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Is it really time to talk about 6G?

By Juan Pedro Tomas
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Introduction

There's a line of thinking in telecoms--real value and innovation only comes with even-numbered Gs. While 5G has been the talk of the industry for years with no signs of slowing, has it really lived up to the long-held world-changing promises used to sell it?

While 5G is still far from ubiquitous, research is progressing in earnest on its successor 6G which will presumably move up into THz frequencies and take the idea of real-time responsiveness to a whole new level.

The main players in the industry and academia consider that there is no time to waste in terms of research activities to determine what 6G will be and what use cases this future technology will enable. The cooperation between the diverse participants of the ecosystem will also be vital to avoid a fragmentation in the investigation and in the future development of 6G that could prevent it from becoming a global, unified standard.

Is it time to start talking about 6G?

Given the pace of change, a key question that usually emerges is will the highly advanced features we generally associate with 5G begin to materialize once we're well into the 6G hype cycle? Taking this into account, we talked with key industry leaders and analysts to get their perspectives.

Several operators and vendors are already engaged in regional 6G research initiatives and some of them have already published white papers about future 6G technologies.

Ericsson is among the companies that is heavily involved in initial research of future 6G technologies and considers that the time to gather together the industry, the government and academia in a combined and collaborative effort toward 6G is now. "I think it is time not only to talk about 6G, but to do something about it. Academia, industry, and governments need to work together in this very early phase. We're not developing standards yet, we're not developing products. We need a very long runway, so things have time to mature, to be discussed and investigated. We think it's a long game, so it is very necessary to get started.," Ali Khayrallah, Senior Scientist, Radio Networks at Ericsson Advanced Technology Group, said.

Khayrallah also said that the initial 6G research phase should be a pre-competitive phase between companies to avoid a potential fragmentation in key research activities. "There's a time when companies are in full competitive mode and they're not sharing anymore, except for standards. But in the early phase, if we don't talk about it, we don't publish it, we don't share it, and then the next company does the same things, then we'll have many efforts which are similar, but not common. At this early point companies should create energy and momentum behind 6G research, and then of course, later companies will pick up on certain technologies and champion them and develop them further."

According to Dimitris Mavrakis, Senior Research Director at ABI Research, the telecommunications industry is already starting to discuss 6G and the next wave of technologies, with some research organizations already looking at specific technologies that may be part of 6G, such as communications in Terahertz spectrum.

"On the other hand, the industry is not sure yet what 6G will provide in addition to 5G and 5G Advanced. Some people say that 6G will enable what 5G promised - especially in the enterprise domain - but we

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Chen Chang, Strategic Business Development Director at National Instruments (NI)

have to wait to see what R&D projects go ahead," Mavrakis said.

"Looking back at 4G and 5G, we know that a new standard takes about a decade to go from definition through standardization and ultimately begin deployments. Early research on enabling technologies for 6G is already beginning and will provide critical input to the standardization process. So while we are still several years away from 3GPP work beginning on 6G, for researchers and scientists it definitely makes sense to not just be talking about 6G, but to be planning and experimenting as well," said Chen Chang, Strategic Business Development Director at National Instruments (NI).

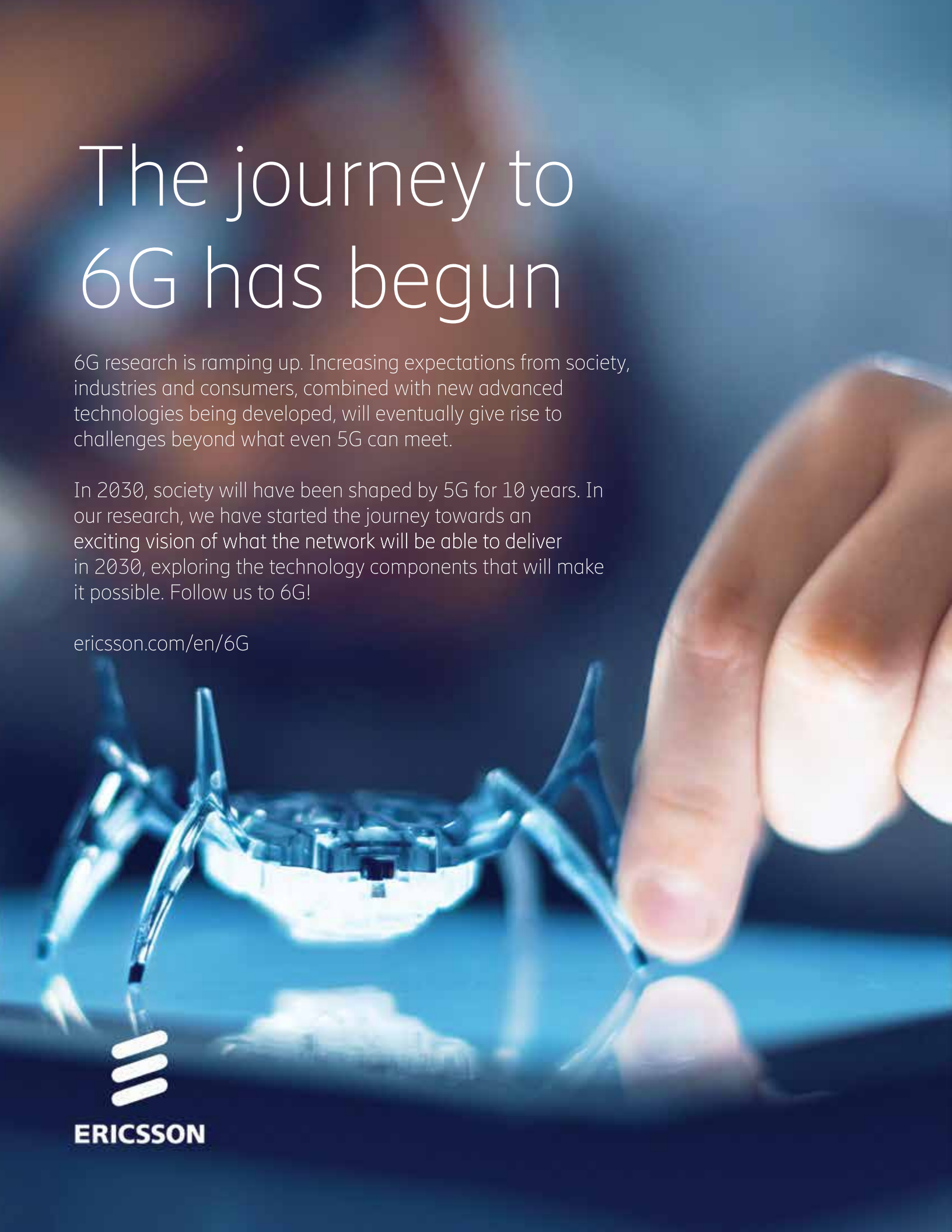
Steve Douglas, Head of Market Strategy at Spirent Communications, noted that cellular generations follow a roughly eight- to 10-year cycle from vision setting, through study items to requirements and then commercial availability. "The big difference this time is government focus and market expectations. In recent years, and especially since 5G, governments have had an increased focus on communication technologies as key enablers for economic stimulation and global leadership. This is creating unprecedented focus and amounts of funding," said Douglas, adding that at a global level, governments have already earmarked over $35 billion of funding towards 6G across the next decade. "We saw this behavior start with 5G but now in the early vision stages of 6G we are seeing mega funding roadmaps from the likes of China, U.S., Japan, Germany, the EU and Korea," he said.

"It's inevitable to focus on future gazing especially when 5G is still in its infancy and real benefits are currently hard to see," Douglas added.

Japanese operator SoftBank is one of the carriers that is already engaged in the race towards 6G. Ryuji Wakikawa, VP and Head of Advanced Technology Division at SoftBank, considered that now is a good time to start discussing and studying technologies that will be part of the 6G concept.

"In terms of 5G, it is certain that lots of new applications will be implemented in the next few years as defined in Release 17, which the standardization body 3GPP has already adopted," Wakikawa said.

Meanwhile, Mike Nawrocki, Managing Director of the Next G Alliance, an initiative launched by The Alliance for Telecommunications Industry Solutions (ATIS) in 2020 with the aim of advancing North American mobile technology leadership over the next decade, also said that new generations of mobile technology have generally taken about eight to 10 years from early development to commercialization. Given the trajectory for 6G technology is the end of this decade, the executive said that


The journey to
6G has begun
6G research is ramping up. Increasing expectations from society, industries and consumers, combined with new advanced technologies being developed, will eventually give rise to challenges beyond what even 5G can meet.
In 2030, society will have been shaped by 5G for 10 years. In our research, we have started the journey towards an exciting vision of what the network will be able to deliver in 2030, exploring the technology components that will make it possible. Follow us to 6G!
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North America needs to be well positioned to take a leadership role in creating a robust 6G marketplace, even as 5G continues to deliver powerful solutions to the market. The Next G Alliance includes over 70 members from industry, government and academia collaborating on a holistic approach, from research to realization. "This includes applied research, development, manufacturing, standardization, market readiness and ultimately commercialization. The Next G Alliance mission is built on a lifecycle approach for 6G that connects all of these phases and brings the power of North American resources to deliver global leadership for 6G and beyond," Nawrocki said.

Another key 6G initiative launched in Europe is the 6G Flagship program, which was developed by the University of Oulu, in Finland. Matti Latva-aho, Director of the 6G Flagship, also believes that now is the time to start with 6G research, with the aim of identifying promising technologies and defining directions and requirements, as it takes several years to identify, to verify and to propose such technologies. "Building early prototypes at the new radio frequencies considered for 6G is very time-consuming," he said.

According to Roger Nichols, 6G Program Manager at Keysight Technologies, 6G has been in active discussion amongst the research community since as early as 2018 and fundamental research necessary for realizing the 6G vision had started before that. "A look through the best whitepapers about 6G will reveal a vision that requires technology, policy, and business model development that will take well over a decade. To realize even introductory production networks in 2030, the work will have had to begin a few years ago. This is due not just to the nature of the necessary advancements, but also to the breadth of the technical work that is necessary—from semiconductor and materials science to next-generation artificial intelligence and everything in between—and it all has to work together in an integrated system." Nichols also noted that Keysight Technologies has had an active 6G program since 2019.

Meanwhile, U.S. chipmaker Qualcomm is also already working to define the potential capabilities of 6G technology. "While it's too early to definitively know about what 6G will be, we're starting to envision what a new 6G platform can do and how it will impact our society in the next decade. Today, we are already working on longer-term foundational research that will feed into both 5G Advanced and 6G," said Danny Tseng, director of technical marketing, at Qualcomm.

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The steps toward 6G

Khayrallah, of Ericsson, said that it would be essential to secure funding for 6G academic research and for collaborations between industry, government and academia. "So let's say in the next three, four or five years there will be this big effort on the research side. We need academia to lead the way, and industry will cooperate with it and increase its efforts to do more over time... We need studies to decide which of these so-called technology components have possibilities and have potential," Khayrallah said. An example of this is Ericsson's research collaboration with MIT covering lithionics-based device research to enable neuromorphic computing, promising exponentially more energy efficient AI-algorithms, and "zero-energy" device research to enable energy harvesting directly from the radio signals. Khayrallah added that the initial 6G studies in standards could begin in 2024 and the first specifications could be completed in 2028. "If things go according to the plans, you will have the first 6G networks around 2030."

According to Chang, of National Instruments, 5G New Radio (NR) is the first unified, global cellular standard, targeting a significantly expanded set of use cases and types of devices. "Release 15 laid the foundation, focusing on the enhanced mobile broadband (eMBB) use case and Releases 16 and 17 extend that to address new verticals enabled by URLLC, like Industrial IoT and transportation, and expand availability of 5G access. Releases 18 and 19 are expected to continue to evolve both eMBB and non-eMBB capability under the '5G Advanced' term, expanding to more new verticals, deployments, use cases and spectrum. While substantial progress has been made, much work remains to achieve the 5G 'connected everything' vision, both from a standardization and a deployment standpoint," Chang said.

Regarding the concrete steps that the industry needs to make until 6G networks could be launched, Mavrakis, of ABI Research, said that it's still not clear whether 6G will include new technology or be an evolutionary step for existing 5G networks. He said that R&D is happening right now and will continue in the next few years, while standardization discussions for 6G will likely take place on or after 2024.

Mikko Uusitalo, Head of Radio Systems Research Finland at Nokia Bell Labs and lead for European 6G Flagship Hexa-X, noted that 5G Advanced will develop 5G to its fullest capabilities and is an important stepping stone for some of the use case capabilities that are intended to be enabled at a larger scale in the 6G era - during which we will see the network evolve towards extreme performance in specialized networks, network of networks, and network-as-a-service. "We expect 6G systems to launch commercially by 2030. Standardization phase 1 will likely start from 2025, leading to the first 6G specification in 3GPP Release 21 by 2028 followed by commercial deployments around 2030. Meanwhile, 5G will be enhanced by 5G Advanced, which will be a key focus for 3GPP in Release 18 and 19 onwards and will power commercial public and private networks starting in 2025 onwards, well before 6G arrives at the end of the decade," Uusitalo said.

Sun Bo, senior expert in wireless technology standardization at ZTE, considers that the existing 5G network system will continue to be enhanced and will have a gradual transition to 5G Advanced and then into 6G. "The 6G era will further

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improve user experience, spectrum utilization, and network efficiency," the expert said.

"From 2022 to 2026, it will be a key window for the implementation and promotion of 5G networks, as well as a research window for 5G-A/6G requirements and enabling technologies. Based on the accumulation of 4G and 5G large-scale commercial network connection technologies, ZTE will continue to promote 5G-A/6G globally cooperation with the global telecommunications industry to ensure the formation of a global unified technical standard, an open telecommunications industry market and credible Industrial security."

"The journey to 6G from vision to realization we estimate will take eight [to]10 years with the latter stages of the 5G Advanced system becoming the evolutionary playground where early 6G capabilities like AI enabled self-driving networks and Reconfigurable Intelligent Surfaces will first be seen," said Douglas, of Spirent. "5G will have an evolutionary path to 6G through four more major standards releases over the next eight years adding enhancements and new capabilities specifically for supporting the enterprise, industrial and non-terrestrial space sectors."

Douglas said that Spirent estimates that the early research and vision phase of 6G, which is currently underway, will probably continue to 2023. "Then the standards feasibility study items between 2023 and 2026, followed by the work items and specifications between 2026 and 2028, with the first commercial release around 2029 or 2030."

However, the executive noted that this timeline could experience

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changes as leading nations push to have 6G trial networks available in the early second half of this decade.

Nawrocki, of the Next G Alliance, said that North America and other regions of the globe are already working on the research phase for 6G. "While there is still a long runway to launching 6G networks,

5G has demonstrated the need for taking a coordinated approach that joins the early learnings in research and development to the needs of market realization. This includes identification of market, societal and policy drivers that will lead to 6G products, services and applications. In North America we should be thinking about how to join outcomes from early research and development to critical areas like education, skill sets, and jobs of the future," he said.

According to Nawrocki, the standardization phase of 6G will likely intensify in the 2025 timeframe. "By addressing the longer-term issues, such as spectrum availability and market-timed policies, North America can be well-positioned to deliver on 6G by the end of the decade. The Next G Alliance will also work with key North American stakeholders through collaboration of the public and private sectors to align on research priorities, funding and other government actions that can incentivize the private sector."

Ericsson believes that the industry should try to elaborate a common set of standards that will

define future 6G technologies. "Having a common set of standards is certainly something we will try for. At Ericsson, we participate in several of these regional efforts. So, hopefully, there's the will from the different regions, and that will is not necessarily technical, it's probably more political, to feed all of their outputs into the same standards. Of course, the standards processes themselves are very competitive. But if there is a global will, we will end up with the same standard, as in the case of 4G and 5G," said Khayrallah of Ericsson.

Latva-aho, of the 6G Flagship, emphasized that the industry has already started collaborating with leading 6G academic research programs. "As the next step, we must jointly define the directions both for technology solutions and technical and other requirements for 6G. Hopefully, 6G will not get overhyped as it happened with 3G and 5G in the past."

Tseng, of Qualcomm said that the steps to enable future 6G technology are somewhat similar to previous generations, from vision, to research, to standardization, to interoperability testing, and finally, to commercialization. "Research is starting now, standardization will likely be in the second half of this decade and commercialization towards the end of this decade."

Meanwhile, according to Nichols, of Keysight, realizing the vision requires advancement in technology, policy, and business model, as it was the case with 5G technology. Nichols said that in the field of technology, the journey starts with fundamental research, which is the kind of work that does not become manifest in commercial implementations for over a decade. "This has been underway for some time yielding things like advancements in materials and semiconductors as well as in software technology, security, and AI. About two years ago we started to see more examples of applied research in which these technologies are used in more integrated systems. For example, new semiconductor and interconnectivity technologies are used to fabricate proof-of-concept integrated circuits and sub-systems. Another example is advanced end-to-end modeling of complex systems related to ultra-reliable and low-latency networks—this latter is a case of theoretical research which paves the way for experimental research when the time comes for proof-of-concept and, later, trial systems. These more integrated systems start with subset capabilities and then evolve to functioning

6G
The Next Generation of Wireless Communication

Although the first 6G consumer devices may be years away, thought leaders from academia and industry at the forefront of these cycles already are experimenting and building an understanding of key technologies critical for standardization. As we look at 6G's possibilities and promise, four candidate technologies stand out in terms of business opportunity and viability:

Integrated Sensing and Communication (ISAC)

The 6G experience requires more data as well as more environmental sensing and awareness. ISAC explores how to use the radio signals that cellular devices emit for radar. Autonomous vehicles, for example, have sophisticated sensing systems powered by machine-learning algorithms fusing data from cameras, lidar, and radar sensors. The advanced communications systems in these vehicles use cellular networks for streaming infotainment, environment and performance data, and vehicle-to-everything communications. The extent to which these two traditionally separate functions merge will depend on regulatory and technical factors, but the combination could potentially define 6G.

Sub-Terahertz Bands

The perpetual demand for more data bandwidth is pushing researchers to explore underutilized spectrum in the sub-THz frequency bands. Frequency bands between 90 GHz and 300 GHz offer many times the amount of spectrum currently used for cellular communications, but pathloss is one of the biggest hurdles in moving to sub-THz bands. While expanding to sub-THz bands may seem premature given the delay in 5G mmWave deployments to date, researchers are hopeful it could significantly increase network capacity.

MIMO

Building on popular multi-antenna techniques, MIMO promises potential benefits across many use cases and frequency bands. While beamforming is key to overcoming sub-THz pathloss challenges, multi-user MIMO improves spectral efficiency for the heavily used sub-6 GHz bands. In bands where antenna size becomes excessively large, distributed MIMO disaggregates the large antenna arrays into multiple, geographically separated radio heads that are significantly smaller. The expansion of MIMO aims to increase cell capacity and provide improved location services.

Artificial Intelligence and Machine Learning

As complexity increases and we seek to squeeze every bit of bandwidth out of the available spectrum, AI/ML offers one way to help optimize the communications system. AI/ML-driven design or adaptation could offer improvements through capabilities such as automatic spectrum allocation, beam management, and RF nonideality cancellation. Deploying AI/ML at the application layer can optimize Quality of Service (QoS), which considers application-specific requirements, along with the environment, for factors such as latency or energy efficiency. The availability of big, open datasets for AI/ML wireless communication research and training will play a significant part in 6G development.

What's more important than technology?

In addition to technology buzzwords like immersive extended reality and KPIs such as 1 Tb/s data rates, 6G discussions now include social and sustainability goals such as "connectivity for all." As we work to develop 5G by extending it beyond enhanced mobile broadband, and as the definition of 6G coalesces, we need to answer these business and social questions as well as the technical ones.

end-to-end networks."

In the field of policy, "all wireless networks and now those with more advanced compute capability with MEC operate in the context of government policy decisions. The most obvious example of these is spectrum policy and we can expect to see work done from the ITU all the way down to local governments regarding spectrum policy. This includes the decisions about which new frequency bands will be used for 6G and how to harmonize these across international boundaries," Nichols said. "Additional policy decisions impact taxation and even company definition—an example is how hyper-scaler companies are assuming part of the roles that up until a few years ago were the sole domain of commercial mobile network operators. These types of companies are taxed and regulated in very different ways and this will have an impact on deployment plans, partnerships, and business models."

Another example of policy decisions is related to cell-site density and placement. Nichols explained that most of the spectral efficiency gains over the past 100 years have been enabled by creating smaller cells—this trend will continue but cell-site deployment is a major policy issue in all regions. "Add to this last the expectation that merging satellite and terrestrial networks will go from nascent in 5G to mainstream in 6G—this means more policy decisions given the global scale of satellite coverage."

Regarding the business model of future 6G technologies, Nichols noted that the ability to create a virtual slice of the network and sell that as a commercial service will change the business model of all mobile operators. "One of the visions for 6G is to enable session-specific slices. One can quickly extrapolate how this will impact the business model of all entities involved from content creator to user. As 6G causes wireless connectivity to become a more pervasive part of society, the business models of all companies involved will have to be evolved to stay competitive and enable the full realization of the vision."

Regarding the timeline until the initial 6G networks could be commercially available, Nichols said that the early proof-of-concept subsystems will go from 2024 to 2030, while 6G standards will be defined during the 2025-2035 period. 6G trials will take place in the 2026-3032 period, while commercial launches will occur in 2028-3032.

"Research has already begun, for example into the use of sub-Terahertz frequencies or the integration of sensing and communication in the wireless network. Findings and demonstrations from this early research are essential to understand what's technically feasible and worth pursuing through standardization, but we will also need to understand what's viable from a commercialization perspective in terms of cost and use case. 6G standardization is expected to start in 2025 targeting rollouts beginning in 2030. Much like earlier generations, 6G functionality will be introduced over multiple releases. In some cases, we may even see some early versions of features get pulled into 5G-Advanced releases, depending on market demand," Chang said.

Describing 6G and its potential use cases

"From a technology perspective, future 6G networks will become more and more softwareized, more cloud based, and we will have a higher ability to control networks with software. What happens always is that the next standard, or the next big jump in technology does what the previous one managed to do, but better," said Khayrallah. The

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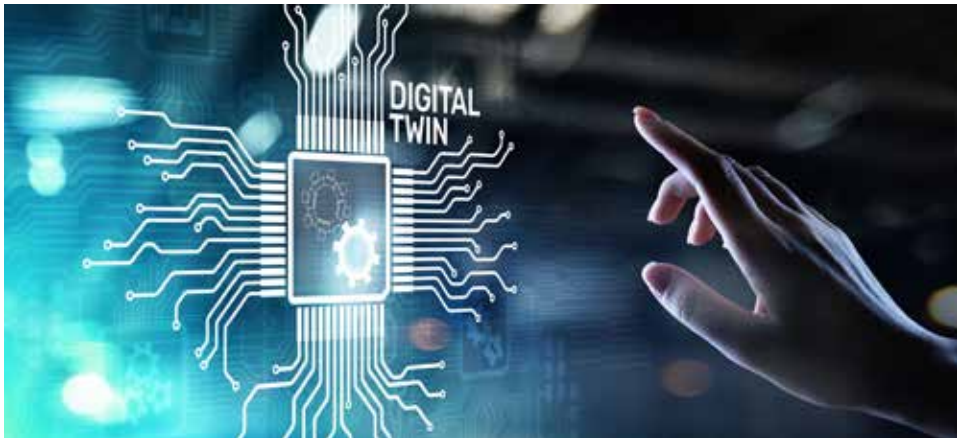
Ericsson scientist said that there will be also more emphasis on the domain of resilience and trustworthiness with future 6G networks.

Khayrallah also noted that future 6G technologies will open up new developments in terms of sensing technologies and digital twins. "Sensing technologies and digital twins are very interesting to us. At Ericsson, a few years ago, as a simple example of sensing, we used our millimeter wave backhaul network to measure microclimates. You can tell if it's raining or foggy by the quality of your links. You can use AI to try to understand what event happened that caused your backhaul rate to drop. And you can actually construct very precise microclimate maps. So that's just an example of using a network to infer something else. You can also go further and design sensing capabilities into the network. This is a very exciting area to look into."

Ericsson views that five key technology building blocks will drive mobile network evolution towards 2030 and beyond. The Swedish vendor said that embedded sensors will allow digital representations creating digital twins of both humans and physical objects as well as their environments, paving the way for the convergence of physical and digital worlds.

The vendor also highlighted that this future network will be powered by limitless connectivity that will dynamically adapt to realize an agile, robust, resilient, and open network framework. Also, future networks will be powered by cognitive AI networks capable of optimizing their own performance by virtue of continuous observation while acting autonomously.

Additionally, Ericsson believes that the convergence of IT technologies will promote a unified network compute ecosystem that seamlessly connects users of the air interface, the internet, cloud services and devices, while confidential computing and Zero Trust Architecture principles will ensure the safety, security, resilience, and privacy of 6G and



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other future networks.

According to Mavrakis, of ABI Research, it is yet uncertain the precise definition of 6G as well as the main features of this technology. "We can't tell for sure yet, but 6G will likely enable new applications and use cases. It will use more processing capabilities distributed throughout the network, rely on automated processes and have high bandwidth, low latency capabilities in the cellular domain."

Uusitalo, of Nokia, highlighted that in the 6G era, the digital, physical and human world will seamlessly fuse to trigger extrasensory experiences. "One of the most notable aspects of 6G will be its ability to sense the environment. The network will become a source of situational information, gathering signals that are bouncing off objects and determining type and shape, relative location, velocity and perhaps even material properties. This sensing network would open the door for many new services. In outdoor environments, the network could detect the location, speed and trajectory of all vehicles and pedestrians in an area, issuing warnings if any of their paths are about to intersect. Factories could use network sensing to make it safer for humans and industrial robots to work side-by-side on the shop floor."

Meanwhile, Douglas, of Spirent, noted that despite the fact that we are still at the early vision forming stage of 6G, the industry is starting to coalesce around several key ideas and ambitions. "One of the grander ambitions for 6G is to combine the physical, digital, and biological worlds into the realms of communications enabling holographic, tactile, and physiological-driven communications where our sensory inputs like touch and feel can be transmitted like voice and video enabling a new range of human machine services such as remote control of machinery and virtual teleportation," Douglas said.

According to the executive, digital twining is another area of great interest where a highly accurate, and synchronous digital representation of physical entities will become critical to optimize decision making in the design and operation of complex systems including networks. "One thing is clear and that is 6G will be an amalgam of complementary technologies coming together to deliver new use cases and value," Douglas added.

Douglas also highlighted that an early area of exploration is opening up the sub-Terahertz and Terahertz radio frequencies, using narrow pencil beams and highly directional antenna to deliver extremely high data rates and secure communications, adding that the radio frequencies could also be used for radio sensing to provide techniques to measure the environment, detect and recognize objects.

The Path to 6G

Rohde & Schwarz is leading discussions and is working with partners and customers on adapting solutions to support the initial phase of research on what might ultimately be called 6G. Explore with us.

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"There is also the exploration around Reconfigurable Intelligent Surfaces to help amplify and redirect the high propagation loss radio signals while providing coverage to unreachable areas. The smart surfaces with many small antennas or reflecting metamaterial elements receive and reflect electromagnetic waves with the capability of controlling the phase-shifts, thus offering tunable reflections and will enhance performance of field deployments and offload the complexity and power consumption overheads foreseen in future 6G distributed massive antenna arrays," he said.

Early research work is being done to develop printable ultra-thin metamaterial-surfaces which could cover our buildings, cars and every-day objects creating an all-encompassing reflective environment with zero or near zero power consumption overheads, Douglas added. "Finally, you have networks of networks. One of the targets of the 6G system architecture is to expand the breadth and depth of coverage beyond the current terrestrial network limitations to include earth orbital networks, high altitude platforms and even deep sea communications. This so-called 3D coverage may be a tight or lose integration and federation of various networks to create an unparalleled coverage landscape."

Douglas also said that in order to realize 6G's ambitions, the industry is already speculating on new targets and KPIs such as data rates with speeds as fast as 1 Tbps (100 x faster than 5G) and latencies as low as 0.1ms (10 x lower than 5G). "Now, the truth of the matter is that at this stage of vision setting and research the targets are mostly aspirational, as in reality we need to research and discover what metrics and ranges really make sense for the new types of services, and the levels of consistency and determinism that will make them useful."

According to Sun Bo, of ZTE, future 6G technologies would enable different application scenarios such as human-centric ultra-low latency and ultra-high transmission rate applications (such as holographic communication, immersive cloud XR), ultra-low latency and ultra-high reliability aimed at supporting vertical industries applications (such as collaborative robots, unmanned fleets, etc.) to support the ultra-large-scale connection required by digital twins, full-area coverage for the integration of air, space, and ground, and service consistency under high-speed movement. "In addition, the development of 5G-A/6G-oriented technologies and applications must consider the social responsibility of carbon peaking and carbon neutrality, as well as the social needs of the sustainable development of

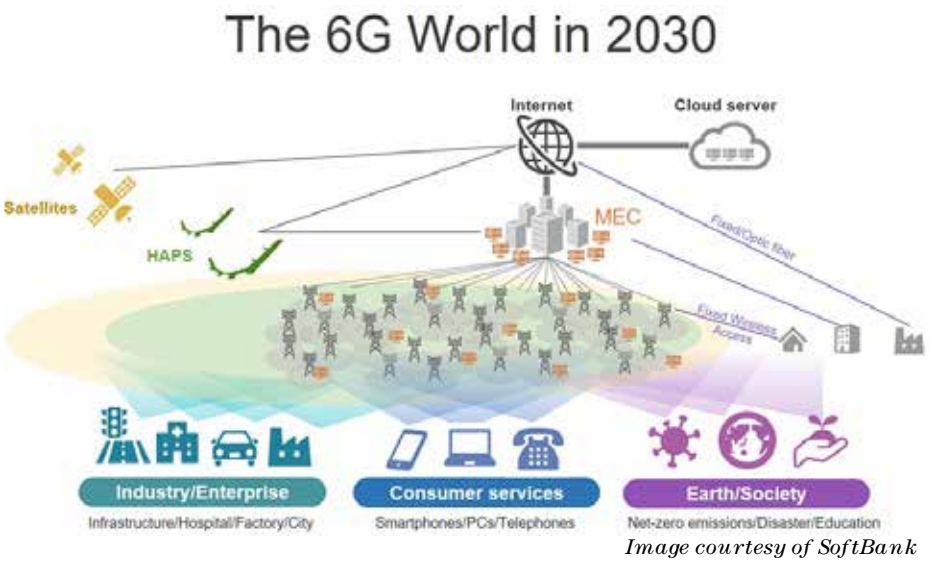

Image courtesy of SoftBank

communication networks and industrial ecology," he added.

Wakikawa, of SoftBank, said that 6G is expected to grow into a social infrastructure that will lead the digital industry to "implement digitalization in the world through mobile networks". In terms of use cases, 6G will support new services such as autonomous driving, smart cities, and X as a Service (XaaS).

Nawrocki, of the Next G Alliance, explained that some of the key technology development areas include AI-native air interfaces, advanced antenna packaging, new approaches to trustworthy solutions, distributed cloud and communications systems, THz and sub-THz radio systems and new sensing technologies. "In addition to 6G technology, it is important to consider the significantly greater reliance on the surrounding environment of predictive, contextual and cognitive data sources that will exist in everyday devices. 6G will leverage the surrounding physical environment to create a new paradigm of applications that are personalized to the user, creating a new digital world experience," Nawrocki said. Regarding potential use cases to be enabled by future 6G technologies, Nawrocki considered that there are many promising application areas including multisensory applications, network-enabled robotics, immersive XR, holographic services, ambient intelligence and human augmented experiences.

"We see two main directions for 6G. The first is mobile broadband beyond 5G to enable immersive user experience, and the second is massive machine type connectivity solutions to be available also for consumer markets. The latter is needed for massive automation of future digital societies [and] also supporting sustainable development," said Latva-aho, of the 6G Flagship.

The executive considers that global connectivity for remote areas has remained unsolved, and it has to be taken into account from a service continuity point of view in addition to sustainable development perspectives. "Professional use cases come first, but businesses will scale up only with services and applications offered for consumers. Maybe the entertainment industry will play an important role in the consumer sector. In professional use, critical infrastructures are likely to lead the way," Latva-aho added.

According to Nichols, of Keysight, 6G is the next generation in integrating wireless communication

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into society—and this time it is especially driven by a focus on further integration of communications, sensing, and computation into business, transportation, government, education, healthcare, industry, entertainment, and finance. Nichols noted that the Hexa-X project sponsored by the European Commission, envisions

five families of use-cases for future 6G technology, namely Sustainable Development, Massive Twinning, Immersive Telepresence, Robots to Cobots and Loca Trust Zones.

Nichols explained that sustainable development covers the use of wireless connectivity to benefit government operations with smart cities, extending education by moving expertise to where it needs to be, improving healthcare using not only the same techniques as in education, and even massive improvements in business by automating supply-chains.

Massive twinning is the logical extension of the concept of "computer simulation"—but not just simulating part of a system or an event, or even a single end-to-end system. "It means extending the virtual simulation to a full city or a group of inter-related factories or business operations. It also includes the idea of a seamless mix of simulation and real-world operation for the sake of periodic maintenance, scenario exploration, and even troubleshooting," Nichols said.

In the Immersive Telepresence field, the executive said that potential applications would be remote-troubleshooting or training that would allow physical interaction with remote people or objects.

"It may be too early to tell what the main features and use cases for 6G will be, but we see that 6G will bring us another step toward the merging of the physical, digital, and virtual worlds, expanding the connected intelligent edge. We are conducting our…research in several key areas, such as AI/ML-powered E2E communication, spectrum expansion/sharing, new radio designs (e.g., full duplex, large-scale MIMO), scalable network architecture, and communications resiliency," said Tseng, of Qualcomm.

According to Chang, of National Instruments, in some ways 6G is going to be an extension of 5G—higher data rates, more devices, enabling more use cases like wireless cognition, immersive extended reality, and e-health—but in other ways, we expect to see a more fundamental shift away from human-centric communication toward machine-centric communication. With advances in technologies like AI/ML and integration of sensing with communication, the network will be able to make many more decisions without human input, optimizing for outcomes based on application."

"Too much money is being spent on deploying 5G nationwide and 6G will not likely replace this. I would say that 6G will augment 5G with faster speeds, lower latency, more responsive communications and service granularity."

Dimitris Mavrakis, Senior Research Director at ABI Research

Key benefits of 6g and the co-existence of 5G and 6G

According to ABI's Mavrakis, 6G will likely be built on top of 5G rather than replace it. "Too much money is being spent on deploying 5G nationwide and 6G will not likely replace this. I would say that 6G will augment 5G with faster speeds, lower latency, more

responsive communications and service granularity."

"If 6G is designed and 'done right' then in my simple opinion it could help solve two of our greatest challenges which the communications world has struggled with since day one: convergence and consistency. True connectivity convergence would create seamless and ubiquitous coverage reducing barriers to innovation and consistency of delivered connectivity is more important than the sporadic peaks and troughs of speeds and coverage which define digital divides and stymie global innovation," said Douglas.

"On top of enhancing 5G's features that include ultra-high-speeds, ultra-low latency, and massive device connectivity, 6G is expected to bring new technology innovations, such as network architecture to make AI function, ensuring high levels of resiliency so that all businesses can utilize these advancements with peace of mind, and contributing to the realization of a carbon-free society," added Wakikawa, of SoftBank.

Nawrocki, of the Next G Alliance, explained that with each subsequent generation of mobile technology, there will be more opportunity to build upon the previous generation to complement existing network capabilities and investments. "While 6G will certainly demand improvements in network metrics like bandwidth and latency, it is also important to consider the many network enablers that will be coincident with 6G realization, such as AI, contextual awareness and distributed computing. Given that the Next G Alliance is focused on the end of this decade, we would envision an environment that takes into account the long term evolution of 5G, early deployment of 6G and commencement of research for beyond 6G. In this respect, we expect that 6G can build on the successes and learnings of 5G, even as new 6G capabilities are delivered to the marketplace."

Nichols, of Keysight, noted that 5G and 6G technologies will co-exist for a long period of time, while the former technology will lay the groundwork to enable the future potential of 6G. "As for 5G and 6G co-existing, one can see evidence of how this may come about by looking at the way 4G and 5G co-exist today. New network technologies do not switch on in a large scale overnight. The world will rely on 5G and even on 4G well into the next decade. 5G will lay the groundwork for some of the revolution of 6G with its far-reaching expansion of virtualization, combining communications and computation, the first steps to merging terrestrial and non-terrestrial networks, and the move to very high-speed and

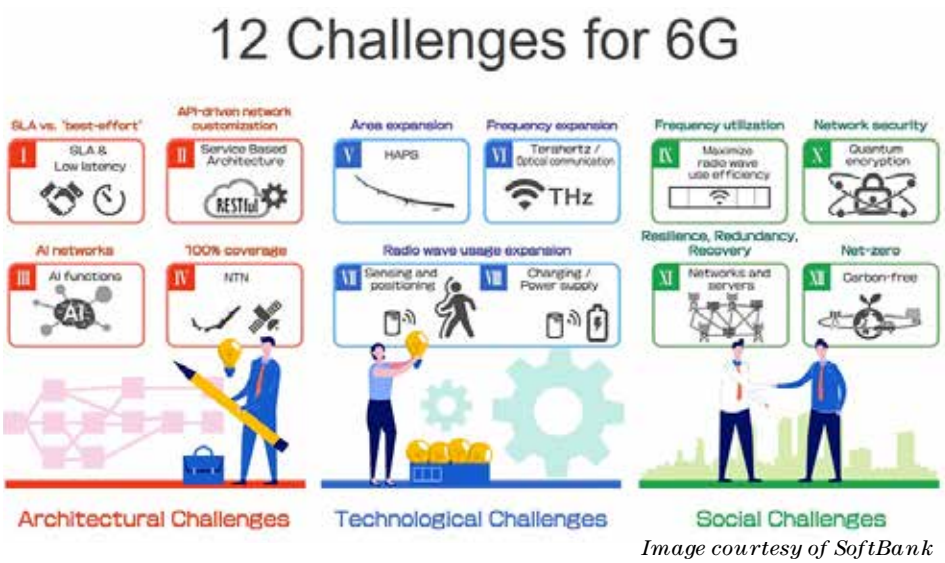

Image courtesy of SoftBank

"The world will rely on 5G and even on 4G well into the next decade. 5G will lay the groundwork for some of the revolution of 6G with its far-reaching expansion of virtualization, combining communications and computation, the first steps to merging terrestrial and non-terrestrial networks, and the move to very high-speed and high-reliability communications."
Roger Nichols, 6G Program Manager at Keysight Technologies

high-reliability communications," Nichols said.

"5G will have several updates along the way. And this will continue and new features will keep adding up. And new use cases will become more realizable, while 6G itself is kind of forming and getting momentum. So, 5G evolution and 6G buildup will occur side by side. And to some extent, 5G and 6G will be interchangeable for mainstream use cases. You will also see, as always, that the new standard takes over the new use cases and the more difficult technical requirements," explained Khayrallah, of Ericsson.

According to Latva-aho, 5G and 6G need to co-exist. 5G and 4G will provide large area coverage, and 6G will provide totally new, mainly local features with a somewhat limited range, he said. "We have to remember that 90% of all mobile data traffic takes place in an indoor environment, and thus, 6G will dramatically improve capabilities compared to 5G by drastically improving local connectivity solutions. Having significantly higher frequency bands alongside currently used low and mid-bands will enable these. Moving to these higher spectrum bands is a challenge both from a technology point of view and from a practical networks deployment view. There is a need also to re-think existing spectrum ownership models to allow the more flexible building of local networks with new capabilities. Openness will be the key for the future, but we should avoid security, privacy, and trust pitfalls."

"One aspect where 6G will differ from 5G is softwaerization, with more and more features becoming pure software solutions. 5G takes the first steps with its split architecture. Open RAN is pushing heavily to standardize interfaces to allow mix and match from different suppliers instead of having incumbents as one-stop-shop. Standardized interfaces and softwariezation, which allow network operators to try things out with little investments before massive roll-out, will be core tenets of 6G. This latter technology will need to be backward compatible with 5G and to co-exist for decades to come," Chang said.

Meanwhile, Uusitalo said that every single improvement in network connectivity that 5G will bring to the end-user will be taken to the next level with 6G. "Multiple key requirements must be reconciled: serve the massively growing traffic and the exploding numbers of devices and markets, while also accomplishing the highest possible standards regarding performance, energy efficiency and strong security, enabling sustainable growth in a trustworthy way," he said.

"While 5G Advanced will expand 5G beyond just data communication and substantially improve positioning accuracy to centimeter-level, especially for indoors and underground facilities where satellite signals are unavailable, 6G will take localization to the next level by taking advantage of wide spectrum and new spectral ranges all the way up to terahertz," Uusitalo added.

Global race to define 6G

Different regions and countries, as well as groups within them, are competing to be the first to define 6G, new use-cases, their requirements, and the technologies to build it. The US, EU, China, Japan and Korea are leading the way in terms of initial 6G research with a number of research initiatives and collaborations between the private sector, the academia and the government.

"With all the geopolitical constraints the market seems to be splitting between East/West. This means that infrastructure vendors – who are the leaders in R&D and defining cellular standards – may lower their involvement in 3GPP, meaning that the global development of 6G and common consensus may slow down. At the end of the day, what matters is essential patents and who owns them. This is a very big discussion but I believe China is very aggressive in 6G R&D and may lead this space," said Mavrakis, of ABI Research.

Douglas, of Spirent, considers that this initial competition towards 6G could be positive for the industry as countries still positively collaborate through global mechanisms such as the standards development organizations and industry bodies and alliances. "Many of the leading technology innovators and suppliers will be global or multi-country in operation meaning knowledge and capabilities will naturally disseminate. In addition, the fact that 6G is being designed on the premise of network of networks also means collaboration and openness will be required for success," Douglas added.

"Maybe this is also the time to stop calling it a 'G,' a 'Generation,' which sets unhelpful leadership connotations. With network of networks, cloud-native agility, and open networking developer ecosystems we are moving away from the generational approach of a transformational release and heading towards continuous and rapid iterations with loosely coupled federations of transient sub-network developers," the executive added.

Wakikawa also believes that it is positive for the industry that R&D is accelerating with the participation of various players toward the practical application of 6G technologies, given that the best standardization can be achieved through the feedback of these results by each participant.

"Other regions of the world are pursuing research initiatives and

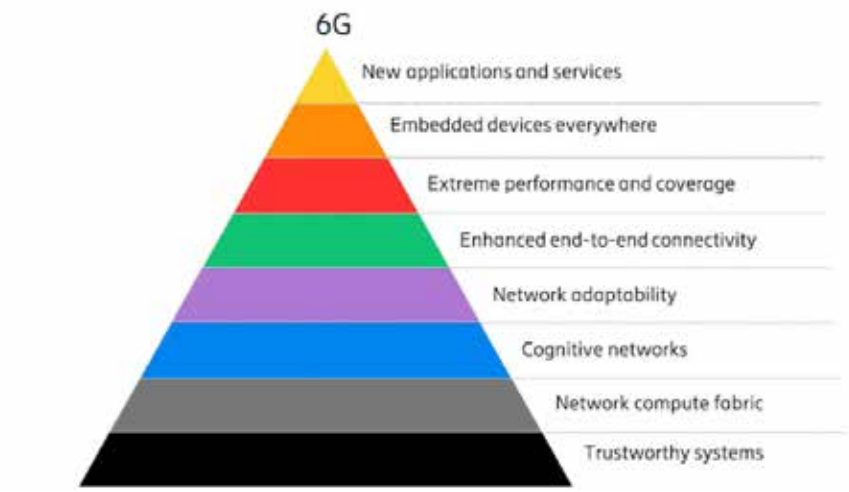

Image courtesy of Ericsson

public/private partnerships that advance 6G needs across their different countries and geographies. The Next G Alliance is focused on North American leadership across our specific market drivers, societal needs, government policies and values. For example, there are vertical markets in North America that are key to future economic competitiveness and societal goals in this region, such as healthcare, smart agriculture, transportation, public safety, remote workplace and education, in addition to many other areas," said Nawrocki. "Meeting regional goals and reaching global interoperability of 6G networks are not mutually exclusive. There will be opportunities for North America to partner with key regional organizations and share research outcomes. However, at a regional level, the Next G Alliance will identify key research priorities, technology development areas and application environments that will advance North America."

"As always, everyone wants to be the first one stating what next-generation technologies should entail, but several coalitions are already forming. The mobile research community worldwide has quite a joint view that only a global standard would lead to successful 6G.

"Meeting regional goals and reaching global interoperability of 6G networks are not mutually exclusive. There will be opportunities for North America to partner with key regional organizations and share research outcomes. However, at a regional level, the Next G Alliance will identify key research priorities, technology development areas and application environments that will advance North America."
Mike Nawrocki, Managing Director of the Next G Alliance

However, it is still possible that geopolitics plays a role in the end," said Latva-aho of Finland's 6G Flagship.

Cooperation with governments

Government grants, incentives, subsidies and other initiatives will be very important to stimulate the market and enable companies to create expertise and IPR/patents in the space, according to Mavrakis. He said that the U.S., Europe and China are very active in terms of cooperation between industry and government in the 6G research field.

"It is very important to allow early alignment on spectrum policy, national sustainability targets, regulatory coverage targets, investments to stimulate innovation and business/industry engagement," said Douglas, of Spirent.

Meanwhile, Wakikawa, of SoftBank, highlighted that collaboration between the public and private sectors will be important for practical applications and noted that the Japanese carrier has conducted joint research on THz wave-based communications with the Japan's National Institute of Information and Communications Technology (NICT) since 2017.

Latva-aho, of the 6G Flagship, said governments must realize that 6G is coming and they should make investments for 6G research now, before it is too late. "Collaboration is crucial. A large European 6G project, Hexa-X, is living proof of how it can work. Trans-Atlantic 6G collaboration has not really

started yet, which has been a bit of a surprise."

Ericsson considers that the timing of investments in 6G research is extremely important as is close cooperation with government. "What we are trying to do more consciously is to make sure that the funding for 6G research happens at the right time. We are very engaged with this issue to make sure that government is very aware and funding is available. Internally, after we launched 5G, and it became less heavily reliant on our research organization, we started gradually moving our internal resources to start 6G research. So today some of our internal efforts are focused on supporting 5G Evolution while others are supporting 6G research," Khayrallah said.

"Competition with regional initiatives is healthy for driving the development of the best possible technologies. However, the days of diverging mobile standards should be behind us. It is important we keep this collective harmonized effort towards 6G and beyond, otherwise the world will see the risk of slowing pace of this digital evolution and increasing

the cost of connectivity," said Nokia's Uusitalo.

6G testbeds and spectrum

According to Chang, of National Instruments, the goal is 2030 for initial 6G deployments, but noted that there are some companies already saying that's too late. "So similar to 5G, we will likely see commercial launches with an initially pared down set of features maybe as early as 2028, but built out over several years to actually deliver significant capability. 6G testbeds are already being developed for research around technologies like sub-THz and integrated sensing and communications."

Regarding the spectrum requirements for the deployment of future 6G networks, Chang highlighted that sub-6 GHz will remain the mainstay, especially with the mid-band frequencies being put into use, while mmWave rollout and adoption will also continue. Sub-THz bands are gaining a lot of attention, but for which use cases they're technically and commercially viable is still being proven out."

"In 6G, we will go even higher in frequency [compared to 5G], what some people call Terahertz, but they're really talking about 100-plus gigahertz. Why would you go there? Because there's more bandwidth available. We're also very interested in spectrum between 7 gigahertz and 20-plus gigahertz; this would be a prime target for 6G, in addition to every band that we already have, which will be eventually re-farmed," said Khayrallah, of Ericsson.

"Best estimate is we will see the standards feasibility study items between 2023 and 2026. Then the work items and specifications between 2026 and 2028," said Douglas, of Spirent.

Meanwhile, Latva-aho, of the 6G Flagship, believes that the first 6G standard will be ready around 2028, while testbeds are expected to kick off by 2026.

"One major element of realizing 6G—just like any of our previous generations—is that of Next-Generation Radio. This term means improving the use of existing spectrum and adding more spectrum for communications. Every previous generation includes advancements in using spectrum already set aside for its predecessor," said Nichols of Keysight. "The industry introduced spectrum above 3.5 GHz all the way up to 52 GHz for 5G. We can expect significant investment in getting even more out of the 3.5-7.1 GHz range as well as the "FR2" spectrum which will soon be up to 71 GHz. Research has started in frequencies from 90 GHz up to as high as 450 GHz for 6G. Will we add all of that spectrum for 6G? Probably not, but there is so much to be gained by leveraging the sensing and imaging that is enabled by these higher bands that I expect we will see at least up to 220 GHz in commercial systems some time during the 2030s," he said.

Conclusion

5G technology still has a long way to go in order to deliver all the promises and use cases anticipated by the industry. Many of these advances will be a reality with the development of 5G Advanced in the coming years. However, while the development and deployment of 5G continues at a global scale, the industry is beginning to develop in a very incipient way what future 6G technology will, for which cooperation between industry, academia and the public sector seems to be essential in the initial research and development phase..

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