A Review of the Development of 6th Generation Network Security Adapting Artificial Intelligence and Distributed Ledger Technology

Innovatus: A Journal on Computing Technology Innovations, In Press.

Angel Nica Elegado
2165184@slu.edu.ph
School of Advanced Studies, Saint Louis University, Baguio City, Philippines

ISSN (Print:) 2651-6993
Pre-print DOI No. In Press.

FOR PUBLISHERS ONLY:
Manuscript received: October 15, 2022; revised: November 18, 2022; accepted: December 2, 2022

ABSTRACT

This paper reviews the network security in 6G applied in various emerging technologies. The content of the paper discusses the 6G, which is expected to be merged with multiple sorts of slicing enabled by new technologies and paradigms to make the system more intelligent and safeguard the network infrastructure. This literature review was performed through a systematic review using a meta-analysis review to draw a conclusion. This paper identifies the issues and challenges of the 6G network and discusses the current research areas in network security, such as AI and DLT, which were found as solutions which can be employed for security at many cybersecurity protection and defense stages. The value of these technologies is based on the benefits of autonomy, increased accuracy, and predictive capabilities for security analytics. Additionally, this study compares which approach is the most viable solution to address network security issues. The researcher wants to investigate further 6G cloud computing for future work, addressed by centralized data centers accessed via the leading network.

KEYWORDS 6g Communications, Network Security, Artificial Intelligence, Distributed Ledger Technology

1 INTRODUCTION

We have come across several emerging technologies that have shifted the course and trends of societies; specifically, in the 1980s, the first-generation cellular networks (1G) were introduced [1], and the advancement of wireless communication technologies began. From 1G to 5G, researchers and engineers in mobile networks and communication have been dedicated to enhancing the quality of the user experience [2]. Mobile networks of the 5G are progressively being deployed worldwide, accelerating the growth of the communication sector and associated industries. According to Navarro et al., 5G technology features a high data rate, reduced latency, less energy consumption, cheaper cost, higher system capacity, and large-scale equipment connection compared to its predecessors [4]. Porambage et al. added that the cloudification of networks with microservice-based architecture [1] is the most notable aspect of 5G. Aside from delivering a revolution, 5G also makes many parts of social and economic life increasingly intelligent [5], such as optimizing service delivery, improving decision-making, and enhancing end-user experience. However, as people rely more on 5G, security concerns are becoming more prevalent. For example, increasing reliance on power and energy infrastructure will impact society's operation. Although the 5G wireless networks are yet to be thoroughly investigated, the visionaries of the 6th generation (6G) echo systems have already come into the discussion lately.

In recent years, the rapidly evolving AI technology and fast-expanding network traffic have required a new, faster, more reliable, and flexible network structure [8]. As part of the fast-paced development of 6G, network security increasingly evolves with the development of IT technology, and the exponential rise of extensive data makes data leakage more likely for various reasons [9]. As a result, 6G is predicted to raise the threshold established by 5G communications by providing improved network security, data availability, data throughput, and seamless pervasive connectivity [10]. Helin Yang and his team anticipated that 6G would accommodate prior unimagined Internet of Everything scenarios with a wide range of complex requirements [3]. However, issues and challenges with network security in the 6G era persist, including channel modelling in complicated situations, radio system limitations, and decreased energy consumption [4].

As 6G networks become more varied and dynamic, achieving effective resource utilization, a consistent user experience, and orchestration become more challenging. Providing network security, data privacy enforcement, and achieving a cost-effective strategy for rapid network implementation and extension focusing on remote and stand-alone places are also challenging, as stated by Alsharif et al. [10]. Additionally, Fitzek and Peeling stated that significant technology to achieve the 6G standards still needs to be improved [11]; even if 6G claims to deliver on many promises, it hinders by the lack of accurate technologies that might significantly progress 6G technology, and the requirements grow dramatically. Many researchers concluded that 6G has no underpinning technology, which is challenging to come up with 6G mobile communication at this time [15], and network security must be enhanced to avoid such issues. On the other hand, Zhang et al. expected network security in 6G to enable a broad spectrum of AI services from network devices to terminal devices, transforming connected things into connected intelligence [12, 13].

Recently, Artificial Intelligence (AI) and Distributed Ledger Technology (DLT) techniques have demonstrated their effectiveness in various fields, including education, smart

Innovatus: A Journal on Computing Technology Innovations

healthcare, and network security. By definition, AI refers to systems that help in decision-making by analyzing their environment and acting independently to achieve specific goals. Because AI encompasses different methodologies and situations, greater accuracy is essential to have meaningful and productive discussions about it [55]. DLT is a decentralized database administered by various contributors across different nodes [56]. DLT may generate cooperative trust across different network entities because of its decentralization, transparency, anonymity, immutability, traceability, and robustness. DLT has a distributed database, consensus protocols, smart contracts, and underlying cryptographic methods that satisfy the 6G requirements for safe and private data transmission, rigorous access control, traceability, and identity verification [57]. Additionally, DLT's establishment of an open market and commercial model for 6G is made possible by DLT. The inherent characteristics of DLT enable diverse network operators, third-party suppliers, and resource providers to participate in developing complex 6G ecosystems in a reliable but auditable way. As a result, 6G is expected to be merged with various sorts of slicing enabled by new technologies and paradigms [7, 12] to make the system more intelligent and flexible and safeguard the network infrastructure [2].

The importance of AI in the envisioned 6G network is immense since the 6G is intimately associated with intelligent network orchestration and management. Since AI and DLT approaches have strong analysis and intelligent recognition capabilities [50], they can perform performance optimization and advanced learning. However, in the study of Lu and Zheng [14], in many circumstances, 6G networks will have ultra-high throughput and ultra-wide bandwidth, posing a significant problem in applying AI and DLT in 6G. Also, Helin Yang et al. [12] also stated that 6G's development would be multi-layered, dynamic, and heterogeneous, which needs to support seamless connectivity. Therefore, they suggested that a literature review considering the advancements and unanticipated issues could be useful. Specifically, Sun et al. [7] and Zhang et al. [51] stated that more fundamental works and efforts to design more robust models, safer data storage, and efficient encryption schemes should be made and done to accelerate the development of 6G. Therefore, to further analyze the network security in 6G, this study aims to identify a systematic literature review on 6G's network security using various emerging technologies and identify issues and challenges along with the proposed solutions. This paper sought to answer the following research questions:

1. What are the issues and challenges that have been identified in the 6g network?
2. What are the recent technologies that address the issues and challenges in 6g network security?
3. In the recent solution presented, which technology is the most feasible solution towards AI-enabled security in 6g networks?

2 METHODOLOGY

In this section, the methodology and procedures were discussed to achieve the research goals.

2.1 General Literature Search and Selection

A systematic literature review was performed through a meta-analysis to answer the identified research questions. In a meta-analysis, results from many research on the same topic are combined and subjected to standardized statistics analysis, patterns are found, and conclusions are formed. Meta-analysis is also related to the logical method to research.

Furthermore, research articles have been searched comprehensively in various online databases such as Google Scholar, ResearchGate, IEEE Xplore, and other repositories such as arXiv and MDPI. These databases have been utilized to discover and access journal articles, conference proceedings, surveys, and other related materials. Here are the steps used in conducting a research review:

2.1.1 Search keywords: The keywords used to search for literature was "6g security," "AI in 6g," and "technology applied in 6g," so the research publications that generally mention these keywords would appear in the search results. These keywords must also include in the article keyword sections to ensure that the topic is connected and related.

2.1.2 Criteria: To compile the articles, a paper was filtered based on the three criteria:

a. The content of the paper has a piece of evidence or supported studies to prove the claims.
b. The abstract, methodology and discussion of the paper are clearly relevant.
c. All gathered articles were published less than five years ago.

2.1.3 Identifying the Challenges in Applying AI for Securing 6g Network

In organizing the data, there are patterns in identifying the issues and challenges based on the data's conciseness and reliability. Having similarities in the identified problems, the researcher grouped them into one category. Additionally, research articles without related evidence or supporting documents to prove the claims are excluded from the review. All of the data are listed in a table and summarized afterward.

2.1.4 Determining Recent Technologies for Addressing the Problem of Securing 6G Network

After identifying the various issues and challenges, the researcher can further determine several solutions. With this, data was collected by searching additional sources to identify and investigate possible solutions. Articles gathered were filtered according to the structure and validity of the solution presented, and those articles were published in the last five years. As a result, the researcher put a table presenting the technologies together with their features and advantages.

2.1.5 Discovering the Best Solutions for Securing 6G Network

In this part, all peer-reviewed articles were filtered to distinguish the best solution for network security. Using a comparison, all solutions will be evaluated according to:

a. Published articles from 2016 to the present,
b. Articles presented the advantages of such technologies.

As a result, a table will be presented containing the identified solution.

3 RESULTS AND DISCUSSIONS

3.1 Literature Search

Figure 1 presents the initial process of browsing articles from different research databases using different keywords. The filtration of paper is from 2017 to 2021. The results are a mix of articles, journals, magazines, surveys, and other patent papers. There are a lot of relevant articles, journals, surveys, and useful articles obtained from academic sources as potential references. However, some paper was excluded from the selection and filtration procedure due to their poor quality and poor content. As a result, thirty-five articles were collected and included for the identification of issues and challenges and determining the recent solution in 6g. Table 1 shows the final tally of the selected articles.

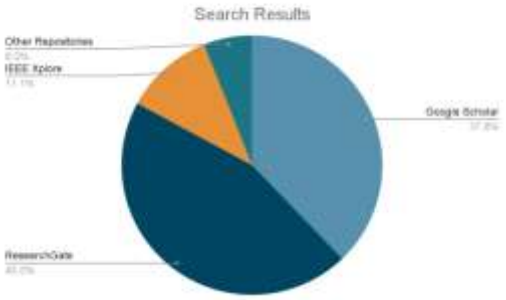

Figure 1: Search Results from the Research Databases

Table 1. The final tally of selected articles

Source	Articles
ResearchGate	[1][10][26][27][29][30][31][32][34][35][44][53][54]
Google Scholar	[20][23][25][28][33][36][37][38][46][52]
IEEE Xplore	[19][21][22][24][32][43]
Other Repositories	[14][15][16][40][41][49]

3.2 Identified Issues and Challenges in 6G

Table 2: Identified Issues and Challenges in 6G

Issues & Challenges	Description	Ref.
Higher energy consumption	The quantity of energy required to operate a piece of electrical equipment. This is in contrast to the level of performance, which is measured by the output of power.	[14][19][20]
Connection flexibility	Connection flexibility in networks refers to the capacity to adjust network resources, such as flows or topology, to changes in design requirements. The connection flexibility serves as the foundation for creating private data networks and connects businesses to the internet.	[21][24]
Spectrum Allocation and usage rule	Spectrum allocation is the process of controlling the usage of the electromagnetic spectrum and distributing it among numerous and sometimes conflicting groups and interests.	[25][32]
Molecular communication	The presence or absence of a specific type of molecule is used to encode messages in molecular communications systems digitally. The molecules are transferred into communication mediums like air and water for transmission.	[15][22][31]

3.2.1 Higher energy efficiency

Large mobile communication networks have become a source of energy consumption across the world. 6G networks will have ultra-high throughput, ultra-wide bandwidth, and ultra-large-scale ubiquitous wireless nodes in the future, posing a significant energy consumption concern [14]. Throughput can be considerably enhanced by increasing spectrum efficiency and spectrum bandwidth, but energy efficiency issues will become more important, requiring a reduction in energy consumption per bit. The general understanding of network sensors will result in energy consumption in two ways: first, a significant number of sensors will result in high overall energy consumption; second, how to provide energy for universal deployment conveniently and effectively will be a challenge. Furthermore, 6G networks will encounter power consumption issues in the future due to massive amounts of data processing power consumption and ultra-large-scale antenna processing power consumption in the intelligent connectivity scenario. Green energy-saving communication is especially critical in light of the forthcoming 6G network's massive energy consumption demand [19, 20].

3.2.2 Connection flexibility

With the development of science and technology, communication nodes, particularly those related to the Internet of Things, will be spread out across a larger area. In order to accomplish the network's connection and interaction demands anytime and anywhere, a ubiquitous Internet of Things (IoT), a universal identification system, and universal networks will be required in the future [24]. Future communication allows everyone to engage with any relevant object for valuable information at any time and from any place [21].

3.2.3 Spectrum allocation and usage rule

The development of 6G will encounter technological challenges and a slew of non-technical issues, including industrial complications, spectrum allocation, usage restrictions, and policies and regulations [25]. With such issues, 6G will penetrate all sectors of societal production and existence and be more tightly interwoven with other industries. As a result, mobile communication will no longer be limited to its industry but will need to collaborate with other companies and fields. However, some traditional businesses' fundamental behavior or benefits will create industry barriers to 6G's entry, either directly or indirectly [32]. Using the 6G terahertz band, for example, will require coordinated allocation from many governments and areas around the world. A consistent frequency range should be assigned as much as possible. Coordination with users in other sections of the spectrum, such as weather radar [25], must also be considered.

3.2.4 Molecular communication

Security and privacy issues relating to communication, authentication, and encryption processes have already been discovered. However, Farsad et al. [22] claimed that an adversary may disrupt this form of communication channel and that just a few research have ever evaluated the safety of molecular communication lines [15, 31]. Malicious behaviors and communication mechanisms are among the security and privacy concerns raised by VLC (visible light communication). Wang and his team also stated that an attacker must be in the line of sight of the victim in order to begin an attack on an ongoing VLC operation. This would obviously make it easier for attackers to be identified [15].

3.2.5 Interoperability of protocols

Both non-terrestrial and terrestrial communication networks will be included in the 6G network. TCP/IP protocols are utilized in terrestrial communication networks but are incompatible with non-terrestrial communication networks, such as satellite communication [16]. Because of the long transmission latency, ultra-wide bandwidth, and greater bit error rate, TCP/IP protocols have poorer efficiency. As a result, TCP/IP protocol changes are required to handle both non-terrestrial and terrestrial communication networks efficiently. Furthermore, both types of communication networks use different protocols. In that situation, protocol interoperability will be a concern [35].

3.3 Recent Solution for the Identified Problems of 6G Network Security

There are many recent popular areas for network security that can address the issue of 6G when applied to different technologies. As a result, these technologies are the most commonly used in 6G due to their effectiveness in various fields, and it is expected to be merged with various sorts of slicing enabled by new technologies and paradigms. Therefore, Table 3 presents the two emerging technologies that provide better network security and provide efficiency in terms of handling parameters.

3.3.1 Distributed and Scalable AI/ML

6G envisions autonomous networks that perform Self-X (self-configuration, self-monitoring, self-healing, and self-optimization) with minimal human involvement [44]. Ongoing specification efforts to integrate AI/ML as an integral component in future networks, such as AI/ML techniques with pervasive automation of network management operations, including security, are critical. Since AI/ML will be widely used in a distributed and large-scale system for a variety of applications, including network management, distributed AI/ML approaches are expected to enforce quick control and analytics on the massive amounts of data generated in 6G networks [1].

Additionally, AI functions will be spatially pushed closer to the source of interest data for ultra-low latency, while ML functions will be distributed over the network to achieve performance advantages owing to optimized models and ensemble decision-making in 6G. Overcoming the practical limits of some network parts, such as computing inadequacies and sporadic connection, on the other hand, is still a work in progress [38]. In 6G, distributed AI/ML may be employed for security at many stages of cybersecurity protection and defense. The value of AI/ML-driven cybersecurity is based on the benefits of autonomy, increased accuracy, and predictive capabilities for security analytics.

3.3.1.1 Features AI/ML in 6G Network Security

a. Distributed Intelligence – One feature of AI is distributed intelligence. With AI, moving target defense strategies are a proactive solution that adds dynamicity to the network and makes AI-enabled attackers' learning process more difficult [1].
b. Trusted computing enablers - The increasing reliance on AI/ML in future networks poses the basic question of whether ML components are trustworthy. When essential network services, such as security, are managed by AI, this becomes much more of a problem. Trusted computing enablers, formal verification approaches, and integrity checks are useful tools for this.
c. Network visibility - Visibility is essential for controllability and accountability. More than black-box operation, security specialists and monitoring demand transparent and coherent insight into AI-based schemes. One research challenge is how to keep track of security-related AI events in real time.

3.3.2 Distributed Ledger Technology (DLT)

Blockchain has recently gotten a lot of attention as a distributed ledger technology (DLT) in the telecommunications business. Disintermediation, immutability, non-repudiation, evidence of provenance, integrity, and pseudonymity are all advantages of DLTs that are particularly significant for enabling different services on 6G networks with trust and security [40]. DLT and other data analytic technologies can be used to create new attack vectors [41]. Since data is the enabler of AI algorithms, it is critical to assure its integrity and provenance from reliable sources [43]. By enabling confidence in AI-driven systems in a multi-tenant/multi-domain environment, DLT offers the ability to guarantee the integrity of AI data via immutable records and distributed trust amongst multiple stakeholders.

Furthermore, most present 5G service models will need to be greatly modified in order to support the role of DLT/blockchain in meeting 6G objectives. For example, safe VNF administration, secure slice brokering, automated Security SLA management, scalable IoT PKI management, and secure roaming and offloading handling can all benefit from DLT [40]. Blockchain is also a promising choice for preserving privacy in content-centric 6G networks. The usage of a shared communication channel in blockchain may allow network participants to be identified by pseudo names rather than their real names or location information.

3.3.2.1 Features of DLT in 6G Network Security

a. Secured model and data resilience - During the learning and inference phases, models should be secure and resilient (e.g., against poisoning attacks). Blockchain [42] might be a solution for a distributed, transparent, and secure data exchange system.
b. Enhanced Privacy - Different machine learning approaches such as neural networks, deep learning, and supervised learning may be used to safeguard data, images, location, and communication privacy (e.g., Android, intelligent vehicles, IoT).

3.4 Comparison of Recent Solution

This section discussed how AI and DLT addressed the issues using different components or proposed solutions which helps in implementing better network security.

Table 3: Comparison of Recent Solutions

Issues & Challenges	AI	DLT
High energy consumption	Energy-efficient wireless communication [10]	Energy harvesting techniques [54] and 6G-driven multimedia data structure [53]
Connection flexibility	Big communications [10]	Big communications [10]
Spectrum allocation and usage rule	Beamforming [46] and Spectrum sharing [48][53]	THz band [52] and Spectrum sharing [48][53]
Molecular communication	Terahertz frequencies [15,46]	Terahertz frequencies [15,46]
Interoperability of protocols	TCP spoofing [49]	x

3.4.1 Higher energy efficiency

6G will almost probably surpass 5G in energy efficiency, and additional energy-saving methods will be implemented [10]. The machine learning algorithms may learn about the wireless environment and choose the best configuration to get the desired results [47]. As stated by Alsharif, 6G will necessitate a comprehensive wireless communication approach that is both energy-efficient and cost-effective that will execute battery-free communications whenever and wherever feasible, with a communication efficiency of 1 pico-joule per bit [10]. Apart from directing beam communication using MIMO antenna arrays, 6G communication provides the advantages of high-power THz-waves, allowing devices to deliver power beams in a specific direction. Moreover, in DLT, by using a 6G-driven multimedia data structure technique, simultaneously enhances QoS and energy consumption in 6G-based smart automation systems [53][54]. Also, energy harvesting approaches for utilizing renewable energy resources would be extremely beneficial in the development of green 6G-IoT systems.

3.4.2 Connection flexibility

6G design envisions linked intelligence and employs artificial intelligence at many levels of the network structure [8]. The multi-connectivity of a device in a mesh network allows numerous base stations to analyze a device's activity using AI classification algorithms and jointly decide the authenticity using weighted average approaches as in. [1].

Both AI and DLT use Big Communication (BigCom) [19] in 6G. Since BigCom provides extensive coverage of urban and remote areas by maintaining resource balance, BigCom allows subscribers to communicate with one another with a high data rate speed. Due to the unconventional technologies adopted by 6G communication systems, it will include operational and environmental aspects and the services of the networks [10].

3.4.3 Spectrum allocation and usage rule

According to Routray & Mohanty, the multiple-input and multiple-output (MIMO) allow excellent approaches to enhance spectral efficiency in 6G by using beamforming which is improved by advanced signal processing and prominent modulation constellations [46]. In DLT, Zhao et al. stated that the THz band would be utilized in the context of 6G-based to improve spectral efficiency and transmission rates, particularly in ultra-dense heterogeneous networks with millions of users [52].

Another approach is the spectrum sharing applied in AI and DLT. Spectrum sharing can help 6G applications to meet high data rate needs since the data rate is directly related to available bandwidth [48][53].

3.4.4 Molecular communication

Intelligent radio is supported by both molecular communication and THz technology. Molecular communication technology is linked to authentication, encryption, and communication security and privacy concerns with THz technology [15]. Other components used are distributed artificial intelligence and intelligent radio intersect with blockchain technology and quantum communication [46].

3.4.5 Interoperability of protocols

Non-terrestrial systems include a terrestrial terminal, an aerial/space station that functions similarly to a terrestrial base station, a service link connecting the terrestrial terminal and the aerial/space station, and (a gateway that connects the non-terrestrial access network to the terrestrial access network. TCP spoofing is employed for Fast TCP full-buffer capacity. TCP multiplexing increases performance by dividing TCP sessions into numerous data flows [49]. The blockchain and distributed ledger technologies are generally safe as the last applications of the 6G network, although they may still be the target of malicious action [15].

4 CONCLUSION

Most network security faces different challenges where they have difficulty integrating various technologies to address the issues. This paper reviews issues and challenges in 6G network security when applied in AI and DLT. Specifically, this paper identifies the five issues in implementing recent technologies such as higher energy efficiency, connection flexibility, tactile challenges, spectrum allocation and usage rule, molecular communication, and interoperability of protocols.

Moreover, there have been many solutions to address the issues mentioned above. Recently, emerging technologies such as AI/ML and Distributed Ledger Technology seem to be the most viable solution for addressing network issues in 6G. AI/ML will be spatially pushed closer to the source of interest data for ultra-low latency, while ML functions will be distributed over the network to achieve performance advantages owing to optimized models and ensemble decision-making in 6G. Overcoming the practical limits of some network parts is still a work in progress. On the other hand, immutability, non-repudiation, evidence of provenance, integrity, and pseudonymity are advantages of DLTs that are particularly significant for enabling different services on 6G networks with trust and security.

Given the problems and solutions, a comparison of technologies was also identified to prove which technology is most suitable for 6G network security. Results show that AI/ML algorithms can be leveraged to learn the wireless environment and derive the appropriate configuration from achieving common objectives, while the DLT still has issues in solving some other areas, and advanced research is needed.

5 FUTURE DIRECTION OF THE STUDY

Since AI is the leading technology in the 6G network, further research would still be beneficial to improve and upgrade the technology. 6G network should also consider the 6G cloud computing addressed by centralized data centers accessed via the leading network. Massive numbers of storage and processing devices near the network's edge, some of which are owned and installed by end-users, but the majority by service providers. This means that cloud services are pushed out from the network's core to the network's edge, resulting in lower latency. Therefore, issues and challenges in cloud computing must be addressed, and more research to avoid these problems in the future.

REFERENCES

[1] Porambage Pawani & Gür Gürkan, Moya Osorio, Diana Pamela & Liyanage Madhusanka, Gurtov Andrei & Ylianttila Mika. 2021. The Roadmap to 6G Security and Privacy. IEEE Open Journal of the Communications Society. DOI: https://doi.org/10.1109/OJCOMS.2021.3078081

[2] Huangqing Chen, Ke Tu, Jian Li, Tang Shuang, Tingquan Li & Zemin Qing. 2020. 6G Wireless Communications: Security Technologies and Research Challenges, 592-595. DOI: https://doi.org/10.1109/ICUEMS50872.2020.00130

[3] Ma Jinsong & Mahammad Yamin. 2020. 5G Network and Security, 249-254. DOI: https://doi.org/10.23919/INDIACom49435.2020.9083731.

[4] Jorge Navarro-Ortiz, Sandra Sendra, Pablo Ameigeiras & Juan Lopez-Soler. 2018. Integration of LoRaWAN and 4G/5G for the Industrial Internet of Things. IEEE Communications Magazine, 56, 60-67. DOI: https://doi.org/10.1109/MCOM.2018.1700625.

[5] Haibo Yi. 2021. Improving security of 5G networks with multiplicative masking method for LDPC codes. Computers & Electrical Engineering, 95, 107384. DOI: https://doi.org/10.1016/j.compeleceng.2021.107384.

[6] Huazi Zhang, et al. 2018. Parity-Check Polar Coding for 5G and Beyond. IEEE International Conference on Communications, Kansas City, USA. ICC.

[7] Sun Yuanyuan, Liu Jiajia, Wang Jiadai, Cao Yurui & Kato Nei. 2020. When Machine Learning Meets Privacy in 6G: A Survey.

[8] Khaled Letaief, Wei Chen, Yuanming Shi, Jun Zhang & Ying A. Zhang. 2019. The roadmap to 6G: AI-empowered wireless networks.
[9] Qingmin Yuan & Xin Tan. 2021. Research on Application of Artificial Intelligence in Network Security Defense. Journal of Physics: Conference Series 2033, 012149
[10] Mohammed Alsharif, Anabi Hilary, Mahmoud Albreem, Shehzad Chaudhry, M. Sultan Zia & Sunghwan Kim. 2020. Sixth Generation (6G) Wireless Networks: Vision, Research Activities, Challenges and Potential Solutions.
[11] Frank Fitzek & Patrick Seeling. 2020. Why we should not talk about 6g. arXiv preprint arXiv: 2003.02079
[12] Helin Yang, et al. 2019. Artificial Intelligence-Enabled Intelligent 6G Networks.
[13] Tara Salman, Deval Bh, Aiman Erbad, Raj Jain & Mohammed Samaka. 2019. Machine Learning for Anomaly Detection and Categorization in Multi-cloud Environments. In 2017 IEEE 4th International Conference on Cyber Security and Cloud Computing.
[14] Yang Lu & Xianrong Zheng. 2020. 6G: A survey on technologies, scenarios, challenges, and the related issues. In Journal of Industrial Information Integration 19. Elsevier Inc.
[15] inghao Wang, Tianqing Zhu, Tao Zhang, Jun Zhang, Shui Yu & Wanlei Zhou. 2020. Security and privacy in 6G networks: New areas and new challenges. In Digital Communications and Networks 6, 281-291. Elsevier Inc.
[16] Sabunima Nayak & Ripon Patgiri. 2020. 6G Communication: Envisioning the Key Issues and Challenges. arXiv preprint. arXiv:2020.04024
[17] Faiza Nawaz, Jawwad Ibrahim, Maida Junaid, Sabila Kousar & Tamseela Parveen. 2020. A Review of Vision and Challenges of 6G Technology. International Journal of Advanced Computer Science and Applications,11(2)
[18] Haitham Mahmoud, Amira Amer & Tawfik Ismail. 2021. 6G: A comprehensive survey on technologies, applications, challenges, and research problems. DOI: https://doi.org/10.1002/ett.4233
[19] Mostafa Chowdhury, Md. Shahjalal, Moh Khalid Hasan & Yeong Min Jang. 2019. The role of optical wireless communication technologies in 5G/6G and IoT solutions: prospects, directions, and challenges. Appl. Sci. 9(20)
[20] Zhengquan Zhang, et al., 2019. 6G wireless networks: vision, requirements, architecture, and key technologies. IEEE Vehicular Technology Magazine, 14(3), 28-41
[21] Zhang Shangwei, Jiajia Liu, Hongzhi Guo, Mingpin Qi & Nei Kato. 2020. Envisioning device-to-device communications in 6G. DOI: https://doi.org/10.1109/MNET.001.1900652
[22] Nariman Farsad, H. Birkan Yilmaz, Andrew Eckford, Chan-Byoung Chae & Weisi Guo. 2016. A comprehensive survey of recent advancements in molecular communication. In IEEE Communication Survey Tutorials, 18 (3) 1887–1919. DOI: https://doi.org/ 10.1109/COMST.2016.2527741
[23] Shuping Dang, Osama Amin, Basem Shihada & Mohamed-Slim Alouini. 2020. What should 6G be? DOI: https://doi.org/ 10.36227/techrxiv.10247726.v2
[24] Guan Gui, Miao Liu, Fengxiao Tang, Nei Kato & Fumiyuki Adachi. 2020. 6G: opening new horizons for integration of comfort, security and intelligence. IEEE Wireless Communication
[25] Yang Ping, Yue Xiao & Shaoqian Li. 2019. 6G Wireless Communications: Vision and Potential Techniques. IEEE Network, 33(4),70-75. DOI:https://doi.org/10.1109/MNET.2019.1800418
[26] Huang Chongwen, et al., 2019. Holographic MIMO surfaces for 6G wireless networks: opportunities, challenges, and trends. arXiv preprint arXiv:1911.12296.
[27] Nei Kato, Bomin Mao, Fengxiao Tang, Yuichi Kawamoto & Jiajia Liu. 2020. Ten challenges in advancing machine learning technologies toward 6G. In IEEE Wireless Communication, 1-8. DOI:https://doi.org/10.1109/MWC.001.1900476
[28] Marcos Katz, Pekka Pirinen & Harri Posti. 2019. Towards 6G: getting ready for the next decade. In 2019 16th International Symposium on Wireless Communication Systems (ISWCS), IEEE, 2019, pp. 714–718
[29] Longfie Yan, Chong Han, Jinhong Yuan. 2020. Hybrid precoding for 6G terahertz communications: performance evaluation and open problems. In 2nd 6G Wireless Summit (6G SUMMIT)
[30] Yifei Yuan, Yajun Zhao, Zong Baiqing & Sergio Parolari. 2020. Potential key technologies for 6G mobile communications. Sci. China Inf. Sci. 63,1-19
[31] Walid Saad, Mehdi Bennis & Mingzhe Chen. 2019. A vision of 6G wireless systems: applications, trends, technologies, and open research problems.
[32] David Szabo, Andras Gulyas, Frank Fitzek & Daniel Lucani, 2015. Towards the tactile internet: decreasing communication latency with network coding and software defined networking. In Proceedings of European Wireless 2015; 21th European Wireless Conference, VDE, 2015, pp. 1–6.
[33] Tao Hong, Cong Liu & Michel Kadoch. 2019. Machine learning based antenna design for physical layer security in ambient backscatter communications, Wireless Commun. Mobile Computer.
[34] Junaid Nawaz, Shree Sharma, Shurjeel Wyne, M.N. Patwary & Md Asaduzzaman. 2019. Quantum machine learning for 6g communication networks: state-of-the-art and vision for the future.
[35] Shanzi Chen, Ying-Change Liang, Shaohui Sun & Mugen Peng. 2020. Vision, requirements, and technology trend of 6g: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed.
[36] Meryem Simsek, Adnan Aijaz, Mischa Dohler, Joachim Sachs & Gerhard Fettweis. 2016. 5G-enabled tactile internet. In IEEE Journal on Selected Areas in Communications, 34(3), 460–473
[37] Kwang Soon Kim, et al. 2018. Ultrareliable and low-latency communication techniques for tactile internet services. Proceedings of the IEEE, 107(2), 376-393
[38] George Plastiras, Maria Terzi, Christos Kyrkou & Theocharis Theocharidcs. 2018. Edge intelligence: Challenges and opportunities of near-sensor machine learning applications. In 2018 IEEE 29th International Conference on Application-specific Systems, Architectures and Processors.
[39] ENISA. 2020. Artificial intelligence cybersecurity challenges. ENISA, Tech.Rep.
[40] Tharaka Hewa, Gurkan G¨ur, Anshuman Kalla, Mika Ylianttila, An Bracken & Madhusanka Liyanage. 2020. The role of blockchain in 6G: Challenges, opportunities and research directions. In 2020 2nd 6G Wireless Summit. IEEE, 2020
[41] Nayak & Patgiri. 2020. 6G Communication Technology: A Vision on intelligent Healthcare. arXiv e-prints, p. arXiv:2005.07532.
[42] Weiwei Li, Zhou Su, Ruidong Li, K. Zhang & Yuntao Wang. 2020. Blockchain-based datasecurity for artificial intelligence applications in 6G networks. IEEE Network, 34(6), 31–37
[43] Hyesung Kim, Jihong Park, Mehdi Bennis & Seong-Lyun Kim. 2018. On-device federated learning via blockchain and its latency analysis. arXiv preprintarXiv:1808.03949, 2018.
[44] Shunliang Zhang & Dali Zhu. 2020. Towards artificial intelligence-enabled 6G: State of the art, challenges, and opportunities. Computer Networks, 183, p. 107556.
[45] Tharaka Hewa, Gurkan G¨ur, Anshuman Kalla, Mika Ylianttila, An Bracken & Madhusanka Liyanage. (2020). The Role of Blockchain in 6G: Challenges, Opportunities and Research Directions. In 2020 2nd 6G Wireless Summit. doi:10.1109/6gsummit49458.2020.90
[46] Sudhir Routray & Sasmita Mohanty. 2020. Why Do We Need 6G? Main Motivation and Driving Forces of Sixth Generation Mobile Communication Networks. In Revista de Sistemas de Informação da FSMA.
[47] Shunliang Zhang & Dali Zhu. 2020. Towards artificial intelligence-enabled 6G: State of the art, challenges, and opportunities.
[48] Ali Hussain Khan, Naveed UL Hassan, Chau Yuen, Jun Zhao, Dusit Niyato, Yan Zhang & Vincent Poor. 2021. Blockchain and 6G: The Future of Secure and Ubiquitous Communication.
[49] Marco Giordani & Michele Zorzi. 2020. Non-Terrestrial Networks in the 6G Era: Challenges and Opportunities. In IEEE Network, 35(2), 244-251
[50] Mirza Kibria, Kien Nguyen, Gabriel Villardi, Ou Zhao, Kentaro Ishizu & Fumihide Kojima. 2018. Big Data Analytics, Machine Learning, and Artificial Intelligence in Next-Generation Wireless Networks. IEEE Access, 6
[51] Lin Zhang, Ying-Chang Liang & Dusit Niyato. 2019. 6G Visions: Mobile Ultra-Broadband, Super Internet-of-Things, and Artificial Intelligence.
[52] Sergey Andreev, Vitaly Petrov, Mischa Dohler & Halim Yanikomeroglu. 2019. Future of Ultra-Dense Networks Beyond 5G: Harnessing Heterogeneous Moving Cells. In IEEE Communications Magazine, 57(6), 86–92
[53] Dinh Nguyen et al. 2021. 6G Internet of Things: A Comprehensive Survey. arXiv e-print, p.arxix:2108.04973v1.
[54] Nan Zhao, Shun Zhang, Richard Yu, Yunfie Chen, Arumugam Nallanathan & Victor Leung. 2017. Exploiting Interference for Energy Harvesting: A Survey, Research Issues, and Challenges. IEEE Access, 5, 10403-10421.
[55] Philip Boucher. 2020. Artificial intelligence: How does it work, why does it matter, and what can we do about it? European Parliamentary Research Service.
[56] Jiaheng Wang, Xintong Ling, Yuwei Le, Yongming Huang & You Xianhu 2021. Blockchain-enabled wireless communications: a new paradigm towards 6G. National Science Review, 8(9). DOI: https://doi.org/10.1093/nsr/nwab069
[57] Chamitha de Alwis et al. 2022. Towards 6G: Key technological directions. In Press.

Authors' Profile

Angel Nica T. Elegado received her BSc degree in Information Technology from Saint Louis University, Baguio City, Philippines, in 2019. She is currently taking her Master's degree in Information Technology at Saint Louis University. Her main research interests include Machine Learning, Wireless Sensor Networks, Internet-of-Things, Web Application Testing, Artificial Intelligence and Security Protocols.