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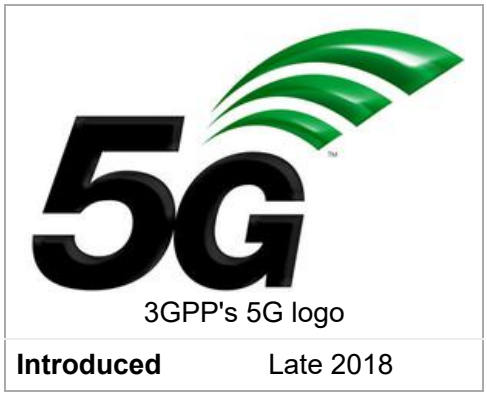
5G



In telecommunications, **5G** is the fifth generation technology standard for cellular networks, which cellular phone companies began deploying worldwide in 2019, the planned successor to the 4G networks which provide connectivity to most current cellphones.[1] Like its predecessors, 5G networks are cellular networks, in which the service area is divided into small geographical areas called *cells*. All 5G wireless devices in a cell are connected to the Internet and telephone network by radio waves through a local antenna in the cell. The main advantage of the new networks is that they will have greater bandwidth, giving higher download speeds,[1] eventually up to 10 gigabits per second (Gbit/s).[2] Due to the increased bandwidth, it is expected that the new networks will not just serve cellphones like existing cellular networks, but also be used as general internet service providers for laptops and desktop computers, competing with existing ISPs such as cable internet, and also will make possible new applications in IoT and M2M areas. Current 4G cellphones will not be able to use the new networks, which will require new 5G enabled wireless devices.

The increased speed is achieved partly by using higher-frequency radio waves than current cellular networks.[1] However, higher-frequency radio waves have a shorter range than the frequencies used by previous cell phone towers, requiring smaller cells. So to ensure wide service, 5G networks operate on up to three frequency bands, low, medium, and high.[3][1] A 5G network will be composed of networks of up to 3 different types of cells, each requiring different antennas, each type giving a different tradeoff of download speed vs. distance and service area. 5G cellphones and wireless devices will connect to the network through the highest speed antenna within range at their location:

Low-band 5G uses a similar frequency range as current 4G cellphones, 600-700 MHz, giving download speeds a little higher than 4G: 30-250 megabits per second (Mbit/s).[3] Low-band cell towers will have a similar range and coverage area to current 4G towers. Mid-band 5G uses microwaves of 2.5-3.7 GHz, currently allowing speeds of 100-900 Mbit/s, with each cell tower providing service up to several miles in radius. This level of service is the most widely deployed, and should be available in most metropolitan areas in 2020. Some countries are not implementing low-band, making this the minimum service level. High-band 5G currently uses frequencies of 25-39 GHz, near the bottom of the millimeter wave band, although higher frequencies may be used in the future. It often achieves download speeds of a gigabit per second (Gbit/s), comparable to cable internet. However, millimeter waves (mmWave or mmW) have a more limited range, requiring many small cells. They have trouble passing through some types of walls and windows. Due to their higher costs, current plans are to deploy these cells only in dense urban environments and areas where crowds of people congregate such as sports stadiums and convention centers. The above speeds are those achieved in actual tests in 2020, and speeds are expected to increase during rollout.[3]

The industry consortium setting standards for 5G is the 3rd Generation Partnership Project (3GPP).[1] It defines any system using 5G NR (5G New Radio) software as "5G", a definition that came into general use by late 2018. Minimum standards are set by the International Telecommunications Union (ITU). Previously, some reserved the term 5G for systems that deliver download speeds of 20 Gbit/s as specified in the ITU's IMT-2020 document.

Contents

Overview

5G networks are digital cellular networks, in which the service area covered by providers is divided into small geographical areas called *cells*. Analog signals representing sounds and images are digitized in the telephone, converted by an analog-to-digital converter and transmitted as a stream of bits. All the 5G wireless devices in a cell communicate by radio waves with a local antenna array and low power automated transceiver (transmitter and receiver) in the cell, over frequency channels assigned by the transceiver from a pool of frequencies that are reused in other cells. The local antennas are connected with the telephone network and the Internet by a high-bandwidth optical fiber or wireless backhaul connection. As in other cell networks, a mobile device crossing from one cell to another is automatically "handed off" seamlessly to the new cell. 5G can support up to a million devices per square kilometer, while 4G supports only up to 100,000 devices per square kilometer.[4][5] The new 5G wireless devices also have 4G LTE capability, as the new networks use 4G for initially establishing the connection with the cell, as well as in locations where 5G access is not available.[6]

Verizon and a few others are using millimeter waves.[7] Millimeter waves have a shorter range than microwaves, therefore the cells are limited to a smaller size. Millimeter waves also have more trouble passing through building walls.[8] Millimeter wave antennas are smaller than the large antennas used in previous cellular networks. Some are only a few inches (several centimeters) long.

Massive MIMO (multiple-input multiple-output) was deployed in 4G as early as 2016 and typically used 32 to 128 small antennas at each cell. In the right frequencies and configuration, it can increase performance from 4 to 10 times.[9] Multiple bitstreams of data are transmitted simultaneously. In a technique called *beamforming*, the base station computer will continuously calculate the best route for radio waves to reach each wireless device and will organize multiple antennas to work together as phased arrays to create beams of millimeter waves to reach the device.[8][2]

Application areas

The ITU-R has defined three main application areas for the enhanced capabilities of 5G. They are Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC).[10] Only eMBB is deployed in 2020; URLLC and mMTC are several years away in most locations.

Enhanced Mobile Broadband (eMBB) uses 5G as a progression from 4G LTE mobile broadband services, with faster connections, higher throughput, and more capacity.

Ultra-Reliable Low-Latency Communications (URLLC) refer to using the network for mission critical applications that require uninterrupted and robust data exchange.

Massive Machine-Type Communications (mMTC) would be used to connect to a large number of devices, 5G technology will connect some of the 50 billion connected IoT devices.[11] Most will use the less expensive Wi-Fi. Drones, transmitting via 4G or 5G, will aid in disaster recovery efforts, providing real-time data for emergency responders.[11] Most cars will have a 4G or 5G cellular connection for many services. Autonomous cars do not require 5G, as they have to be able to operate where they do not have a network connection.[12] While remote surgeries have been performed over 5G, most remote surgery will be performed in facilities with a fiber connection, usually faster and more reliable than any wireless connection.

Performance

Speed

5G speeds will range from ~50 Mbit/s to over a gigabit.[13] The fastest 5G, known as mmWave. As of July 3, 2019, mmWave had a top speed of 1.8 Gbit/s[14] on AT&T's 5G network.

Sub-6 GHz 5G (mid-band 5G), by far the most common, will usually deliver between 100 and 400 Mbit/s, but will have a much farther reach than mmWave, especially outdoors.[14]

Low-band spectrum offers the farthest area coverage but is slower than the others.

5G NR speed in sub-6 GHz bands can be slightly higher than the 4G with a similar amount of spectrum and antennas,[15][16] although some 3GPP 5G networks will be slower than some advanced 4G networks, such as T-Mobile's LTE/LAA network, which achieves 500+ Mbit/s in Manhattan[17] and Chicago.[18] The 5G specification allows LAA (License Assisted Access) as well, but LAA in 5G has not yet been demonstrated. Adding LAA to an existing 4G configuration can add hundreds of megabits per second to the speed, but this is an extension of 4G, not a new part of the 5G standard.[17]

The similarity in terms of throughput between 4G and 5G in the existing bands is because 4G already approaches the Shannon limit on data communication rates. 5G speeds in the less common millimeter wave spectrum, with its much more abundant bandwidth and shorter range, and hence greater frequency reuseability, can be substantially higher.[19]

Latency

In 5G, the "air latency"[20] in equipment shipping in 2019 is 8–12 milliseconds.[21] The latency to the server must be added to the "air latency" for most comparisons. Verizon reports the latency on its 5G early deployment is 30 ms:[22] Edge Servers close to the towers can reduce latency to 10–20 ms; 1–4 ms will be extremely rare for years outside the lab.

Standards

Initially, the term was associated with the International Telecommunication Union's IMT-2020 standard, which required a theoretical peak download speed of 20 gigabits per second and 10 gigabits per second upload speed, along with other requirements.[23] Then, the industry standards group 3GPP chose the 5G NR (New Radio) standard together with LTE as their proposal for submission to the IMT-2020 standard.[24][25]

The first phase of 3GPP 5G specifications in Release-15 is scheduled to complete in 2019. The second phase in Release-16 is due to be completed in 2020.[26]

5G NR can include lower frequencies (FR1), below 6 GHz, and higher frequencies (FR2), above 24 GHz. However, the speed and latency in early FR1 deployments, using 5G NR software on 4G hardware (non-standalone), are only slightly better than new 4G systems, estimated at 15 to 50% better.[27][28][29]

IEEE covers several areas of 5G with a core focus in wireline sections between the Remote Radio Head (RRH) and Base Band Unit (BBU). The 1914.1 standards focus on network architecture and dividing the connection between the RRU and BBU into two key sections. Radio Unit (RU) to the Distributor Unit (DU) being the NGFI-I (Next Generation Fronthaul Interface) and the DU to the Central Unit (CU) being the NGFI-II interface allowing a more diverse and cost-effective network. NGFI-I and NGFI-II have defined performance values which should be compiled to ensure different traffic types defined by the ITU are capable of being carried. 1914.3 standard is creating a new Ethernet frame format capable of carrying IQ data in a much more efficient way depending on the functional split utilized. This is based on the 3GPP definition of functional splits. Multiple network synchronization standards within the IEEE groups are being updated to ensure network timing accuracy at the RU is maintained to a level required for the traffic carried over it.

5G NR

5G NR (New Radio) is a new air interface developed for the 5G network.[30] It is supposed to be the global standard for the air interface of 3GPP 5G networks.[31]

Pre-standard implementations

- 5GTF: The 5G network implemented by American carrier Verizon for Fixed Wireless Access in late 2010s uses a pre-standard specification known as 5GTF (Verizon 5G Technical Forum). The 5G service provided to customers in this standard is incompatible with 5G NR. There are plans to upgrade 5GTF to 5G NR "Once [it] meets our strict specifications for our customers," according to Verizon.[32]
- 5G-SIG: Pre-standard specification of 5G developed by KT Corporation. Deployed at Pyeongchang 2018 Winter Olympics.[33]

Internet of things

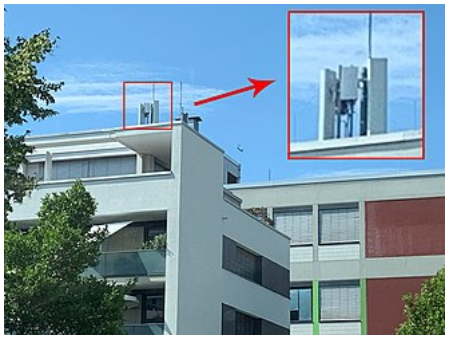
In the Internet of things (IoT), 3GPP is going to submit evolution of NB-IoT and eMTC (LTE-M) as 5G technologies for the LPWA (Low Power Wide Area) use case.[34]

Deployment

Beyond mobile operator networks, 5G is also expected to be used for private networks with applications in industrial IoT, enterprise networking, and critical communications.

Initial 5G NR launches depended on existing LTE (4G) infrastructure in non-standalone (NSA) mode (5G NR software on LTE radio hardware), before maturation of the standalone (SA) mode (5G NR software on 5G NR radio hardware) with the 5G core network.

As of April 2019, the Global Mobile Suppliers Association had identified 224 operators in 88 countries that have demonstrated, are testing or trialling, or have been licensed to conduct field trials of 5G technologies, are deploying 5G networks or have announced service launches.[35] The equivalent numbers in November 2018 were 192 operators in 81 countries.[36] The first country to adopt 5G on a large scale was South Korea, in April 2019. Swedish telecoms giant Ericsson predicted that 5G internet will cover up to 65% of the world's population by the end of 2025.[37] Also, it plans to invest 1 billion reais ($238.30 million) in Brazil to add a new assembly line dedicated to fifth-generation technology (5G) for its Latin American operations.[38]



5G 3.5 GHz Cell Site of Deutsche Telekom in Darmstadt, Germany

When South Korea launched its 5G network, all carriers used Samsung, Ericsson, and Nokia base stations and equipment, except for LG U Plus, who also used Huawei equipment.[39][40] Samsung was the largest supplier for 5G base stations in South Korea at launch, having shipped 53,000 base stations at the time, out of 86,000 base stations installed across the country at the time.[41]

5G 3.5 GHz Cell Site of Vodafone in Karlsruhe, Germany

The first fairly substantial deployments were in April 2019. In South Korea, SK Telecom claimed 38,000 base stations, KT Corporation 30,000 and LG U Plus 18,000; of which 85% are in six major cities.[42] They are using 3.5 GHz (sub-6) spectrum in non-standalone (NSA) mode and tested speeds were from 193 to 430 Mbit/s down.[43] 260,000 signed up in the first month and 4.7 million by the end of 2019.[44]

Nine companies sell 5G radio hardware and 5G systems for carriers: Altiostar, Cisco Systems, Datang Telecom/Fiberhome, Ericsson, Huawei, Nokia, Qualcomm, Samsung, and ZTE.[45][46][47][48][49][50][51]

Spectrum

Large quantities of new radio spectrum (5G NR frequency bands) have been allocated to 5G.[52] For example, in July 2016, the U.S. Federal Communications Commission (FCC) freed up vast amounts of bandwidth in underused high-band spectrum for 5G. The Spectrum Frontiers Proposal (SFP) doubled the amount of millimeter-wave unlicensed spectrum to 14 GHz and created four times the amount of flexible, mobile-use spectrum the FCC had licensed to date.[53] In March 2018, European Union lawmakers agreed to open up the 3.6 and 26 GHz bands by 2020.[54]

As of March 2019, there are reportedly 52 countries, territories, special administrative regions, disputed territories and dependencies that are formally considering introducing certain spectrum bands for terrestrial 5G services, are holding consultations regarding suitable spectrum allocations for 5G, have reserved spectrum for 5G, have announced plans to auction frequencies or have already allocated spectrum for 5G use.[55]

Unlicensed spectrum

MNO's are increasingly using unlicensed spectrum in the 2.4- and 5-gigahertz (GHz) frequency bands. 4G and 5G networks also use these bands to offload traffic in heavily congested areas and provide connectivity for billions of IoT devices. Advancements in Wi-Fi, LTE in Unlicensed spectrum (LTE-U), License Assisted Access (LAA), and MulteFire use 4G & 5G technologies in these bands.

5G devices

In March 2019, the Global Mobile Suppliers Association released the industry's first database tracking worldwide 5G device launches.[57] In it, the GSA identified 23 vendors who have confirmed the availability of forthcoming 5G devices with 33 different devices including regional variants. There were seven announced 5G device form factors: (telephones (×12 devices), hotspots (×4), indoor and outdoor customer-premises equipment (×8), modules (×5), Snap-on dongles and adapters (×2), and USB terminals (×1)).[58] By October 2019, the number of announced 5G devices had risen to 129, across 15 form factors, from 56 vendors.[59]

In the 5G IoT chipset arena, as of April 2019 there were four commercial 5G modem chipsets and one commercial processor/platform, with more launches expected in the near future.[60]

On March 6, 2020 the first-ever all-5G smartphone Samsung Galaxy S20 was released. According to *Business Insider*, the 5G feature was showcased as more expensive in comparison with 4G; the line up starts at US$1,000, in comparison with Samsung Galaxy S10e which started at US $750.[61] On March 19, HMD Global, the current maker of Nokia-branded phones, announced the Nokia 8.3, which it claimed as having a wider range of 5G compatibility than any other phone released to that time. The mid-range model, with an initial Eurozone price of €599, is claimed to support all 5G bands from 600 MHz to 3.8 GHz.[62]

Samsung Galaxy S10 5G, the first smartphone able to connect to 5G networks[56]

Availability

Technology

New radio frequencies

The air interface defined by 3GPP for 5G is known as New Radio (NR), and the specification is subdivided into two frequency bands, FR1 (below 6 GHz) and FR2 (mmWave),[63] each with different capabilities.[64]

Frequency range 1 (< 6 GHz)

The maximum channel bandwidth defined for FR1 is 100 MHz, due to the scarcity of continuous spectrum in this crowded frequency range. The band most widely being used for 5G in this range is 3.3–4.2 GHz. The Korean carriers are using 3.5 GHz although some millimeter wave spectrum has also been allocated.

Frequency range 2 (> 24 GHz)

The minimum channel bandwidth defined for FR2 is 50 MHz and the maximum is 400 MHz, with two-channel aggregation supported in 3GPP Release 15. In the U.S., Verizon is using 28 GHz and AT&T is using 39 GHz. 5G can use frequencies of up to 300 GHz.[65] The higher the frequency, the greater the ability to support high data-transfer speeds.

FR2 coverage

5G in the 24 GHz range or above use higher frequencies than 4G, and as a result, some 5G signals are not capable of traveling large distances (over a few hundred meters), unlike 4G or lower frequency 5G signals (sub 6 GHz). This requires placing 5G base stations every few hundred meters in order to use higher frequency bands. Also, these higher frequency 5G signals cannot penetrate solid objects easily, such as cars, trees, and walls, because of the nature of these higher frequency electromagnetic waves. 5G cells can be deliberately designed to be as inconspicuous as possible, which finds applications in places like restaurants and shopping malls. [66]

Cell types		Deployment environment	Max. number of users	Output power (mW)	Max. distance from base station
5G NR FR2	Femtocell	Homes, businesses	Home: 4–8 Businesses: 16–32	indoors: 10–100 outdoors: 200–1000	10s of meters
	Pico cell	Public areas like shopping malls, airports, train stations, skyscrapers	64 to 128	indoors: 100–250 outdoors: 1000–5000	10s of meters
	Micro cell	Urban areas to fill coverage gaps	128 to 256	outdoors: 5000−10000	few hundreds of meters
	Metro cell	Urban areas to provide additional capacity	more than 250	outdoors: 10000−20000	hundreds of meters
Wi-Fi (for comparison)		Homes, businesses	less than 50	indoors: 20–100 outdoors: 200–1000	few 10s of meters

Massive MIMO

Massive MIMO (multiple input and multiple output) antennas increases sector throughput and capacity density using large numbers of antennas and Multi-user MIMO (MU-MIMO). Each antenna is individually-controlled and may embed radio transceiver components. Nokia claimed a five-fold increase in the capacity increase for a 64-Tx/64-Rx antenna system. The term "massive MIMO" was coined by Nokia Bell Labs researcher Dr. Thomas L. Marzetta in 2010, and has been launched in 4G networks, such as Softbank in Japan.[67]

Of more than 562 separate 5G demonstrations, tests or trials globally of 5G technologies, at least 94 of them have involved testing Massive MIMO in the context of 5G.[68]

Edge computing

Edge computing is delivered by computing servers closer to the ultimate user. It reduces latency and data traffic congestion.[69][70]

Small cell

Small cells are low-powered cellular radio access nodes that operate in licensed and unlicensed spectrum that have a range of 10 meters to a few kilometers. Small cells are critical to 5G networks, as 5G's radio waves can't travel long distances, because of 5G's higher frequencies.

Beamforming

Beamforming, as the name suggests, is used to direct radio waves to a target. This is achieved by combining elements in an antenna array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. This improves signal quality and data transfer speeds. 5G uses beamforming due to the improved signal quality it provides. Beamforming can be accomplished using phased array antennas.

Convergence of Wi-Fi and cellular

One expected benefit of the transition to 5G is the convergence of multiple networking functions to achieve cost, power, and complexity reductions. LTE has targeted convergence with Wi-Fi band/technology via various efforts, such as License Assisted Access (LAA; 5G signal in unlicensed frequency bands that are also used by Wi-Fi) and LTE-WLAN Aggregation (LWA; convergence with Wi-Fi Radio), but the differing capabilities of cellular and Wi-Fi have limited the scope of convergence. However, significant improvement in cellular performance specifications in 5G, combined with migration from Distributed Radio Access Network (D-RAN) to Cloud- or Centralized-RAN (C-RAN) and rollout of cellular small cells can potentially narrow the gap between Wi-Fi and cellular networks in dense and indoor deployments. Radio convergence could result in sharing ranging from the aggregation of cellular and Wi-Fi channels to the use of a single silicon device for multiple radio access technologies.

NOMA (non-orthogonal multiple access)

NOMA (non-orthogonal multiple access) is a proposed multiple-access technique for future cellular systems via allocation of power.

SDN/NFV

Initially, cellular mobile communications technologies were designed in the context of providing voice services and Internet access. Today a new era of innovative tools and technologies is inclined towards developing a new pool of applications. This pool of applications consists of different domains such as the

Internet of Things (IoT), web of connected autonomous vehicles, remotely controlled robots, and heterogeneous sensors connected to serve versatile applications.[71] In this context, network slicing has emerged as a key technology to efficiently embrace this new market model.[72]

Channel coding

The channel coding techniques for 5G NR have changed from Turbo codes in 4G to polar codes for the control channels and LDPC (low-density parity check codes) for the data channels.[73][74]

Operation in unlicensed spectrum

Like LTE in unlicensed spectrum, 5G NR will also support operation in unlicensed spectrum (NR-U).[75] In addition to License Assisted Access (LAA) from LTE that enable carriers to use those unlicensed spectrum to boost their operational performance for users, in 5G NR it will support standalone NR-U unlicensed operation that will allow new 5G NR networks to be established in different environments without acquiring operational license in licensed spectrum, for instance for localized private network or lower the entry barrier for providing 5G internet services to the public.[75]

Electromagnetic interference

The spectrum used by various 5G proposals will be near that of passive remote sensing such as by weather and Earth observation satellites, particularly for water vapor monitoring. Interference will occur and will potentially be significant without effective controls. An increase in interference already occurred with some other prior proximate band usages.[76][77] Interference to satellite operations impairs numerical weather prediction performance with substantially deleterious economic and public safety impacts in areas such as commercial aviation.[78][79]

The concerns prompted U.S. Secretary of Commerce Wilbur Ross and NASA Administrator Jim Bridenstine in February 2019 to urge the FCC to delay some spectrum auction proposals, which was rejected.[80] The chairs of the House Appropriations Committee and House Science Committee wrote separate letters to FCC chair Ajit Pai asking for further review and consultation with NOAA, NASA, and DoD, and warning of harmful impacts to national security.[81] Acting NOAA director Neil Jacobs testified before the House Committee in May 2019 that 5G out-of-band emissions could produce a 30% reduction in weather forecast accuracy and that the resulting degradation in ECMWF model performance would have resulted in failure to predict the track and thus the impact of Superstorm Sandy in 2012. The United States Navy in March 2019 wrote a memorandum warning of deterioration and made technical suggestions to control band bleed-over limits, for testing and fielding, and for coordination of the wireless industry and regulators with weather forecasting organizations.[82]

At the 2019 quadrennial World Radiocommunication Conference (WRC), atmospheric scientists advocated for a strong buffer of −55 dBW, European regulators agreed on a recommendation of −42 dBW, and US regulators (the FCC) recommended a restriction of −20 dBW, which would permit signals 150 times stronger than the European proposal. The ITU decided on an intermediate −33 dBW until September 1, 2027 and after that a standard of −39 dBW.[83] This is closer to the European recommendation but even the delayed higher standard is much weaker than that pleaded for by atmospheric scientists, triggering warnings from the World Meteorological Organization (WMO) that the ITU standard, at 10 times less stringent than its recommendation, brings the "potential to significantly degrade the accuracy of data collected".[84] A representative of the American Meteorological Society

(AMS) also warned of interference,[85] and the European Centre for Medium-Range Weather Forecasts (ECMWF), sternly warned, saying that society risks "history repeat[ing] itself" by ignoring atmospheric scientists' warnings (referencing global warming, monitoring of which could be imperiled).[86] In December 2019, a bipartisan request was sent from the US House Science Committee to the Government Accountability Office (GAO) to investigate why there is such a discrepancy between recommendations of US civilian and military science agencies and the regulator, the FCC.[87]

Criticism

Surveillance

Due to fears of potential espionage of users of Chinese equipment vendors, several countries (including the United States, Australia and the United Kingdom as of early 2019)[88] have taken actions to restrict or eliminate the use of Chinese equipment in their respective 5G networks. Chinese vendors and the Chinese government have denied these claims.

A report published by the European Commission and European Agency for Cybersecurity details the security issues surrounding 5G while trying to avoid mentioning Huawei. The report warns against using a single supplier for a carrier's 5G infrastructure, specially those based outside the European Union. (Nokia and Ericsson are the only European manufacturers of 5G equipment.)[89]

It has been alleged that the United States via the FBI, the UK via GCHQ and other intelligence agencies have sought to adjust 5G standards through 3GPP in order to allow as much metadata as possible to be collected for mass surveillance purposes.[90]

Environmental impact

Concerns have been raised about the visual impact of 5G transmitters on historically and environmentally sensitive areas.

In August 2019, a court in the United States decided that 5G technology will not be deployed without environmental impact and historic preservation reviews.[91]

Security concerns

On October 18, 2018, a team of researchers from ETH Zurich, the University of Lorraine and the University of Dundee released a paper entitled, "A Formal Analysis of 5G Authentication".[92][93] It alerted that 5G technology could open ground for a new era of security threats. The paper described the technology as "immature and insufficiently tested," the one that "enables the movement and access of vastly higher quantities of data, and thus broadens attack surfaces". Simultaneously, network security companies such as Fortinet,[94] Arbor Networks,[95] A10 Networks,[96] and Voxility[97] advised on personalized and mixed security deployments against massive DDoS attacks foreseen after 5G deployment.

IoT Analytics estimated an increase in the number of IoT devices, enabled by 5G technology, from 7 billion in 2018 to 21.5 billion by 2025.[98] This can raise the attack surface for these devices to a substantial scale, and the capacity for DDoS attacks, cryptojacking, and other cyberattacks could boost proportionally.[93]

Health

The scientific consensus is that 5G technology is safe and arguments to the contrary are based on a conspiratorial red herring that cites the newness of the technology as a reason not to trust it.[99][100][101][102] Misunderstanding of 5G technology has given rise to conspiracy theories claiming it has an adverse effect on human health.[103]

An international appeal to the European Union made on September 13, 2017, garnered over 180 signatures from scientists representing 35 countries.[104] They cite unproven concerns over the 10 to 20 billion connections to the 5G network and the subsequent increase in RF-EMF exposure affecting the global populace constantly. A further letter by many of the same scientists was written in January 2019, demanding a moratorium on 5G coverage in Europe until potential hazards for human health have been fully investigated.[105][106]

In April 2019, the city of Brussels in Belgium blocked a 5G trial because of radiation laws.[107] In Geneva, Switzerland, a planned upgrade to 5G was stopped for the same reason.[108] The Swiss Telecommunications Association (ASUT) has said that studies have been unable to show that 5G frequencies have any health impact.[109] Several Swiss cantons adopted moratoriums on 5G technology, though the federal offices in charge of environment and telecommunications say that the cantons have no jurisdiction to do so.[110]

According to CNET,[111] "Members of Parliament in the Netherlands are also calling on the government to take a closer look at 5G. Several leaders in Congress have written to the Federal Communications Commission expressing concern about potential health risks. In Mill Valley, California, the city council blocked the deployment of new 5G wireless cells."[111][112][113][114][115] Similar concerns were raised in Vermont[116] and New Hampshire.[111] After campaigning by activist groups, a series of small localities in the UK, including Totnes, Brighton and Hove, Glastonbury, and Frome passed resolutions against the implementation of further 5G infrastructure.[117][118][119]

There have been a number of concerns over the spread of disinformation in the media and online regarding the potential health effects of 5G technology. Writing in *The New York Times* in 2019, William Broad reported that RT America began airing programming linking 5G to harmful health effects which "lack scientific support", such as "brain cancer, infertility, autism, heart tumors, and Alzheimer's disease". Broad asserted that the claims had increased. RT America had run seven programs on this theme by mid-April 2019 but only one in the whole of 2018. The network's coverage had spread to hundreds of blogs and websites.[120]

Arson attacks

During the COVID-19 pandemic, several conspiracy theories circulating online posited a link between severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and 5G.[121] This has led to dozens of arson attacks being made on telecom masts in the Netherlands (Amsterdam, Rotterdam, etc.), Ireland (Belfast, Cork,[122] etc.), Cyprus, Scotland, Wales, England (Dagenham, Huddersfield, Birmingham and Liverpool[123][124]), Belgium (Pelt), Italy (Maddaloni), Croatia (Bibinje[125]) and Sweden.[126] It led to at least 61 suspected arson attacks against telephone masts in the United Kingdom alone[127] and over twenty in The Netherlands.

Marketing of non-5G services

In various parts of the world, carriers have launched numerous differently branded technologies, such as "5G Evolution", which advertise improving existing networks with the use of "5G technology".[128] However, these pre-5G networks are an improvement on specifications of existing LTE networks that are not exclusive to 5G. While the technology promises to deliver faster speeds, and is described by AT&T as a "foundation for our evolution to 5G while the 5G standards are being finalized," it cannot be considered to be true 5G. When AT&T announced 5G Evolution, 4x4 MIMO, the technology that AT&T is using to deliver the faster speeds, had already been put in place by T-Mobile without being branded with the 5G moniker. It is claimed that such branding is a marketing move that will cause confusion with consumers, as it is not made clear that such improvements are not true 5G.[129]

History

- In April 2008, NASA partnered with Geoff Brown and Machine-to-Machine Intelligence (M2Mi) Corp to develop 5G communications technology.[130]
- In 2008, the South Korean IT R&D program of "5G mobile communication systems based on beam-division multiple access and relays with group cooperation" was formed.
- In August 2012, New York University founded NYU Wireless, a multi-disciplinary academic research centre that has conducted pioneering work in 5G wireless communications.[131][132][133]
- On October 8, 2012, the UK's University of Surrey secured £35M for a new 5G research centre, jointly funded by the British government's UK Research Partnership Investment Fund (UKRPIF) and a consortium of key international mobile operators and infrastructure providers, including Huawei, Samsung, Telefonica Europe, Fujitsu Laboratories Europe, Rohde & Schwarz, and Aircom International. It will offer testing facilities to mobile operators keen to develop a mobile standard that uses less energy and less radio spectrum, while delivering speeds faster than current 4G with aspirations for the new technology to be ready within a decade.[134][135][136][137]
- On November 1, 2012, the EU project "Mobile and wireless communications Enablers for the Twenty-twenty Information Society" (METIS) starts its activity toward the definition of 5G. METIS achieved an early global consensus on these systems. In this sense, METIS played an important role of building consensus among other external major stakeholders prior to global standardization activities. This was done by initiating and addressing work in relevant global fora (e.g. ITU-R), as well as in national and regional regulatory bodies.[138]
- Also in November 2012, the iJOIN EU project was launched, focusing on "small cell" technology, which is of key importance for taking advantage of limited and strategic resources, such as the radio wave spectrum. According to Günther Oettinger, the European Commissioner for Digital Economy and Society (2014–2019), "an innovative utilization of spectrum" is one of the key factors at the heart of 5G success. Oettinger further described it as "the essential resource for the wireless connectivity of which 5G will be the main driver".[139] iJOIN was selected by the European Commission as one of the pioneering 5G research projects to showcase early results on this technology at the Mobile World Congress 2015 (Barcelona, Spain).
- In February 2013, ITU-R Working Party 5D (WP 5D) started two study items: (1) Study on IMT Vision for 2020 and beyond, and; (2) Study on future technology trends for terrestrial IMT systems. Both aiming at having a better understanding of future technical aspects of mobile communications toward the definition of the next generation mobile.[140]
- On May 12, 2013, Samsung Electronics stated that they had developed a "5G" system. The core technology has a maximum speed of tens of Gbit/s (gigabits per second). In testing, the transfer speeds for the "5G" network sent data at 1.056 Gbit/s to a distance of up to 2 kilometers with the use of an 8*8 MIMO.[141][142]
- In July 2013, India and Israel agreed to work jointly on development of fifth generation (5G) telecom technologies.[143]

- On October 1, 2013, NTT (Nippon Telegraph and Telephone), the same company to launch world's first 5G network in Japan, wins Minister of Internal Affairs and Communications Award at CEATEC for 5G R&D efforts.[144]
- On November 6, 2013, Huawei announced plans to invest a minimum of $600 million into R&D for next generation 5G networks capable of speeds 100 times faster than modern LTE networks.[145]
- On April 3, 2019, South Korea became the first country to adopt 5G.[146] Just hours later, Verizon launched its 5G services in the United States, and disputed South Korea's claim of becoming the world's first country with a 5G network, because allegedly, South Korea's 5G service was launched initially for just six South Korean celebrities so that South Korea could claim the title of having the world's first 5G network.[147] In fact, the three main South Korean telecommunication companies (SK Telecom, KT, and LG Uplus) added more than 40,000 users to their 5G network on the launch day.[148]
- In June 2019, Philippines became the first in Southeast Asia to roll out 5G network after Globe Telecom commercially launched its 5G data plans to customers.[149]
- AT&T bring 5G service to consumers and businesses in December 2019 ahead of plans to offer nationwide 5G in the first half of 2020.[150][151]

Other applications

Automobiles

5G Automotive Association have been promoting the C-V2X communication technology that will first be deployed in 4G. It provides for communication between vehicles and communication between vehicles and infrastructures.[152]

Public safety

Mission-critical push-to-talk (MCPTT) and mission-critical video and data are expected to be furthered in 5G.[153]

Fixed wireless

Fixed wireless connections will offer an alternative to fixed line broadband (ADSL, VDSL, Fiber optic, and DOCSIS connections) in some locations.[154][155][156]

Wireless video transmission for broadcast applications

Sony has tested the possibility of using local 5G networks to replace the SDI cables currently used in broadcast camcorders.[157]

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