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5G AND 6G EVOLUTION

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Abstract. The constant evolution in telecommunications is recognized both as a market driver and as a driver for R&D, since R&D activities are built to support consumer and business demands. The market pressures and recent past recessions have considerably shifted the focus of companies to product development and incremental research. This current focus on short term gains has paved the way for applied research to the furthest extent. Research and technological development, which is a founding block of any field of science and technology, was explained from the point of view of ICT with a primary focus on the telecom industry. The research ecosystem along with its shortcomings were also presented. It is important that governments and the ICT industry re-evaluate the R&D ecosystem and consider having both a 3 to 5-year view along with a 30 to 40-year long vision. 5G technology started to roll out effectively to ordinary users in 2019 (development of this technology started in April 2008), and in 2020 it was expected to spread to even more countries, and then in a few years it will be global. This is despite various studies that point out that 5G radiation will have negative effects on human health (which has also been claimed for 4G and 3G), while organisations such as the *US Communications Commission* (US FCC) and almost all similar organisations state that 5G radiation has no significant effects on human health. Another concern is the security of communications over 5G networks, especially equipment sold by China. Australia and the UK - in early 2019, took steps to restrict or eliminate the use of Chinese-sourced equipment in their 5G networks. Also in 2019 the US via the FBI and the UK via *Government Communications Headquarters* (GCHQ) other intelligence services, began to get more involved in changing surveillance standards. Including at the NATO meeting in London in December 2019, 5G network security and development was discussed. In addition to high download speeds, the 5G network also has a low "air latency" (between phone and antenna) of 8-12 milliseconds.

Keywords: *5G mobile communication, robust research ecosystem, 6G, wireless network, NTT DOCOMO, R & D process, significantly faster speeds, Nokia 2G 6G, making 6G a reality.*

Rezumat. Evoluția constantă în telecomunicații este recunoscută atât ca un motor de piață, cât și drept un motor pentru cercetare și dezvoltare, construite pentru a susține cerințele consumatorilor și ale afacerilor. Presiunile pieței și recesiunile recente au mutat considerabil concentrarea companiilor către dezvoltarea de produse și cercetarea incrementală. Accentul actual asupra câștigurilor pe termen scurt a deschis larg calea cercetării aplicate. Cercetarea

și dezvoltarea tehnologică, care este un bloc fondator al oricărui domeniu al științei și tehnologiei, a fost explicată din punctul de vedere al TIC, cu accent primar pe industria telecomunicațiilor. Au fost prezentate și ecosistemul de cercetare împreună cu deficiențele acestuia. Este important ca guvernele și industria TIC să reevalueze ecosistemul de cercetare și dezvoltare și să ia în considerare atât o viziune pe 3 până la 5 ani, cât și o viziune pe o perioadă de 30 până la 40 de ani. Tehnologia 5G a început să se răspândească în mod eficient către utilizatorii obișnuiți în 2019 (dezvoltarea acestei tehnologii a început în aprilie 2008), iar în 2020 era de așteptat să se răspândească în mai multe țări, iar apoi în câțiva ani să devină globală. Acest lucru se întâmplă în ciuda diferitelor studii care subliniază că radiațiile 5G vor avea efecte negative asupra sănătății umane (care a fost revendicată și pentru 4G și 3G), în timp ce organizații precum Comisia de Comunicații din SUA (US FCC) și aproape toate organizațiile similare declară că 5G radiațiile nu au efecte semnificative asupra sănătății umane. O altă preocupare este securitatea comunicațiilor prin rețelele 5G, în special echipamentele vândute de China. Australia și Regatul Unit al Marii Britanii au luat măsuri pentru a restricționa sau elimina utilizarea echipamentelor provenite din China în rețelele lor 5G. De asemenea, în 2019, SUA prin intermediul FBI și Marea Britanie prin intermediul cartierului general de comunicații guvernamentale (GCHQ) și alte servicii de informații, au început să se implice mai mult în schimbarea standardelor de supraveghere. Și la reuniunea NATO de la Londra din decembrie 2019 s-a discutat despre securitatea și dezvoltarea rețelei 5G. Pe lângă viteze mari de descărcare, rețeaua 5G are și o „latență a aerului" scăzută (între telefon și antenă) de 8-12 milisecunde.

Cuvinte cheie: *comunicații mobile 5G, ecosistem robust de cercetare, 6G, rețea fără fir, NTT DOCOMO, proces de cercetare și dezvoltare, viteze semnificativ mai mari, Nokia 2G 6G, transformând 6G în realitate.*

Introduction

As stated earlier, the 5G vision has been mainly focused on serving three applications: eMBB, uRLLC, and mMTC. These three applications however, require focused network planning around optimizing throughput, latency, and coverage respectively. The eMBB application is particularly challenging in dense urban environments where there is expected to be a massive installation of outdoor small cells as well as an extensive underground fiber optic network to support the traffic and throughput demands from the urban center [1]. Because of this, there has been a major effort around realizing millimeter-wave (mmW) communications technology for mobile networks—a spectrum space that was traditionally exclusively utilized for military and science purposes for radar and imaging [2].

This has proliferated mmW-based research in antennas, RF transceivers, and fabrication processes so that they are more readily integrated into user equipment. This all comes with the typical power (EIRP) and propagation requirements/considerations that are native to cellular components and networks. This has been particularly challenging considering the path loss at mmW frequencies—the high frequency signal attenuates greatly over distance causing the need for line-of-sight (LoS) links at close distances [3, 4]. Moreover, mmW frequency signals tend to scatter at an obstacle as opposed to its low frequency counterpart that can often diffract around an obstacle.

The uRLLC applications rely upon a highly synchronized network, at low-to-medium throughputs, with a very high device density [5-8]. Table 1 shows some sample uRLLC scenarios, often in an industrial automation setting. However, public safety and medical

applications are also required to have low latency and reliable communications. For instance, in a remote surgery application where a surgeon must be little time delay between the controller and equipment. This type of communications requires a dedicated backhaul backbone, low time errors in the synchronization path/clock chain from the primary reference time clock (PRTC) down to the telecom transparent clock (T-TC), with stringent end-to-end quality of service (QoS) goals.

Table 1

URLLC applications

Table 1 Performance requirements for uRLLC use cases							
Scenario	Max Allowable E2E Latency (ms)	Survival Time (ms)	Reliability (%)	User Experience Data Rate (Mbps)	Payload Size	Traffic Density (Gbps/km^2)	Connection Density (/km^2)
Discrete Automation	10	0	99.99	10	Small to large	1000	100,000
Process Automation - Remote Control	60	100	99.9999	1 to 100	Small to large	100	1,000
Process Automation - Monitoring	60	100	99.9	1	Small	10	10,000
Electricity Distribution - Medium Voltage	40	25	99.9	10	Small to large	10	1,000
Electricity Distribution - High Voltage	5	10	99.999	10	Small	100	1,000
Intelligent Transport Systems - Infrastructure Backhaul	30	100	99.999	10	Small to large	10	1,000

The mMTC applications almost directly correspond to the proliferation of IoT devices in industry vertices from commercial to industrial. This is supported by the ever-growing presence of new IoT protocols and the marketplace for IoT development platforms, bringing previously unknown data to the cloud for complex analysis and feedback [9, 10]. The network for this type of communication does not have the bandwidth constraints of eMBB nor the stringent latency requirements of uRLLC, rather, strict battery life/node maintenance expectations along with coverage in the unconnected areas of the globe [11-13]. Power saving protocols and energy harvesting techniques are used in these compact nodes with smart placement in order to ensure ideal connectivity along with OTA firmware updates for minimal maintenance after installation.

NTT DOCOMO R&D (Nippon Telegraph and Telephone do communications over the mobile network) has been in the forefront of mobile technology, not only in Japan, but also at a global scale. During 2014, it created one of the first labs dedicated to conducting R&D on 5G and to speeding up work on its standardization. It contributes about 2.5% of its revenue to research and development. It is evident that the vendor community spends over 10% of its revenue on R&D, whereas operators' spending hovers around 2% (if any). R&D spending by some of the largest operators is on the order of a few hundred million dollars, whereas it runs into billions for large-scale manufacturers [14]. Orange Labs and DOCOMO are the two key R&D spenders in the operator community, whereas the vast majority of the service providers do not set aside a budget for R&D.

R & D process (telecom)

Established vendors and start-ups are always seeking to bring research and innovations to their customers, that is, the operators. In the majority of cases, operators have the final say as to whether or not to take the supplier's innovation to the next level [15]. The established suppliers, big or small, have deeper pockets and more leverage over operators as compared to start-ups. The start-ups spend considerable time seeking funding from venture capital firms and endorsements from operators for their technology incubation. As the research starts to mature, suppliers start working to sell their ideas, which leads to technology

development (or technology incubation for start-ups). Technology development enables development and enhancement of practical solutions. Technologies are first normally standardized and then utilized during product development.

Nothing is more normal than to project oneself into the future when one works in tech. The telecom pros are already well advanced in their thinking. The planning has already been done: 6G is expected to be launched in 2028 and commercialised in 2030, and these few years will not be too long for telecom research, patenting and agreement on new standards.

We have gone from SMS to interactive video to IoT in a few years and 6G will propel us into another world [16].

Telecoms companies are working hard to implement 5G connectivity into our everyday lives, and some are reportedly already working on the upcoming 6G network. Samsung released a white paper called "*The Next Hyper-Connected Experience for All*" in which it detailed what the key areas for development are and what the hurdles are.

According to Samsung, 6G could launch in 2028 at the earliest, while mass adoption could happen ten years from now, or 2030. The timeframe is similar to the eight years it took the 5G network to develop from concept to reality. In comparison, the 3G network was developed in 15 years.

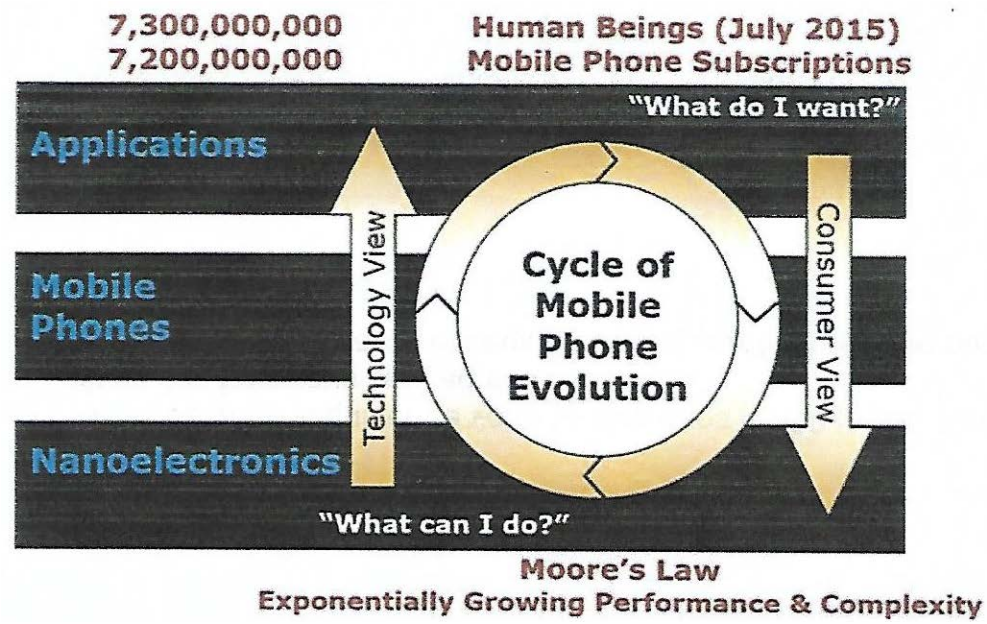

Figure 1. Cycle of mobile phone evolution.

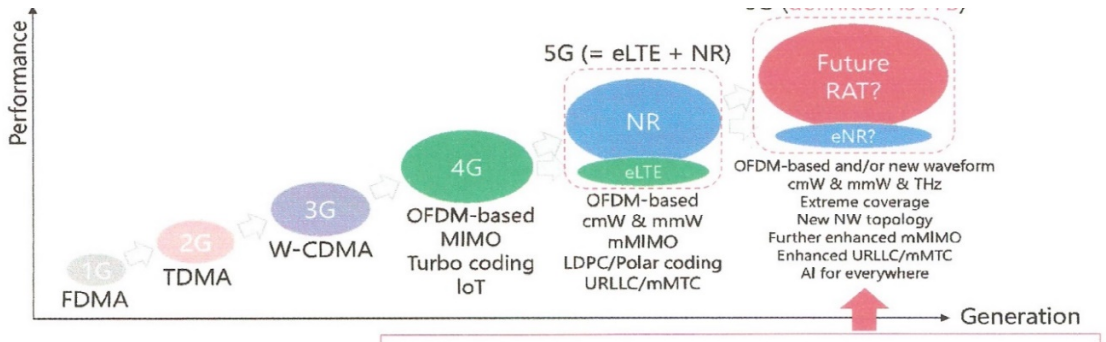

Figure 2. Technological evolution up to 5G in mobile communications.

Robust research ecosystem

A robust research ecosystem comprises strong government policies, energetic university and industrial research institutions, emerging start-ups, mature technology companies, funding for both basic and applied technologies from government and private institutions (including venture capital firms), and a large pool of talented researchers [17]. Only a few countries have all of the ingredients required to establish and maintain a dynamic ICT research ecosystem. Thus, strong collaboration is required at the global level so that one country can address the missing elements of another nation. A critical element for continuation of this ecosystem is investment in basic research, which is almost nonexistent, particularly in the ICT sector, worldwide. Most of the investment since the last decade has been pouring into applied research for immediate returns. This trend is expected to continue as ICT companies operate in a highly competitive and commoditized environment, which is forcing them to quickly bring products to market with razor thin margins.

Samsung also suggests that both people and machines will use 6G, which will enable a truly immersive extended reality (XR) experience, lead to high-fidelity holograms and digital replicas.

Figure 2 shows the technological evolution up to 5G in mobile communications.

What is 6G?

The applications have a natural progression to more a ubiquitous virtual experience with AR/VR applications, tactile internet along with intensive predictive analysis/modeling via the proliferation of artificial intelligence (AI) processing within said devices [18]. These push current technologies to the next level. The mixed reality (MR) experience uses 3D objects and AI to provide a seamless, immersive experience with a high integrity 6G connection.

An example of this would be holographic communications where conventional video conferences are augmented with a realistic projection for a three-dimensional image. The concept of connected robots and autonomous systems to provide basic services such as mail/package delivery also requires a high-fidelity wireless connection to enable the proper feedback necessary to control the destinations of such equipment.

Other future wireless applications include a brain-computer interface (BCI) where appliances can be controlled via a communication path between the user's brain and the device's RF front-end. This can be extended to the medical field with medical wearables tracking/monitoring a patient's health while they are in hospice [19]. Entirely automated industrial facilities with intensive computing will require a reliable connection to the cloud in order to perform the complex data analytics necessary for remote control and predictive analysis.

The 6G infrastructure is expected to be built upon 5G with some critical additions that diverge from the traditional contemporary cellular technologies. One major aspect of 6G is the incorporation of the terahertz spectrum from 0.1 THz to 10 THz [20]. This massive block of additional spectrum has the bandwidth to support the connectivity needed through the use of photonic and hybrid electronic-photonic transceivers. The benefit of this technology over most mmW technology is that a line-of-sight (LoS) link is not required. A cell-less architecture is called upon to support 6G where user equipment (UE) is connected to the RAN as opposed to a singular cell. This can be realized through the tight integration of difference communication technologies (e.g., sub-6 GHz, mmW, THz, and visible light communications

(VLC) where 6G devices can support all these heterogeneous radios within the device. This eliminates the gaps in coverage that come with handovers.

Figure 3 shows an Image of technological development toward 6G.

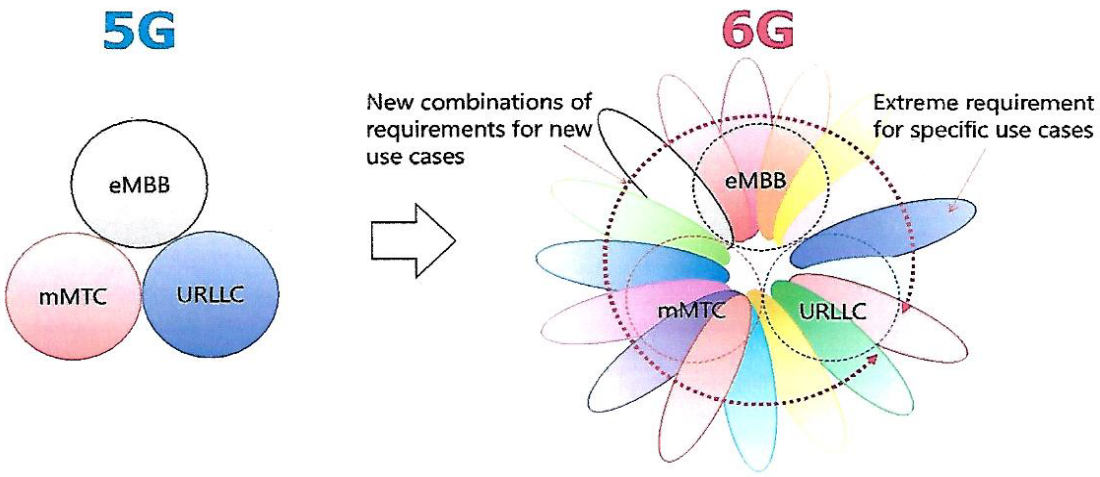

Figure 3. Image of technological development toward 6G (after NTT DOCOMO)
eMBB: enhanced mobile broadband; **mMTC**: massive machine type communication; **URLLC**: ultra-reliable and low latency communications.

Significantly faster speeds

As for the future of 6G technology, the future is looking bright, with data transfer speeds of 1 §TB per second that would, in theory, make it possible to download 142 hours of content at the highest resolution currently possible - 4K - every second. If these figures seem abstract, it's easiest to imagine a show like Supernatural, which will have 15 seasons of around 20-21 episodes each when it's finished, being downloadable using 6G in less than two minutes.

Despite the performance this technology could achieve, it's still a long way off before it can be integrated into the devices we use every day. Clearly, the physical limits of communications networks need to be overcome to support such a data flow [21-23].

As for the launch date of 6G technology, it will be available on the market after 2030, which means that it will take a few more years before it becomes dominant in the smartphone market.

Some reports also suggest that China is not alone in the race for 6G, with Japan already working to achieve this communications speed standard.

6G will not arrive before the end of the decade, but it will not only be a new increase in speeds and a reduction in latency. It is a true fusion of the real and digital worlds that is coming, with the human being always at the center [23].

5G is being rapidly deployed around the world and brings its share of new features with even more throughput, reduced latencies opening new possibilities (autonomous cars, industry 4.0, fine control at a great distance...) and an infrastructure that starts to be aware of its environment by adapting its capacities in real time according to the needs or emergencies [24, 25].

These elements will be found in 6G, the next generation of mobile technology that will take its first steps by the end of the decade and deploy more widely during the 2030s.

It will take these notions further by enabling a fusion between the real and digital worlds to create digital duplicates of the physical elements, filled with a whole set of data provided by multiple sensors and information bases.

Nokia 2G 6G

This fusion of the two worlds could endow humans with "superpowers" and analytical capabilities that go beyond their vision of the physical world by accessing a whole new set of information on their surrounding environment.

The equipment manufacturer Nokia is among the pioneers preparing this revolution through its Nokia Bell Labs research centers and talks about this upcoming transformation.

Every aspect introduced with 5G will be improved in 6G, with an intermediate evolution 5G-advanced that will prepare the ground around 2025 (as there was a 4G-advanced before 5G) [25]. The big theme of 6G is about creating these digital doubles, or "Digital Twin", of cities, infrastructure and factories. This trend is already underway with 5G, but it will take on a new dimension with the next generation by enabling much faster detection and response to out-of-the ordinary conditions and phenomena, whether it's an incident or a need to redirect resources to a specific point [26].

What remains now is to identify/finalize the technologies and put in place the intellectual property that will create this vision. Nokia estimates that the first 6G systems will be operational by 2030, following a classic 10-year cycle between generations of cellular communications, with the first phase of standardization by 2026, within 3GPP Release 20.

5G-Advanced will pave the way through 3GPP Release 18, with a rollout from 2025. As a reminder, Nokia is the project leader of the Hexa-X program, which should put Europe back at the heart of 6G developments [27].

Nokia for NASA

Nokia to develop a 4G network on the Moon for NASA. Nokia has received funding from NASA to study the possibility of designing a 4G network on the Moon as part of the human colonization project of our natural satellite [28].

5G: Nokia to build its own experimental mobile network in Finland. Nokia plans to build an experimental 5G mobile network in Finland that could be up and running by early next year.

Making 6G a reality

There are already research initiatives kicked-off in different countries in order to realize 6G. In Finland, the University of Oulu kickstarted Finnish 6G research in 2018. The FCC opened up the 95 GHz to 3 THz spectrum for experimental licenses, opening up research opportunities for optical/photonic communication links in the U.S. As of 2019, South Korea and China began putting together working groups dedicated to 6G research between companies, government departments, and universities [29]. It goes without saying that 6G is very much a nascent platform. However, between the potential new technological solutions and the KPIs, it will become the new goalpost for innovation beyond 5G [30].

Conclusion

Hyperconnectivity, the trend towards online work and communication has been fueled by both technical and social trends. Entire companies and even industries have moved to online working. And after the workday is over, people switch from video calls to online gaming. From virtual reality games to massively multiplayer immersive experiences,

participation in online games has skyrocketed. People no longer come together at an office building to work or at a sports stadium to watch a game. They go online, in millions of homes, to meet colleagues, drive virtual race cars, or cheer on their favorite rock stars at a virtual concert.

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