An Abstracted Survey on 6G: Drivers, Requirements, Efforts, and Enablers

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Abstract—As of today, 5G mobile systems have been already widely rolled out, it is the right time for academia and industry to explore the next generation mobile communication system beyond 5G. To this end, this paper provides an abstracted survey for the 6G mobile system. We shed light on the key driving factors for 6G through predicting the growth trend of mobile traffic and mobile service subscriptions until the year of 2030, envisioning the potential use cases and applications, as well as deriving the potential use scenarios. Then, a number of key performance indicators to support the 6G use cases are identified and their target values are estimated in a quantitatively manner, which is compared with those of 5G clearly in a visualized way. An investigation of the efforts spent on 6G research in different countries and institutions until now is summarized, and a potential roadmap in terms of the definition, specification, standardization, and spectrum regulation is given. Finally, an introduction to potential key 6G technologies is provided. The principle, technical advantages, challenges, and open research issues for each identified technology are discussed.

Index Terms—6G, 6G, wireless, communication networks

I. INTRODUCTION

The year of 2019 opens a new era of the 5G mobile communications. As we are writing the paper, a list of countries such as South Korea, United States, Switzerland, United Kingdom, and Spain have launched commercial 5G services for the general public, while this list grows quickly and is envisioned to become much longer in the near future. As a revolutionary technology, 5G will penetrate into all aspects of society, generating tremendous economic and societal benefits. From the perspective of technology research, however, it is already the time to start considering what the future beyond-5G (B5G) or 6G mobile networks should be, in order to satisfy the demand on communications and networking in 2030.

Since 2018, several pioneering projects have been launched aiming at the next generation of mobile networks. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Focus Group Technologies for Network 2030 (FG NET-2030) was established in July 2018, intending to study the capabilities of networks for the year 2030 and beyond, when it is expected to support novel forward-looking scenarios. The European Commission initiated to sponsor beyond-5G research activities, such as its recent Horizon 2020 call - 5G Long Term Evolution – where a number of pioneer projects will be kicked off at the early beginning of 2020. In Finland, the University of Oulu began ground-breaking 6G research as part of Academy of Finland’s flagship program, 6G-Enabled Wireless Smart Society and Ecosystem (6Genesis). Besides, other counties such as the United States, China, Japan, and South Korea already formally started the research and development of key 6G technologies or at least announced their ambition to support the 6G works.

During the same period, there has also been a significant literature conducted for 6G, as listed in Tab. I. Some of these works focus on the description of use cases or applications, some list a number of potential key technologies but only in rough introduction, while some others are providing detailed technological description to very specific categories of technologies. To the best of our knowledge, yet there is no comprehensive survey that can provide a complete view to link the aforementioned related works into an organic structure. To fill this gap, in this article we attempt to provide a complete and through view of the state-of-the-art advances in the development and research of 6G by providing vision, use cases, use scenarios, requirements, efforts, roadmap, as well as an introduction to the promising key technologies.

The rest of this article is organized as follows: Sec. II discusses the key driving factors for the necessity of developing 6G, including the prediction of the explosive growth of mobile traffic and mobile users by 2030, the envision and use cases and application scenarios. Sec. III analyzes the requirements for the 6G systems by quantitatively depicting a number of key performance indicators. The efforts of research, regulatory, and standardization of the main players in the mobile communication industry are summarized and the potential timelines and roadmap for development and standardization are estimated in Sec. IV. Sec. V provides a brief survey of a dozen of key technologies that are identified as the key enablers for 6G. Finally, Sec. VI concludes this article.

II. DRIVERS

As of today, the commercial deployment of 5G mobile networks has been rolled out for around one year across the world, and the network scale in some countries is already very large. Following the historical tradition in the mobile industry, i.e., a new generation every ten years, it is the right time to discuss the successor of 5G in the research and standardization community. The key driving forces for the development of a next-generation system are not only from the exponential growth of mobile traffic and connectivity demand, but also from new disruptive services and applications on the horizon.

A. Explosive Mobile Traffic

We are in an unprecedented era where a massive number of smart products, services, and applications emerge and evolve
quickly, imposing a huge demand on mobile traffic. It can be foreseen that the 5G system designed before 2020 cannot well satisfy such a demand in 2030 and beyond. Due to the proliferation of rich-video applications, enhanced screen resolution, Machine-to-Machine (M2M) communications, mobile cloud services, etc., the global mobile traffic will continuously increase in an explosive manner, up to 5016 EB per month in the year of 2030 compared with 62 EB per month in 2020, according to the estimation of ITU-R made in 2015 [19]. A report by Ericsson [20] revealed that the global mobile traffic had reached around 33 EB per month by the end of 2019, which partially proves the correctness of ITU-R’s estimation. The number of smartphones and tablets will further increase, while other devices such as wearable electronics will grow in a faster pace, amounting to a total of 17.1 billion mobile subscriptions in 2030. In addition to the human-centric communications, the M2M terminals will experience a more-rapid growth and will become saturated no earlier than 2030. It is envisioned that the number of M2M subscriptions will reach 97 billion, as shown in Fig.1 around 14 times over that of 2020. The traffic from mobile video services already dominated, account for two-thirds of all mobile traffic. However, the usage of video services keeps growing, such as the boom of Tik-Tok recently, and the resolution of video continuously improves. In some developed countries, strong traffic growth before 2025 is driven by rich-video services and long-term growth wave will continue due to the penetration of Augmented/Virtual Reality (AR/VR) applications. The average data consumption for every mobile user per month, as illustrated in Fig.1, will increase from around 5 GB in 2020 to over 250 GB in 2030.

B. Use cases

With the advent and evolution of cutting-edge fields, such as displaying, robotics, edge computing, AI, unmanned aerial vehicle (UAV), and space technology, in combination with the mobile system, many unprecedented use cases can be fostered. Here, we envision several cases with high potential, as summarized in Tab. I.

C. Use scenarios

In the 5G systems, three usage scenarios have been firstly defined by ITU-R recommendation M.2083 in 2015 [21]. More specifically: the enhanced Mobile Broad-band (eMBB)
TABLE II
SOME 6G USE CASES WITH HIGH POTENTIAL.

| Use Case              | Typical Applications                                      | Key Requirements                        |
|-----------------------|-----------------------------------------------------------|-----------------------------------------|
| Extended reality (ER) | immersive gaming, remote surgery, remote industrial control | high data rate (>1.6 Gbps/device), low latency, high reliability |
| Holographic telepresence | online education, collaborative working, deep-immersive gaming | ultra-high data rate (terabits per second) |
| Multi-sense experience | remote surgery, tactile Internet, remote controlling and repairing | stringently low latency |
| Tactile Internet for Industry 4.0 | industrial automation, smart energy consumption | ≤1 ms E2E latency |
| Intell. transport & logistics | Automated road speed enforcement, real-time parking management | stringently high reliability and low latency |
| Ubiquitous global roaming | World-wide roaming services for UEs, portable devices, industrial apps. | low-cost fully global coverage |
| Pervasive intelligence | computer vision, SLAM, speech recognition, NLP, motion control | high decision accuracy and transparency, complex data privacy |

FIG. 1. The estimated global mobile subscriptions and traffic from 2020 to 2030. Source: ITU-R Report M.2370-0 [19].

FIG. 2. The envisioned use scenarios for 6G systems.

addresses the human-centric applications for a high-data-rate access to mobile services, multi-media content and data; the Ultra-Reliable Low-Latency Communications (URLLC) focuses on enabling mission-critical connectivity for new applications with stringent requirements on reliability, latency, and availability; while the massive Machine-Type Communications (mMTC) aims at support to dense connectivity with a very large number of connected devices that are low-cost, low-power consumption but typically transmitting a low volume of delay-tolerate data [22].

Being customized for highly specialized applications, all 5G use scenarios achieve extreme performance in some aspect by sacrificing in others, and cannot fully satisfy the requirements of envisioned 6G use cases. For instance, an user wearing a lightweight VR glass playing interactive immersive games requires not only ultra-high data throughput but also very low latency connectivity. Autonomous vehicles on the road or flying drones demand both high data rate and high-reliability low-latency connectivity. Through extending the scope of current 5G use scenarios, as shown in Fig. 2, we envision four extra scenarios to cover their overlapping areas.

To accommodate the increasing capacity requirement from commercial passenger planes, helicopters, ships, high-speed trains and the demand of connectivity in remote areas, a ubiquitous coverage of MBB service for the whole planet is expected in 6G, which we named ubiquitous Mobile BroadBand (uMBB) as an use scenario for 6G. Another key aspect of uMBB is the capacity improvement for hot spots so as to support the proliferation of new services, e.g., VR with a data rate of up to 1 Gbps/user. Ultra-reliable Low-latency Broadband Communication (ULBC) supports the services with low-latency high-reliability connectivity and high data throughput, such as moving robots and Automatic Guided Vehicle (AGV) in industrial sites. The scenarios of massive Ultra-reliable Low-latency Communication (mULC) combines the features of mMTC and URLLC, facilitating the deployment of massive sensors and actuators in verticals.

III. KEY PERFORMANCE INDICATOR REQUIREMENTS
To satisfy the technical requirements of use scenarios and applications in 2030 and beyond, the 6G system will provide more system capacity and network performance. Most of the key performance indicators (KPIs) applied for quantitatively or qualitatively evaluating 5G networks are also valid for 6G networks while some new KPIs must be considered for the new features. We briefly summarize our overview to the KPI comparison between 5G and 6G in Fig. 3 and Tab. III

IV. ROADMAP AND EFFORTS
Although a discussion is ongoing within the wireless community about whether counting should be stop at 5, several pioneering works on the next-generation wireless networks have been initiated, as summarized in Fig. 4.

V. TECHNOLOGICAL ENABLERS
To pave the road towards the expected extreme performance, so as to realize the envisioned use cases and use scenarios, a diverse set of technologies are expected to play their roles in the future evolution of mobile networks. We can generally categorize them into the following groups: New Spectrum
TABLE III
COMPARISON BETWEEN 5G AND 6G ON SOME KPI REQUIREMENTS

| KPI                              | 5G Requirement                     | 6G Requirement                     |
|----------------------------------|------------------------------------|------------------------------------|
| Peak data rate                   | 20/10 Gbps (DL/UL)                 | 1 Tbps                             |
| User-experienced data rate       | 100/50 Mbps (DL/UL, dense urban)   | ≥ 1 Gbps                           |
| Latency                          | UP: 4/1 ms (eMBB/URLLC)            | CP: 10 ms (eMBB/URLLC)             |
|                                  | CP: remarkably improved            | CP: 10 μs to 100 μs                |
| Mobility                         | up to 500 km/h (high-speed trains) | up to 1,000 km/h (airlines)        |
| Connection density               | 10^m per km^2 (with relaxed QoS)   | 10^2 per km^2                      |
| Network energy efficiency        | not defined                        | 10 - 100 times better than that of 5G |
| Peak spectral efficiency         | 90/45 Gbps/Hz (DL/UL)              | 90/45 Gbps/Hz (DL/UL)              |
| Area traffic capacity            | 10 MBps/m^2                        | 1 Gbps/m^2                         |
| Reliability                      | ≥ 99.999% (URLLC, 32 bytes within 1 ms, urban macro) | ≥ 99.99999% |
| Signal bandwidth                 | ≥ 100 MHz                          | ≥ 1 GHz                            |
| Positioning accuracy             | 5/m,10/m                           | cm level                           |
| Hit奈ess                         | undefined                          | considered                         |

Fig. 3. The envisioned KPI requirements for 6G in comparison with 5G.

VI. CONCLUSIONS

In this paper, we provided an abstracted outlook at the drivers, requirements, efforts, and enablers for the next-generation mobile system beyond 5G. The prediction of the trends, the envision of the future societal and technological evaluation, and the identification of key research directions might be rough, partial and even somehow inaccurate with the limitation of the knowledge of the authors and the information we can collect up to now.

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Fig. 4. The roadmap for main 6G research and developments.

TABLE IV
CATEGORIZED KEY ENABLERS WITH ADVANTAGES AND CHALLENGES

| Category   | Enabler                                  | Advantages                                                                 | Challenges                                                                 |
|------------|------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Spectrum   | THz                                      | high bandwidth, narrow beams, high integration level [7], [23], [25]         | severe attenuation & blockage, low range                                     |
|            | OWC (incl. VLC)                          | almost unlimited bandwidth, license-free, low cost, security, health-friendly| frail MIMO gain, HW implementation, noise, loss, nonlinearity, dispersion, pointing errors [8], [8] |
|            | DSSM                                     | coexistence of licensed/unlicensed users                                    |service heterogeneity, SDN controller placement, auto network management [80] and orchestration [81], E2E QoS control [82], [83], [84] |
|            | NFV & SDN                                | high flexibility, low operational cost [67]                                 | rely on 3rd party assessments, business framework                           |
|            | RAN Nslicing                             | flexibility, resource efficiency, security                                  | arch. framework supporting multi-use-case verticals [85]                     |
| Networking | O-IOAN                                    | efficiency, intelligence, flexibility, dynamic                              | lack of tech. convergence & standardization efforts                         |
|            | Security                                 | service-based E2E security                                                  | AI & ML deployment                                                          |
| Air interface | Massive MIMO                          | high capacity, statistical multiplexing gain                                | extremely large aperture, channel prediction [27], [86], intell. env. aware adaptation, holographic mMIMO, 6G positioning, large-scale MIMO radar [87], [88] |
|            | IRS, aka RIS/SRE                         | high MIMO gain, low imp. cost, low power [42], [43]                        | rely on 3rd party assessments, business framework                           |
|            | CoMP                                     | BS-level spatial diversity, cell-free’ potential                           | clustering, sync. channel est., backhaul [44]                               |
|            | New modulation                           | intell. OFDMA                                                             | waveform design [45], out-of-band radiation [46]                           |
| Architecture | Large-scale LEO satellite constellation | ubiquitous coverage, resistance to natural disasters, lower channel loss and cost than GEO [45], [47] | integration with terrestrial networks, launching cost                       |
|            | HAP                                      | large coverage, unobstructed, flexible deployment; lower cost, easier access to infrastructure and better | channel modelling [50], deployment, path planning, operational altitude, interference, energy limit, reliability [51] |
|            | UAV                                      | channel than satellite, new use scenarios [52], [53]                      | security, real-time demand [53]                                             |
|            | AI                                       | Deep learning                                                             | computational complexity [53]                                               |
|            | AI as a service                          | low latency AI service for end-user at terminals                           | new distributed AI techniques, new APIs                                     |
|            | Block-chain                              | immutability, decentralization, transparency, security and privacy [55]     | majority vulnerability, double-spending, transaction privacy leakage, scalability, quantum computing [59] |
|            | Digital twin                             | improved quality of products, services, processes, devices, etc. in Industry 4.0 and IoT | scalability, self-management, lack of models and methodologies, security and privacy [60], [63], [62] |
|            | Edge intelligence                         | resolves MEC issue caused by service requirement diversity among a massive number of users | customized AI algorithms, resource management and task scheduling [60]        |
|            | CoCoCo convergence                       | resolves timeliness and resilience problems due to the coupling between communication, computation, and control systems [64], [65] | in-loop co-design methodologies & frameworks                                  |

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