# Role of 6G Networks: Use Cases and Research Directions

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***Abstract*—In a rapidly transforming world, data and connectivity are going to define next-generation wireless communication. Race for 5G deployment is on full swing across the globe. Smart connectivity makes people's life more enjoyable, secure. The demands of unprecedented data requirements and billions of interconnected devices open new directions in future interest groups working on beyond 5G. For sustained development in next-generation communication, researchers are working for future 6G networks. This article deals with 6G requirements, challenges, and use case deployment and future research directions.**

**Keywords: 3GPP, 5G, 6G, Artificial Intelligence, IoE, IoT.**

## I. Introduction

In every decade in this millennium, we are witnessing the change in the generation of wireless communication. Global research and partnership increased after 3GPP formation. Very recently, 3GPP Releases 15 for 5G standards [1]. Since then, rapid change in the mobile industry emerges. Currently, we do have 5G enabled devices in the market for sub 6 GHz band, however, many countries yet to auction for the spectrum of 5G. The scope of 5G includes mutually connected people and things [2]. The mobile subscription market is projected as in Fig. 1. It is projected by the Ericsson mobility report in 2019, that in 2024, one-third wireless user population in 1st world countries will be connected by 5G technology [3]. Massive amounts of data expected in the coming decades, which cannot continue to generate enormous user-centric applications. The trillion-dollar business is already in 4G and racing to move into 5G technology.

Researchers and telecommunication industries are working in Release 16, which is expected to come in later quarters of 2020 [4]. The 5G wireless communication includes enhanced mobile broadband radio (eMBB), massive internet of things, and mission-critical services that give a real-world experience. To achieve this new radio (5G-NR) technology targets, multi Gbps data rate, extreme capacity, and deep awareness for enhanced broadband mobile networks. It also requires ultra-low latency, high availability, robust security, and high reliability for mission-critical services. In addition to this 5G's ensures low cast, in-depth coverage, ultra-low energy, and deep coverage for massive internet of things. We are expecting rapid 5G deployment shortly. The key concepts in 5G involve one unified global standard, which changes the user experience in real-time high-speed connection with person and machines. The 5G predominately will be software controlled smart radio communication with increased artificial intelligence (AI) capability. The 5G services require "eMBB", massive machine type communication "mMTC", and ultra-reliable low latency communication "uRLTC". The 5G addresses the complete re-design of the core network [5].



To support the requirements of future demand and emerging use cases such as the requirement of the data-centric process which demands throughput in the order of terabits per second, mission-critical services application, i.e., advanced health care and industry 4.0 needs latency of microseconds and due to urbanization in compact cosmopolitan cities where it requires $10^7$ connections per $km^2$. Researchers are working on beyond 5G capabilities. The 6G networks can operate for an even higher range of frequency spectrum as compared to 5G, which can be utilized for the demand of the future and converge 5G technology. The band of frequencies higher than 60 GHz can operate in the visible and non-visible band of spectrum. This enormous wireless spectrum is going to be free licensing in some bands. Success seeds of 5G technology motivate researchers to look for a new evaluation of wireless communication [6].

As most of the population living in developing countries, in particular Asia and Africa, sharing 77% of the global population. Sustainable growth is significant in this developing continent. 5G deployment will gear up shortly, and massive demand will generate a data-driven market in future world countries. It is vital to address sustained growth in telecommunication demands while making mega smart cities projects which are in rendering and pipeline shortly [7]. We should consider the requirement of 5G and extended version of 5G evolution, i.e. future 6G networks to build smart infrastructure.

We anticipate that in future 6G connections will move beyond three vertices of 5G technology towards the next generation IoT (NG-IoT) concept. It will not only connect people but also helping in massive machine communication, autonomous vehicle communication, biological connectivity, trillions of wearable, and sensor devices connectivity. It is expected that 6G technology 1st standard will come out at the end of the current decade. However, research for 6G is already started since 2018 [8].

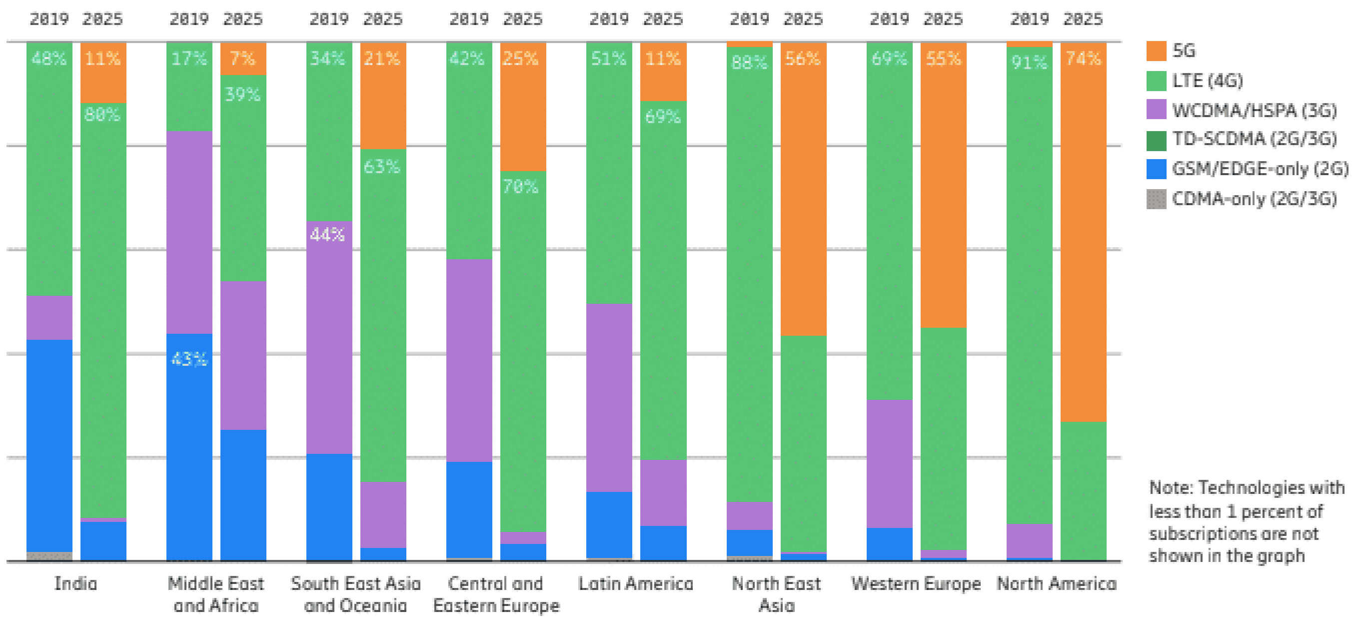


Fig. 1. Mobile subscription by region and technology (percentage)

Furthermore, we present 6G related research work in Section II. Section III deals with uses cases of 6G. Section IV presents challenges and possible solutions and Section V will conclude this work.

## II. 6G RELATED RESEARCH WORK

The International Telecommunication Union (ITU) formed the focus group network 2030 (FG NET-2030) in July 2018. This group aimed for exploring new technologies for 2030 and beyond considering the gap in 5G technologies [9]. Since then, 6G research work started in several countries. 6G services include virtually zero latency holographic communication, visible light communication, a high precision industry, ubiquitous use of artificial intelligence (AI), health care applications, and support gigantic IoT devices communication [10]. 6G technologies overcome gaps and services not supported by 5G.

In recent years, some countries planned a road map for 6G standards development and invested in a lab setup. Finland Oulu university announced its 6 Genesis Flagship program in 2018. It is a long term program with a volume of USD 290 Million to develop a 6G enabled ecosystem. The primary economy in Europe, such as the UK and Germany, also investing in quantum technology, which is also observed as a possible potential technology to integrate into 6G core architecture. The USA also started its research in the terahertz range of the 6G spectrum. China's Ministry of ICT also made an official declaration of 6G related research focused on the promotion of 6G [11].

### A. Drivers of 6G System

In the future, new demand for the internet of everything (IoE) systems, connection billion of people, and trillion of machines will strategically shift data-centric enhanced mobile broadband (eMBB) services in the extreme stretch which also require ultra-reliable low-latency communication (URLLC). We still wait for witnessing the performance of 5G technologies. Although 5G services support basic IoE and URLLC services such as industry 4.0, on-demand health care, etc. It is expected initial phase of 5G services uses a sub-6GHz spectrum for mobility. While extraordinary demand of IoE remains to continue which requires an even higher range of mmWave to visible light communication spectrum for fulfilling the demand of network capacity. The need for a self-sustaining intelligent network, which can survive with heterogeneous networks for the next decade is one of the driving forces for 6G future networks. Moreover, drivers for 6G depends upon the inheritance of 5G extension services and survivability [12].

### B. 6G vision Comparison with 5G Technologies

We summarize 6G vision requirement as compare to 5G is as in Table 1 [10], [13]–[20].

It is predicted that green 6G is considered to deploy somewhere at the start of 2030. It is expected to achieve 1000 times more capacity as compared to 5G networks. 6G offers ubiquitous connectivity by incorporating satellite and underwater communication to support global coverage [21]. In addition, three new 6G customer services described as: ultrahigh-speed-with-low-latency communications (uHSLLC),

TABLE I
6G VISION REQUIREMENT AND ITS COMPARISON TO 5G

| Constraint | 5G | 6G |
|---|---|---|
| Traffic Capacity | 10 Mb/s/m2 | $\sim$1-10 Gb/s/m3 |
| Throughput: downlink | 20 Gb/s | >1 Tb/s (1000x) |
| Throughput: uplink | 10 Gb/s | 1 Tb/s |
| Uniform user experience | 50Mb/s, 2D everywhere | 10Gb/s. 3D everywhere |
| Latency (radio interface) | 1ms | $\sim$50ns |
| Latency (end to end) | 10ms | 1ms |
| Reliability (Block error rate) | 1-10-5 | 1-10-9 |
| Energy/bit | $\sim$10mJ/b | 1pJ/b |
| Localization precision | 10 cm in 2D | 1 cm in 3D |
| Network type | mmWave | THz Wave |
| Frequency band | 3 GHz-100 GHz | mmwave, VLC, 300GHz-3 THz |
| Transmission Range | <1Km | <1Km |
| Application scenarios | Massive MIMO, Macro/pico cell | Tiny THz cells, |
| Device types | Smart Phones, Sensors, Drones, AR/VR devices, wearable devices | In addition with 5G, XR, smart implants, Brain Computer Interface (BCI) devices |
| Mobility | 200 Km/h – 500 Km/h | 500 Km/h (Bullet train) -1000 Km/h (plane) |
| Channel Codes | LDPC and Polar codes | NB-LDPC and Polar codes |
| Channel Bandwidth | 100 MHz | 500-1000 MHz |
| Jitter | $\sim 100ms$ | $1\ \mu s$ |

ubiquitous mobile ultra-broadband (uMUB), and ultrahigh data density (uHDD) [12]. For achieving the highly diversified objective in 6G, several technologies are worthwhile to be discussed extensively in the research community. Few examples are the Space-Air-Ground integrated network [22]. Visible light communication (VLC) is already proven throughput in the order of Tbps with ultra-scale massive MIMO [12]. Moreover, AI-assisted communication also drives the roadmap of 6G. It is expected that 6G future networks will offer 1000 times price reduction (Approximately 0.1 USD) wireless connection as compare to 5G conventional systems [18]. Fig. 2 demonstrate 6G flagship vision by NTT-DOCOMO [23].

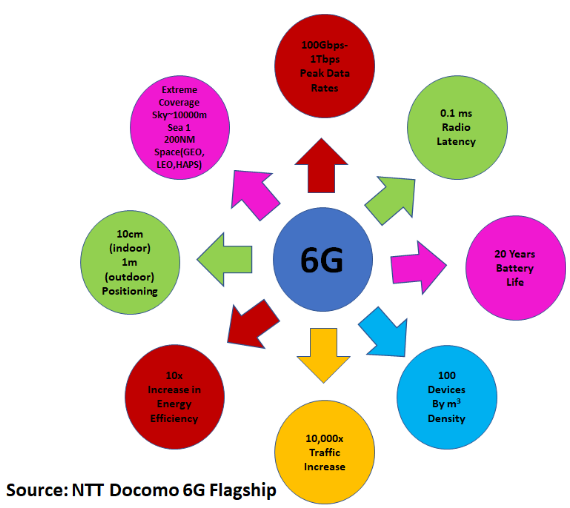


Fig. 2. 6G flagship vision by NTT docomo

## III. USE CASE OF 6G

6G wireless system extends use cases of 5G in the extreme end. It also adds on gap existed in 5G such as short-packet, limitations of delivery of highly reliable services, e.g. Augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (XR). Sustainability is also a big issue with respect to the deployment of costly RAN hardware, lack of confidence in virtual RAN (vRAN) [15]. Upcoming IoE services require the convergence of communication, control, sensing, and computational functionalities, which is not considered in 5G standards. 6G technologies integrate IoE services technologies with consideration of socio-economical and environmental aspects in a holistic fashion. Fig. 3 describes shift dimensions from 5G to 6G [23]. Use cases of 6G technologies are summarized in consequent sub-sections.

### A. High-Precision based Beyond Industry 4.0

Industry automation reduces human intervention in manufacturing and packing processes using an automatic control system. In future, it requires exact calculation with high reliability. It includes real-time massive data processing with low latency [24].

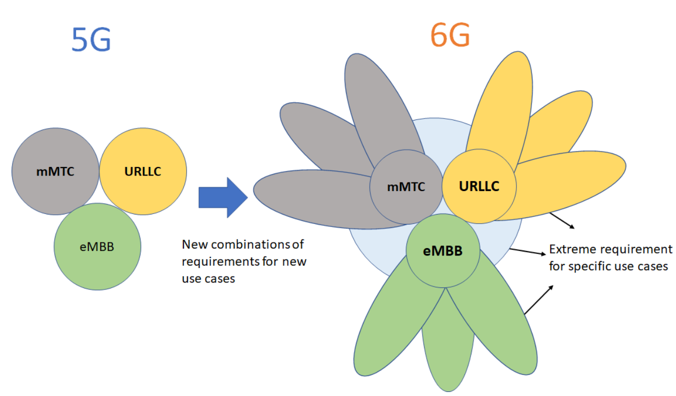


Fig. 3. Paradigm shift from 5G to 6G

### B. Holographic Telepresence

It is always present in fiction to real-time human transportation, and it requires severe communication challenges in future 6G networks. Data rate constraints for 3D holographic display with full colours, no raw compression hologram, full-duplex, and 30 fps would require 4.32 Tbps including latency in the order of sub-ms as opposite of requirement for AR/VR applications. This use case is going to be a key KPI for 6G [12].

### *C. Intelligent Health Care Services*

6G Extended URLLC and eMBB can assure health care for remote area access. It can eliminate distancing and outreach problem for future patients. Quality of services (QoS) requirements include seamless high-speed connectivity and availability of medical practitioners for continuous monitoring. With increased bandwidth and intelligent network, 6G technologies can guarantee e-health care in never before experience [7].

### *D. Unmanned Mobilty*

Recent advancement in autonomous vehicle projects on demand services in mobility. It will require connectivity in order of 1000x traffic capacity, high data rate and ultra-reliable network with market of USD 7 trillion [25]. Furthermore, air-ground-underwater communication demand heterogenous networking. Ever-increasing sensors in autonomous vehicle require few terabits data rate per driving hour [26]. Challenges in this direction requires 6G technology integration in autonomous vehicles all through hardware, software and RAN deployment. At this stage, it is impractical to comment on breakthrough advancement of 6G in unmanned mobility, however this paradigm shift of driving experience is one of the key factor on future technology networks.

### *E. Sustainable Devlopment*

IoE devices are expected to take part in 6G connectivity. It requires sustainable development of architecture to inculcate 5G and 6G services. Design of real-state and public transport should be developed with consideration of smart telecommunication support and future sustainability. Energy consumption targeted in 6G vision will be virtually battery-free devices require 1pJ/b [27]. Therefore, 6G devices development leads to highly-energy efficient wireless communication.

### *F. Decentralized Seamless Eco-friendly Monitoring*

United nations sustainable development growth focuses on green technology and environmental consideration. Since the deployment of 5G, we are witnessing a big debate in research and socio-public community for high range of GHz spectrum towards environment safety. Blockchain supports decentralized collaborative environmental sensing services, which can be integrated into 6G technology. It also encourages reliable IoT devices communication among stakeholders [28]. Environmental monitoring not only saves cost objectives but also contributes to the sustainability of the planet. Blockchain support offers shared learning implementation in data analytics and interpretation procedure for environmental safety using a decentralized approach [29].

### *G. Ubiquitous Connectivity*

The connected device is expected to grow twice in 5-6 years of time frame, as depicted in Fig. 4. By 2021 itself, 28 Billion devices, the majority are non-cellular demands ubiquitous connectivity and require networks with the very high device per Km density. It is expected by 2030, about 125 Billion devices present in worldwide. It leads to high demand for massive bandwidth and an alternate way for communication. 6G networks will be capable of handling pervasive connectivity in future needs its spectrum crosses beyond 60 GHz to visible light communication [17].

## IV. FUTURE RESEARCH OPPORTUNITIES

IoE will play important role in connection among machines, people, data mining, and things. It will be in future convergence of technology which is path-breaking in 6G integration and upcoming research agenda. IoE requires huge data storage and its analysis, which open research opportunities in cloud computing [30]. Blockchain and cloud technology will have to sort out this problem and needs further investigations. While AI has a significant presence in 5G networks, in future, it also connects to human intelligence and sensor implants in living cells. Reinforcement learning gives new heights of self-sustained intelligent 6G networks. Quantum computing helps in ultra-high-speed communication, and research is underway for quantum computing. Research direction in 6G also includes multidisciplinary domain such as biological computing, material science, environment-friendly applications. Additionally, socio-economic welfare with environmental protection will be significant challenges in future 6G research areas.

## V. CONCLUSION

Driving force for 6G research includes gap areas in 5G technology and massive demands for ubiquitous connectivity. This paper compares various available parameters for 5G standards to 6G vision in Table 1. We also discuss numerous digital cases and requirements for 6G technologies. This paper open new horizons for the future research area in 6G domain, which will be expected to available in 2030 and beyond.

## REFERENCES


[1] M. Giordani, M. Polese, A. Roy, D. Castor, and M. Zorzi, "Standalone and non-standalone beam management for 3gpp nr at mmwaves," *IEEE Communications Magazine*, vol. 57, no. 4, pp. 123–129, 2019.

[2] O. Queseth, Ö. Bulakci, P. Spapis, P. Bisson, P. Marsch, P. Arnold, P. Rost, Q. Wang, R. Blom, S. Salsano *et al.*, "5g ppp architecture working group: View on 5g architecture (version 2.0, december 2017)," 2017.

[3] T. Ericsson, "Ericsson mobility report: November 2018," 2019.

[4] K. Samdanis and T. Taleb, "The road beyond 5g: A vision and insight of the key technologies," *IEEE Network*, vol. 34, no. 2, pp. 135–141, 2020.

[5] T. Taleb, K. Samdanis, B. Mada, H. Flinck, S. Dutta, and D. Sabella, "On multi-access edge computing: A survey of the emerging 5g network edge cloud architecture and orchestration," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 3, pp. 1657–1681, 2017.

[6] E. Dahlman, S. Parkvall, J. Peisa, and H. Tullberg, "5g evolution and beyond," in *2019 IEEE 20th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*. IEEE, 2019, pp. 1–5.

[7] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6g networks: Use cases and technologies," *IEEE Communications Magazine*, vol. 58, no. 3, pp. 55–61, 2020.

[8] I. Tomkos, D. Klonidis, E. Pikasis, and S. Theodoridis, "Toward the 6g network era: Opportunities and challenges," *IT Professional*, vol. 22, no. 1, pp. 34–38, 2020.

[9] K. David and H. Berndt, "6g vision and requirements: Is there any need for beyond 5g?" *IEEE Vehicular Technology Magazine*, vol. 13, no. 3, pp. 72–80, 2018.

[10] W. Saad, M. Bennis, and M. Chen, "A vision of 6g wireless systems: Applications, trends, technologies, and open research problems," *IEEE network*, 2019.

[11] L. Zhang, Y.-C. Liang, and D. Niyato, "6g visions: Mobile ultra-broadband, super internet-of-things, and artificial intelligence," *China Communications*, vol. 16, no. 8, pp. 1–14, 2019.

[12] B. Zong, C. Fan, X. Wang, X. Duan, B. Wang, and J. Wang, "6g technologies: Key drivers, core requirements, system architectures, and enabling technologies," *IEEE Vehicular Technology Magazine*, vol. 14, no. 3, pp. 18–27, 2019.

[13] S. Zhang, J. Liu, H. Guo, M. Qi, and N. Kato, "Envisioning device-to-device communications in 6g," *IEEE Network*, vol. 34, no. 3, pp. 86–91, 2020.

[14] Q. Bi, "Ten trends in the cellular industry and an outlook on 6g," *IEEE Communications Magazine*, vol. 57, no. 12, pp. 31–36, 2019.

[15] T. Huang, W. Yang, J. Wu, J. Ma, X. Zhang, and D. Zhang, "A survey on green 6g network: Architecture and technologies," *IEEE Access*, vol. 7, pp. 175 758–175 768, 2019.

[16] H. Viswanathan and P. E. Mogensen, "Communications in the 6g era," *IEEE Access*, vol. 8, pp. 57 063–57 074, 2020.

[17] E. C. Strinati, S. Barbarossa, J. L. Gonzalez-Jimenez, D. Ktenas, N. Cassiau, L. Maret, and C. Dehos, "6g: The next frontier: From holographic messaging to artificial intelligence using subterahertz and visible light communication," *IEEE Vehicular Technology Magazine*, vol. 14, no. 3, pp. 42–50, 2019.

[18] S. Zhang, C. Xiang, and S. Xu, "6g: Connecting everything by 1000 times price reduction," *IEEE Open Journal of Vehicular Technology*, vol. 1, pp. 107–115, 2020.

[19] M. Saadi, A. Bajpai, Y. Zhao, P. Sangwongngam, and L. Wuttisittikulkij, "Design and implementation of secure and reliable communication using optical wireless communication," *Frequenz*, vol. 68, no. 11-12, pp. 501–509, 2014.

[20] A. Bajpai, G. Srirutchataboon, P. Kovintavewat, and L. Wuttisittikulkij, "A new construction method for large girth quasi-cyclic ldpc codes with optimized lower bound using chinese remainder theorem," *Wireless Personal Communications*, vol. 91, no. 1, pp. 369–381, 2016.

[21] A. Yastrebova, R. Kirichek, Y. Koucheryavy, A. Borodin, and A. Koucheryavy, "Future networks 2030: Architecture & requirements," in *2018 10th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*. IEEE, 2018, pp. 1–8.

[22] N. Zhang, S. Zhang, P. Yang, O. Alhussein, W. Zhuang, and X. S. Shen, "Software defined space-air-ground integrated vehicular networks: Challenges and solutions," *IEEE Communications Magazine*, vol. 55, no. 7, pp. 101–109, 2017.

[23] N. DOCOMO, "White paper 5g evolution and 6g," *Accessed on*, vol. 1, 2020.

[24] S. Chen, S. Sun, G. Xu, X. Su, and Y. Cai, "Beam-space multiplexing: Practice, theory, and trends-from 4g td-lte, 5g, to 6g and beyond," *arXiv preprint arXiv:2001.05021*, 2020.

[25] N. Lu, N. Cheng, N. Zhang, X. Shen, and J. W. Mark, "Connected vehicles: Solutions and challenges," *IEEE internet of things journal*, vol. 1, no. 4, pp. 289–299, 2014.

[26] J. Choi, V. Va, N. Gonzalez-Prelcic, R. Daniels, C. R. Bhat, and R. W. Heath, "Millimeter-wave vehicular communication to support massive automotive sensing," *IEEE Communications Magazine*, vol. 54, no. 12, pp. 160–167, 2016.

[27] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6g wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *arXiv preprint arXiv:1909.11315*, 2019.

[28] M. L. Memon, N. Saxena, A. Roy, and D. R. Shin, "Backscatter communications: Inception of the battery-free era—a comprehensive survey," *Electronics*, vol. 8, no. 2, p. 129, 2019.

[29] T. Hewa, G. Gür, A. Kalla, M. Ylianttila, A. Bracken, and M. Liyanage, "The role of blockchain in 6g: Challenges, opportunities and research directions," in *2020 2nd 6G Wireless Summit (6G SUMMIT)*. IEEE, 2020, pp. 1–5.

[30] B. Mao, Y. Kawamoto, and N. Kato, "Ai-based joint optimization of qos and security for 6g energy harvesting internet of things," *IEEE Internet of Things Journal*, 2020.