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Editorial

6G Wireless Communication Systems: Applications, Opportunities and Challenges

Kelvin Anoh [1], Chan Hwang See [2,*], Yousef Dama [3], Raed A. Abd-Alhameed [4] and Simeon Keates [5]

[1] School of Engineering, University of Bolton, Deane Road, Bolton, BL5 3AB, UK
[2] School of Computing, Engineering and the Built Environment, Edinburgh Napier University, 10 Colinton Road, Edinburgh, EH10 5DT, Scotland, UK
[3] Faculty of Engineering and Information Technology, An-Najah National University, Nablus 44859, Palestine
[4] School of Engineering and Informatics, University of Bradford, Bradford, BD7 1DP, UK
[5] University of Chichester, College Lane, Chichester, West Sussex, P19 6PE, UK
* Correspondence: c.see@napier.ac.uk

Abstract: As the technical specifications of the 5th Generation (5G) wireless communication standard are being wrapped up, there are growing efforts amongst researchers, industrialists, and standardisation bodies on the enabling technologies of a 6G standard or the so-called Beyond 5G (B5G) one. Although the 5G standard has presented several benefits, there are still some limitations within it. Such limitations have motivated the setting up of study groups to determine suitable technologies that should operate in the year 2030 and beyond, i.e., after 5G. Consequently, this Special Issue of *Future Internet* concerning what possibilities lie ahead for a 6G wireless network includes four high-quality research papers (three of which are review papers with over 412 referred sources and one regular research). This editorial piece summarises the major contributions of the articles and the Special Issue, outlining future directions for new research.

Keywords: future internet technologies; beyond 5G; 6G; COVID-19; pandemic resilient; 6G internet security; enabling technologies; applications; challenges; opportunities

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1. Introduction

The 5th Generation (5G) network standard is the latest wireless telecommunication network standard for data transfer from one location to another, which is presently being rolled out globally. In developed countries, non-standalone 5G network examples were deployed in a limited number of cities (e.g., London, Manchester, and Edinburgh in the UK) to learn more about their real-world performances; these were non-standalone because they used the existing 4G network infrastructure. Afterwards, the lessons operators learned from the 5G non-standalone deployments were used to revise and improve the technologies. It is these revised systems that are presently being deployed around the world. It has been said that all the technologies that could not be incorporated into the 5G standard by the end of 2020 will be considered for the Beyond 5G (B5G) network standard [1]. In the literature, the B5G network is also referred to as the 6th Generation (6G) network. This editorial piece summarises the contributions of the four papers [2–5] published in this Special Issue together with some added outputs from other related sources included for completeness.

In the previous (2G, 3G, 4G and 5G) standards, the major motivations for the enabling technologies for a future network were either the problems caused (or unsolved) by the prevailing standard at that time or the changing market requirements as supporting technologies matured, such as mobile phone capabilities. Put differently, the enabling technologies are poised towards solving the problem of speed, coverage, data rate, throughput, energy efficiency, scalability, and privacy. As we look to the future, in a 6G standard a third dimension of such motivations is to anticipate a pandemic such as COVID-19, its impacts and how the emerging technologies would be resilient to the crises it would cause. Other limitations of the 5G wireless network standard and how they could be resolved in 6G network are discussed in [3]. In [4], holographic radio technology is identified as a critical enabler of the 6G network and should adaptively confront such crises.

In addition, the future 6G standard should also forecast the likelihood of both responding to and driving changes in the culture of business modes of operations; remote working, teleworking, face-to-face working, and hybrid working and the innovative technologies that will support these. There are sustainability and security problems too, especially with the proliferation of the Internet of Things (IoT) edge devices. The Third Generation Partnership Project (3GPP) recommends using orthogonal frequency division multiplexing (OFDM) in the uplink and downlink of 5G networks, although it warns about high power consumption [6]. For IoT and other low-power edge devices, an algorithm for OFDM implementation for 6G applications is provided in [7]. On top of that, industry 4.0 and IoT are interlinked technologies that motivate new technologies and requirements for a next-generation network such as the 6G.

Looking at the previous standards, the expected timeline for the emergence and development of a new network standard has been, on average, a decade. For 6G networks, the 'real' interest in 6G started around 2018 when a) the International Telecommunications Union (ITU) created The Focus Group NET-2030 to study the potential networks for 2030 and beyond and b) The Third Generation Partnership Project (3GPP) Group introduced Release 15 (Rel-15 TR 21.915) that discussed V2X communication, unlicensed spectrum use, network slicing, etc., that were aimed at supporting the B5G network. In 2020, the International Telecommunication Union Radio (ITU-Radio) division completed and presented the IMT-2020 5-year plan for the forthcoming B5G network [3]. As the 5G network is expected to reach its limit by 2030, many experts have predicted that year would also mark the birth of the 6G network, coinciding with the conventional decade average length lifespan of the previous network standards.

Regarding the enabling technologies that will underpin 6G, existing discussions suggest the need to model internet frameworks that include, for example, holographic internet, data internet, energy internet, internet of things (IoT) and the internet of everything (IoE). Low-power wide area network technologies [8] will support B5G networks for obvious sustainability reasons. For the 6G network standard, future internet will harness the above forms of the internet more intelligently. In other words, artificial intelligence, computational intelligence, machine learning, and deep learning will support the future holographic, data, energy and things internets to play valuable roles [5]. Future smart grids will become sustainable microgrids equipped with intelligent virtual microgrids [9]. On top of radio communication in the THz frequency bands, a 6G network will operate with optical communications, including light-based IoT technologies [1]. On top of the existing network services, the enabling 6G technologies will see applications in four key areas: enhanced energy efficiency (e.g., smart energy cities), ultra-low latency (e.g., medical imaging), extremely high-reliability domains, and Green and Highly Efficient MIMO Transceiver Systems [10].

Regarding the business model, recall that previous network standards had enabled a shift in paradigm from an office-based working model to a flexible (hybrid) working model. Apart from a handful of companies (largely IT industries), the hybrid (office and non-office-based) working model was unpopular until COVID-19 in the early months of 2020. In the same way, with the instance of COVID-19 pandemic which forced conventional businesses to change from the face-to-face (or the so-called office-based) operational model to a hybrid working model, the 6G network standard is challenged even more to consider flexible working model within its enabling technologies for future businesses. The 6G network standard is also confronted with finding the enabling technologies that would be suitable, sustainable, secure, and cost-effective for hybrid working; one notable example is holographic radio communication technology.

2. Contributions

The different papers in this Special Issue have made specific contributions, which we summarise in this section. To start with, [3] concentrated on identifying the limitations of 5G and how the 6G standard could solve these problems. The authors in [3] criticised the 5G standard for more data-intensive, low-latency, and ultra-high reliability applications. It characterised the enabling technologies for a future 6G network in terms of social, economic, and technological requirements. Although not included in that discussion, a fourth requirement is cultural as several cultural barriers might hinder the acceptance of any new technology.

The authors in [4] envisage the 6G network from the practical perspectives and implementation examples of the Internet of Things. Examples of sectors discussed include healthcare sectors, smart grid, transport, and Industry 4.0. These sectors can be said to follow from the six domains of a sustainable city, which were motivated by the emergence of IoT and Industry 4.0.

As the IoT, Industry 4.0 and data intelligence through machine learning and artificial intelligent technologies have pioneered low-power smart devices, future, modern technologies, and businesses will proliferate data intelligence orchestrated by the huge amount of data created from enabling IoT, Industry 4.0, and artificial intelligence. Fuzzy logic and new biological-inspired technologies will be explored to play significant roles in meeting the requirements for 6G in the future internet. On this premise, the authors in [5] surveyed the characteristics, challenges, potential use cases, and market drivers of intelligent edge computing devices for 6G applications. The intelligent edge computing devices will form the backbone for future services and emerging wireless communication networks. They are an improvement of cloud computing technology deployed to simplify access of near-end users to the generic network.

The emergence of 5G networks has been dominated by IoT edge devices, most of which are intelligent edge devices. Besides the problem of privacy and security in the IoT edge devices, the other worry is about the sustainable future of the batteries of the billions of the IoT edge devices. In building sustainable cities and communities in the 6G era, a circular economy business model requires that these devices and their batteries should be reused, recycled, or refurbished at the end of their 10-year average life span. To minimise these concerns in the 6G era, energy-neutral IoT edge devices are discussed in [2] for position finding application as an example. In particular, the energy-neutral devices, which may be active or passive, can harvest energy from nature and use such energy sources to operate. The energy that they harvest are usually more than or equal to the energy they use to operate.

Finally, future internet technologies including the immediate forthcoming 6G network standard should explore the opportunities to cushion its emergence and the generic bias of causing pandemic or health problems, as was the case of COVID-19, to avoid slowing down the uptake (and/or destruction) of such technology infrastructure. It should consider how to sensitise the community ahead of the installation and launch of the 6G technology network, especially if it coincides with an outbreak of a new pandemic.

3. Conclusions

The 6th generation of wireless network standard or the so-called Beyond 5G network is the next and future wireless network standard that aims at solving the immediate problems of speed, data rate, throughput, ultra-low latency, and the enabling of IoT edge devices security concerns already identified in the 5G and other previous wireless generation standards. There are study groups set up by ITU and 3GPP including several research efforts from the academia to define suitable enabling technologies for 2030 and beyond. It follows that the 6G wireless network standard should be expected to be up and running just under 10 years from now. The applications of the 6G network include healthcare, smart grid, and transport. This editorial piece also identified these application niches as the subsets of the six domains of sustainable cities and communities.

Data Availability Statement: Not Applicable, this study does not report any data.

References

1. Rajatheva, N.; Atzeni, I.; Bjornson, E.; Bourdoux, A.; Buzzi, S.; Dore, J.-B.; Erkucuk, S.; Fuentes, M.; Guan, K.; Hu, Y.; et al., White paper on broadband connectivity in 6G. *arXiv* **2020**, arXiv:2004.14247.
2. Cox, B.; Buyle, C.; Delabie, D.; de Strycker, L.; van der Perre, L. Positioning Energy-Neutral Devices: Technological Status and Hybrid RF-Acoustic Experiments. *Future Internet* **2022**, *14*, 156.
3. Salameh, A.I.; El Tarhuni, M. From 5G to 6G—Challenges, Technologies, and Applications. *Future Internet* **2022**, *14*, 117.
4. Barakat, B.; Taha, A.; Samson, R.; Steponenaite, A.; Ansari, S.; Langdon, P.M.; Wassell, I.J.; Abbasi, Q.H.; Imran, M.A.; Keates, S. 6G opportunities arising from internet of things use cases: A review paper. *Future Internet* **2021**, *13*, 159.
5. Al-Ansi, A.; Al-Ansi, A.M.; Muthanna, A.; Elgendy, I.A.; Koucheryavy, A. Survey on intelligence edge computing in 6G: Characteristics, challenges, potential use cases, and market drivers. *Future Internet* **2021**, *13*, 118.
6. Sultan, A. 5G System Overview. In *The 5g Standard*; 3GPP: Geneva, Switzerland, 2022.
7. Anoh, K.; Tanriover, C.; Ribeiro, M.V.; Adebisi, B.; See, C.H. On the Fast DHT Precoding of OFDM Signals over Frequency-Selective Fading Channels for Wireless Applications. *Electronics* **2022**, *11*, 3099.
8. Ikpehai, A.; Adebisi, B.; Rabie, K.M.; Anoh, K.; Ande, R.E.; Hammoudeh, M.; Gacanin, H.; Mbanaso, U.M. Low-power wide area network technologies for Internet-of-Things: A comparative review *IEEE Internet Things J.* **2018**, *6*, 2225–2240.
9. Anoh, K.; Maharjan, S.; Ikpehai, A.; Zhang, Y.; Adebisi, B. Energy peer-to-peer trading in virtual microgrids in smart grids: A game-theoretic approach *IEEE Trans. Smart Grid* **2019**, *11*, 1264–1275.
10. Al-Yasir, Y.I.A.; Abdulkhaleq, A.M.; Parchin, N.O.; Elfergani, I.T.; Rodriguez, J.; Noras, J.M.; Abd-Alhameed, R.A.; Rayit, A.; Qahwaji, R. Green and Highly Efficient MIMO Transceiver System for 5G Heterogenous Networks. *IEEE Trans. Green Commun. Netw.* **2022**, *6*, 500–511.