with ever more devices coming online. Engineers hope to meet that demand with fifth-generation (5G) networks that will increase data rates from millions to billions of bits per second.



CLOUD COMPUTING

Much of the world's digital information is moving to the cloud: a global network of data centres that are linked together with high-capacity fibre-optic cables. Building more data centres and introducing higher-capacity cables promise to make the cloud more responsive.



Nik Spencer/Nature, August 10, 2016, doi:10.1038/536139a

Another approach is to make the devices much more adaptive. Instead of operating on a single, hard-wired set of frequencies, a mobile device could use what is sometimes called cognitive radio: a device that uses software to switch its wireless links to whatever radio channel happens to be open at that moment. That would not only keep data automatically moving through the fastest channels, says Tafazolli, but also improve network resilience by finding ways to route around failure points. And, he says, it's much easier to upgrade performance by replacing software than by replacing hardware.

Meanwhile, a crucial policy challenge for the 5G transition is finding a radio spectrum that offers adequate bandwidth and coverage. International agreements have already allocated almost every accessible frequency to a specific use, such as television broadcasting, maritime navigation or even radio astronomy. So final changes will have to wait for the 2019 World Radiocommunication Conference. But the US Federal Communications Commission (FCC) is trying to get a head start by auctioning off frequencies below 1 gigahertz to telecommunications companies. Once reserved for broadcast television because they are better than higher frequencies at penetrating walls and other obstructions—but no longer needed after television's shift to digital—these low frequencies are particularly attractive for serving sparsely populated areas, says Tafazolli: only a few base stations would be required to provide broadband service to households and driving data to autonomous cars on motorways.

Other bands in the 1–6-gigahertz range could be opened up for 5G use as 2G and 3G technologies are phased out. But the best hope for dense urban areas is to exploit frequencies above 6 gigahertz, which are currently little-used because they have a

very short range. That would require 5G base stations up to every 200 metres in dense urban areas, one-fifth the spacing typical of urban 4G networks. But the FCC considers the idea promising enough that on 14 July, it formally approved opening these frequencies for high-speed, fast-response services. Ofcom, the UK regulatory body, is considering similar steps.

Companies are particularly interested in these higher frequencies as a way to extend 5G technology for other uses. In the United States, wireless carrier Verizon and a consortium of equipment-makers including Ericsson, Cisco, Intel, Nokia and Samsung have tested 28-gigahertz transmission at sites in New Jersey, Massachusetts and Texas. The system uses 5G technology to deliver data at 1 gigabit per second, and Verizon is adapting it for use in fixed wireless connections to homes, which it plans to test next year. The company has been pushing fixed wireless as an alternative to wired connections, because connection costs are much lower.

BIGGER PIPES

“When I take out my cell phone, everyone thinks of it as a wireless communications device,” says Neal Bergano, chief technology officer of TE SubCom, a submarine-cable manufacturer based in Eatontown, New Jersey. Yet that is only part of the story, he says: “Users are mobile, but the network isn't mobile.” When someone uses their phone, its radio signal is converted at the nearest base station to an optical signal that then has to travel to its destination through fixed fibre optics.

These flexible glass data channels have been the backbone of the global telecommunications network for more than a quarter of a century. Nothing can match their bandwidth: today, a single hair-thin fibre can transmit 10 terabits (trillion bits) per second across the Atlantic. That is the equivalent of 25 double-layer Blu-ray Discs per second, and is 30,000 times the capacity of the first transatlantic fibre cable, laid in 1988. Much of that increase came when engineers learned how to send 100 separate signals through a single fibre, each at its own wavelength. But as traffic continues to increase over heavily used routes, such as New York to London, that approach is coming up against some hard limits: distortion and noise that inevitably build up as light passes along thousands of kilometres of glass have made it

effectively impossible to send more than 100 gigabits per second on a single wavelength.

To overcome that limit, manufacturers have developed a new type of fibre. Whereas standard fibres send the light through a 9-micrometre-wide core of ultrapure glass running down the middle, the newer design spreads the light over a larger core area at lower intensity, reducing noise. The trade-off is that the new fibres are more sensitive to bending and stretching, which can introduce errors. But they work very well in submarine cables, because the deep sea provides a benign, stable environment that puts little strain on the fibre.

Last year, networking-systems firm Infinera in Sunnyvale, California, sent single-wavelength signals at 150 gigabits per second through a large-area fibre for 7,400 kilometres—more than 3 times the distance possible with a standard fibre, and easily enough to cross the Atlantic. They also transmitted 200-gigabit-per-second signals a shorter distance.

The highest-capacity commercial submarine cable now in service is the 60-terabit-per-second FASTER system that opened in June between Oregon and Japan. It sends 100-gigabit-per-second signals on 100 wavelengths in each of 6 pairs of large-core fibres. But in late May, Microsoft and Facebook jointly announced plans to beat it with MAREA: a large-area fibre cable spanning the 6,600 kilometres between Virginia and Spain. When completed in October 2017, the cable will link the two companies' data centres on opposite sides of the Atlantic at 160 terabits per second.

Another approach to reducing performance-limiting noise was demonstrated last year by a group at the University of California, San Diego. Fibre-optic systems normally use separate lasers for each wavelength, but tiny, random variations can generate noise. Instead, the group used a technique known as a frequency comb to generate a series of uniformly spaced wavelengths from a single laser (E. Temprana et al. Science 348, 1445–1448; 2015). “It worked like a charm” to reduce noise, says group member Nikola Alic, an electrical engineer. With further development, he says, the approach could double the data rate of fibre-optic systems.

TIME OF FLIGHT

Impressive bandwidth is useful, but promptness also matters. Human speech is so sensitive to interruption that a delay of one-quarter of a second can disturb a phone or video conversation. Video requires a fixed frame rate, so streaming video stalls when its input queue runs dry. To overcome such problems, FCC rules allow special codes that give priority passage for packets of data carrying voice calls or video frames, so that they flow quickly and uniformly through the Internet.

New and emerging services including telerobotics, remote surgery, cloud computing and interactive gaming are also sensitive to network responsiveness. The time it takes for a signal to make a round trip between two terminals, often called latency, depends largely on distance—a reality that shapes the geography of the Internet. Even though data travel through fibre-optic cable at 200,000 kilometres per second, two-thirds the velocity of light in the open air, a person tapping a key in London would still need 86 milliseconds to get a response from a data centre in San Francisco, 8,600 kilometres away—a delay that would make cloud computing crawl.

Emerging mobile applications require both broad bandwidth and low latency. Autonomous cars, for example, need real-time data on their environment to warn them about hazards, from potholes to accidents ahead. Conventional cars are becoming wireless nerve centres, needing low latency for 'hands-free' voice-control systems.

A potentially huge challenge is the emergence of 3D virtual-reality systems. Interactive 3D gaming requires data to travel at 1 gigabit per second—20 times the speed of a typical video feed from a Blu-Ray Disc. But most crucially, the image must be rewritten at least 90 times per second to keep up with users turning their heads to watch the action, says computer scientist David Whittinghill of Purdue University in West Lafayette, Indiana. If the data stream slips behind, the user gets motion sickness. To keep that from happening, Whittinghill has installed a special 10-gigabit-per-second fibre line to his virtual-reality lab.

To speed up responses, big Internet companies such as Google, Microsoft, Facebook and Amazon store replicas of their data in multiple server farms around the world,

and route queries to the closest. Video cached at a local data centre is what allows viewers to fast-forward as if the file was stored on a home device, says Geoff Bennett, director of solutions and technology for Infinera. But the proliferation of these data centres is also one of the biggest drivers of bandwidth demand, he says: vendors' efforts to synchronize private data centres around the world now consume more bandwidth than public Internet traffic. The Microsoft–Facebook cable is being built expressly for this purpose.

So far, most data centres are where the customers and cables are: in North America, Europe and east Asia. “Many parts of the world still rely on remote access to content that is not stored locally,” says Kreifeldt. South America has few data centres, he says, so much of the content comes from well-wired Miami, Florida: traffic between Chile and Brazil might be routed through Miami to save money, but at a cost in latency. The same problem plagues the Middle East, where 85% of international traffic must travel to centres in Europe. That is changing, says Kreifeldt, but progress is slow. Amazon Web Services launched its first cloud data centre in India this year, in Mumbai; it has had a similar centre in São Paulo, Brazil, since 2011.

INTERNAL COMMUNICATIONS

Bandwidth is also crucial on the very smallest scale: on and between the chips in the banks of servers in a data centre. Expanding the flow here can help information to move more quickly within the data centres and get out to users faster. Chip clock speeds—how fast the chip runs—flat-lined at a few gigahertz several years ago, because of heating problems. The most practical way to speed up processors significantly is to divide the operations that they perform between multiple 'cores': separate microprocessors operating in parallel on the same chip. That requires high-speed connections within the chip—and one way to make them is with light, which can move data faster than electrons can.

The biggest obstacle has been integrating microscale optics with silicon electronics. After years of research on 'silicon photonics', engineers have yet to find a way to efficiently generate light from silicon, a key step in optical information processing. The best semiconductor light sources, such as indium phosphide, can be bonded to

silicon chips, but are very difficult to grow directly on silicon, because their atoms are spaced differently. Optical and electronic components have been integrated on indium phosphide, but so far only on a small scale.

In an effort to scale up photonic integration to a commercial level, the United States last year launched the American Institute for Manufacturing Integrated Photonics in Rochester, New York, which is supported by $110 million from federal agencies and $502 million from industry and other sources. Its target is to develop an efficient technology to make integrated photonics for high-speed applications, including optical communications and computing.

Separately, a Canadian-funded team earlier this year demonstrated a photonic integrated circuit with 21 active components that could be programmed to perform 3 different logic functions (W. Liuet al. Nature Photon. 10, 190–195; 2016). That's an important step for photonic microprocessors, comparable in complexity to the first programmable electronic chips that opened the door to microcomputers. “Compared to current electronics, it's simple, but compared to photonic integrated circuits it is quite complicated,” says study co-author Jianping Yao, an electrical engineer at the University of Ottawa in Canada.

Further development could lead to varied applications. For example, Yao says that after the chip is optimized for manufacture, it could convert a 5G smartphone signal received at a base station into an analogue optical signal, which could be transmitted by fibre optics to a central facility, and then digitized.

The quest for faster chips, like other parts of the Internet problem, is a daunting challenge. But researchers such as Bergano see a lot of potential for improvements. After 35 years of working on fibre optics, he says, “I remain a complete optimist when I think about the future.”

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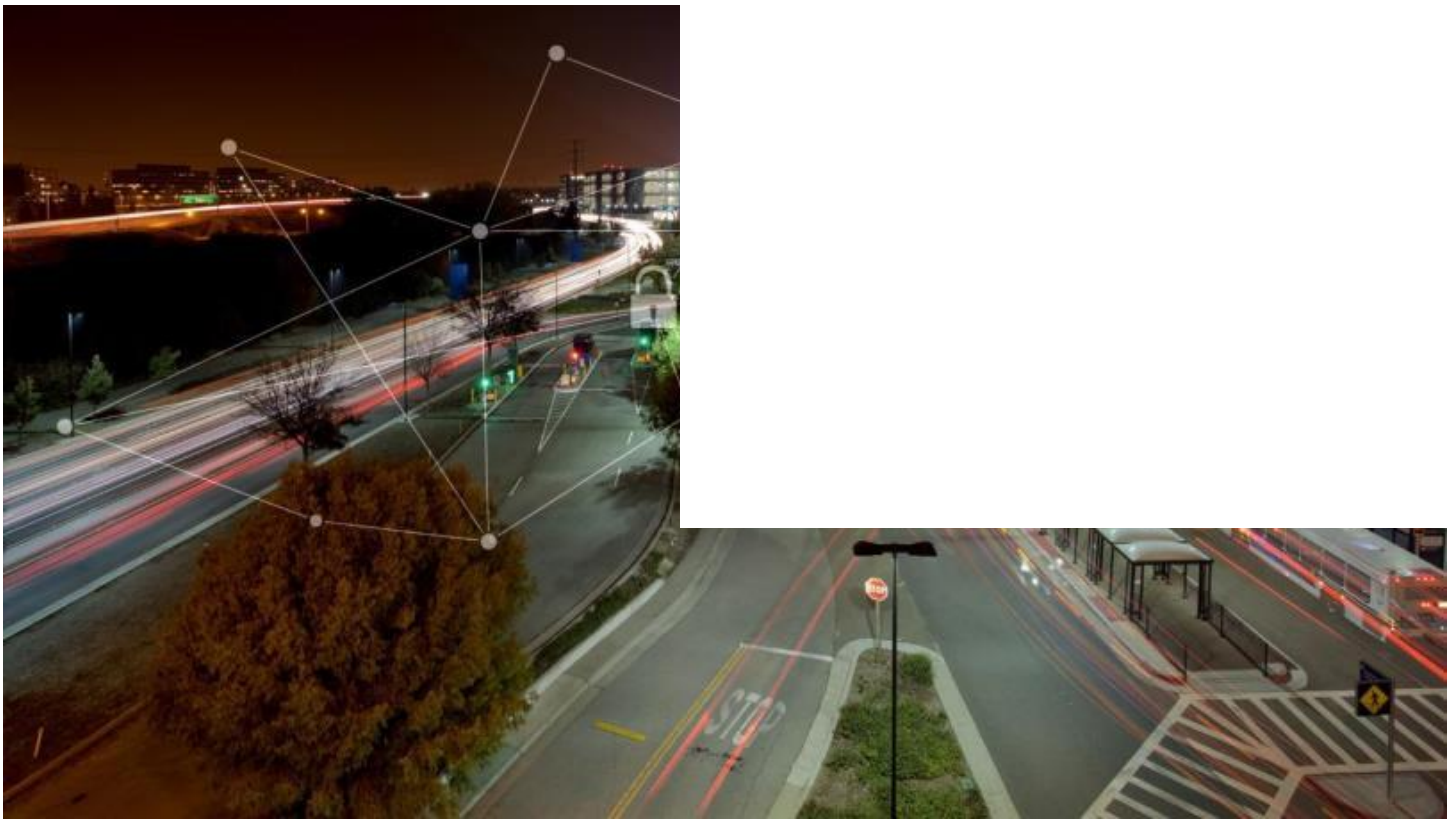
What Is 5G?

BY SASCHA SEGAN JUNE 21, 2016 4 COMMENTS

AT&T, Verizon Wireless, and other carriers will exactly is 5G? Here's what we know so far.



We've only had 4G cellular networks for a few years, but all the wireless carriers are already talking about 5G. It's actually surprisingly easy to do because there isn't any official definition of 5G yet. What's happening now is that all the players in the wireless world, from chipset makers to carriers, are jockeying to be able to define 5G and establish themselves as 5G leaders.