engineering proceedings

MDPI

Proceeding Paper

A Review of Recent Developments in 6G Communications Systems †

Srikanth Kamath *, Somilya Anand, Suyash Buchke and Kaushikee Agnihotri

Department of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, Karnataka, India; somilya.anand@learner.manipal.edu (S.A.); suyash.buchke@learner.manipal.edu (S.B.); kaushikee.agnihotri@learner.manipal.edu (K.A.)

* Correspondence: srikanth.kamath@manipal.edu

† Presented at the International Conference on Recent Advances in Science and Engineering, Dubai, United Arab Emirates, 4–5 October 2023.

Abstract: Currently, we exist in the 5G division of the wireless technology cycle, where the standardization is complete and deployment is being carried out. However, 5G networks do not have the capacity to deliver an automated and intelligent network that supports connected intelligence. 6G is what enables this, and globally, countries are aiming to lay the foundation for the communication needs of 2030. This brings out a very key question and discussion on how wireless communications will develop in the future, particularly adapting to the range and set of applications and user cases. Industry and academic efforts have started to explore beyond 5G and uncover 6G as 5G becomes more internationally accessible. We forecast that 6G will undergo a transition that is unheard of in the history of wireless cellular systems. 6G exists beyond mobile internet and will be required to support omnipresent AI services from the network's core to its endpoints. Meanwhile, artificial intelligence (AI) will be crucial for developing and improving 6G designs, protocols, and operations. URLLC plays a crucial role in next-generation communication systems, particularly in 6G, for applications requiring ultra-low latency and reliability. These services support cutting-edge technologies like driverless vehicles, remote robotic surgery, smart factories, and augmented reality applications. URLLCs ensure robust connectivity and real-time responsiveness, enabling time-sensitive and safety-critical services in 6G communication infrastructures. This article illustrates the importance of URLLCs in 6G and their integration with deep learning, the security challenges, and their potential solutions. Further on, it establishes its relationship with key aspects of federated learning and security in the 6G domain.

Keywords: 5G; 6G; blockchain; federated learning; machine learning; security

Citation: Kamath, S.; Anand, S.; Buchke, S.; Agnihotri, K. A Review of Recent Developments in 6G Communications Systems. *Eng. Proc.* **2023**, *59*, 167. https://doi.org/10.3390/engproc2023059167

Academic Editors: Nithesh Naik, Rajiv Selvam, Pavan Hiremath, Suhas Kowshik CS and Ritesh Ramakrishna Bhat

Published: 17 January 2024

1. Introduction

Even though, as of present, 5G is widely available to use for a lot of us, research into 6G has already begun in various nations and organizations. The Network 2030 focus group, established by the International Telecommunication Union in 2018, aims to explore the advancement of system technologies through 2030 and beyond.

The 6G 2030 network concepts include new holographic communication, services, network architecture, and Internet Protocol (IP). This section discusses visions, limitations, requirements, and system architectures, focusing on computational holographic radio and photonics-based cognitive radio. This research analyzes primary studies, fundamental criteria, and system designs and technologies to provide a comprehensive understanding of the future of the network.

1.1. 5G Limitations and 6G Vision

5G, the fifth generation of cellular networks, has significantly improved mobile communications with faster data speeds, lower latency, and higher capacity. However, it has

limitations, such as the need for a vast network of tiny cells, increasing infrastructure costs, and deployment difficulties in rural areas (Figure 1). Additionally, higher frequencies can result in decreased penetration through obstructions, leading to coverage gaps indoors or in crowded metropolitan areas.

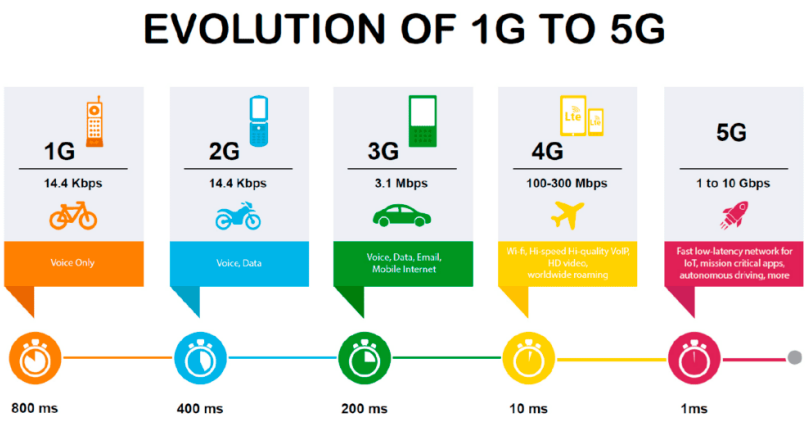

Figure 1. Evolution of Wireless Technology.

The future of 6G promises to overcome these constraints and add even more game-changing capabilities. The sixth generation of wireless communication is expected to operate at even higher frequencies, utilizing the terahertz spectrum. This technology aims to be energy-efficient and environmentally sustainable, addressing concerns about the carbon impact of current wireless technologies. It is also expected to be more flexible, with dynamic spectrum sharing and better coverage, allowing seamless access even in secluded and difficult terrains.

The 6G vision for 2030 aims to meet the needs of 5G and address areas that 5G cannot satisfy. The vision can be divided into four key categories: "Intelligent Connectivity", "Deep Connectivity", "Holographic Connectivity", and "Ubiquitous Connectivity".

1.2. Application and Use Cases

6G is expected to revolutionize various industries by offering ultra-low latency and high data throughput. It will enhance immersive experiences in AR and VR, enabling real-time interactions and high-definition content streaming. The healthcare industry will benefit from 6Gs reliable connectivity, while smart cities can improve traffic management, energy efficiency, and public safety through networked sensors and IoT devices. Additionally, 6G will enable real-time data sharing and accurate positioning for autonomous systems like self-driving cars and drones.

1.3. Challenges during the Transition to 6G and Its Solutions

The 6G wireless communication transition presents significant challenges for the telecoms sector and society. The current infrastructure requires renovation, with 6G requiring a denser base station network, more capacity, and better signal propagation technologies.

Implementing these components is expensive and time-consuming, and ensuring a seamless transition without affecting existing services is challenging. Interoperable technologies and standards are also a barrier. To address these issues, stakeholders must invest in research and development, cooperate with governments, telecommunications providers, and technology manufacturers, accelerate standardization, and promote mass adoption through public awareness programs. A proactive and collaborative attitude can simplify the transition to 6G, maximizing the possibilities of this game-changing technology.

2. Ultra-Reliable Low-Latency Communications in 6G

2.1. Key Performance Indicators

1. Reliability: URLLC plans to replace wired connections with wireless ones, addressing production and haptic use in medical applications. This approach is needed for telesurgery, automated guided vehicles, and automated factories, aiming for up to 1–10^{-9} reliability (Table 1) [1].
2. Low-Latency: End-to-End (E2E) Round Trip Latency (RTL) measures data travel between application layers on a source and end device, including propagation, processing delays, and request and response. For tactile internet haptic feedback, RTL within 20 ms is necessary, while strict E2E RTL is required for haptic steering.
3. Spectral-Efficiency: Spectral efficiency measures the quantity of data transferable under a given bandwidth constraint [2]. With 6G, a greater number of devices will expand, necessitating support for a greater number of services within a given bandwidth.
4. Jitter: The launch of 6G will increase the appeal of mobile augmented reality/virtual reality (AR/VR) applications [2]. To provide the greatest user experience possible, the jitter and delay between consecutive updates should be kept to a minimum.

Table 1. Comparison of Performance Metrics for URLLCs in 5G and 6G.

Key Performance Indicators (KPIs)	5G	6G
Maximum Achievable Data Rate	10 Gbps	1 Tbps
End-to-End latency	10 ms	1 ms
Spectral Efficiency	30 bps/Hz	100 bps/Hz
Reliability (FER)	10^{-5}	10^{-9}
Jitter	Not Specified	1 us

2.2. Integration of URLLCs with Deep Learning

6G networks are incorporating more multidimensional, heterogeneous, large-scale, and highly dynamic systems. All of these elements necessitate the development of unique adaptive, adaptable, and intelligent solutions in order to achieve a revolutionary leap in communications with ultra-broadband, ultra-massive access support, ultra-reliability, and low latency [2].

As 6G networks deploy computational and storage capacity at both edge and central servers, 6G will be able to train deep learning algorithms [2].

1. Supervised Learning: Apart from contributions in the field of computer science, supervised deep learning will also play a major role in wireless networks. Some of the areas where it will be useful are channel estimation or prediction, quality of service (QoS) prediction, quality of experience (QoE) prediction, and traffic prediction [2].
2. Unsupervised learning: Unsupervised learning algorithms use unlabeled training data to identify hidden patterns and clusters, enabling optimal policy determination in URLLCs. K-means and fuzzy C-means address interference mitigation and node clustering, while deep neural networks optimize and train for QoS criteria using unsupervised DL [3].
3. Deep Reinforcement Learning: The deep-RL and URLLC work together to deliver more dependable peak data throughput and reduce interface latency by enabling autonomous symbol creation, protection, energy harvesting, beamforming, channel-tracking, and complicated network layer multi-routing. Some of the deep reinforcement learning techniques useful in resource allocation are Q-learning, fuzzy RL, and deep deterministic policy gradient (DDPG) [3].

2.3. Real-Life Applications

1. Industrial Automation—Utilize 6G URLLCS; a key driver of the fourth industrial revolution; alongside artificial intelligence; genetic engineering; and 3D printing; for reliable connectivity and enhanced capabilities like sonar; GPS; radar; and odometry.

2. Extended-Reality—Extended Reality (XR) combines AR; VR; and MR; utilizing 3-D objects and artificial intelligence. Wearable gadgets with XR technology, high-definition visuals, and five communication senses enable human-to-human and object conversations [4].
3. Healthcare Industry—URLLC is utilized by healthcare organizations for patient visits; asset tracking; real-time patient monitoring; and staff training. It enables remote surgery with low latency and a reliable 6G network, enabling rapid and reliable data transport in the medical industry [4].

2.4. Extreme URLLCs (xURLLC)

The KPIs of URLLCs, eMBB, and mMTC will be confused in certain services due to the different QoS needs in future application situations. Such a new trend has been proposed and is known as extreme URLLCs [4].

xURLLC is essential for 5G and 6G networks, providing mission-critical services with high dependability and immediate reaction times. It supports real-time control applications like driverless vehicles, remote surgery, and industrial IoT systems. xURLLC offers low latency and excellent reliability, ensuring swift and accurate information transfer even in challenging conditions [4].

2.5. Challenges

To successfully deploy Extreme Ultra Reliable Low Latency Communication (URLLC), several obstacles must be removed. Ultra-low latency requires reducing processing and transmission delays, streamlining protocols, reducing packet overhead, and speeding up propagation. Robust error correction techniques, redundancy mechanisms, and fault tolerance mechanisms are needed to limit channel impairments and node failures [5]. Ensuring extreme dependability is another challenge. Infrastructure modifications are needed to accommodate increased bandwidth and low latency demands. High-capacity networks, network densification, and resource allocation are essential for fulfilling these requirements.

3. Federated Learning in 6G

3.1. Introduction

6G communications are increasingly being considered by businesses and academia as 5G networks become more widely implemented. To support data-driven Machine Learning solutions in heterogeneous and scalable networks, 6G is believed to be based on pervasive AI.

Standard ML approaches require centralized data collection and processing, leading to privacy concerns. Federated learning, a distributed AI technique, is on the rise and is considered a primary solution for establishing ubiquitous AI in 6G, making it appealing for various wireless applications.

3.2. Advantages of Federated Learning

Federated learning is essential for 6G wireless communication because it allows for dispersed learning across numerous devices while upholding data confidentiality and privacy (Figure 2). It has gained significant traction in the field of computer vision recently, with applications in many different areas, such as large-scale classification, medical imaging, domain generalization, and many others [2].

The main advantages are:

1. Privacy preservation: Federated learning in 6G communication aims to preserve the privacy of users' data by keeping it on their devices rather than centralizing it.
2. Decentralized learning: Federated learning allows for machine learning models to be developed and improved in a decentralized manner, leveraging the computational resources of multiple devices.

3. Improved accuracy: The aggregation of data and computation from multiple devices leads to more robust and accurate models compared to traditional centralized learning approaches.
4. Reduced latency: By bringing the computation to the data, federated learning reduces the latency and bandwidth requirements for communication, improving the overall efficiency of the system.
5. Enhanced security: Federated learning protects against data breaches, tampering, and other security threats by keeping sensitive data on the devices of users rather than centralizing it in a single location.

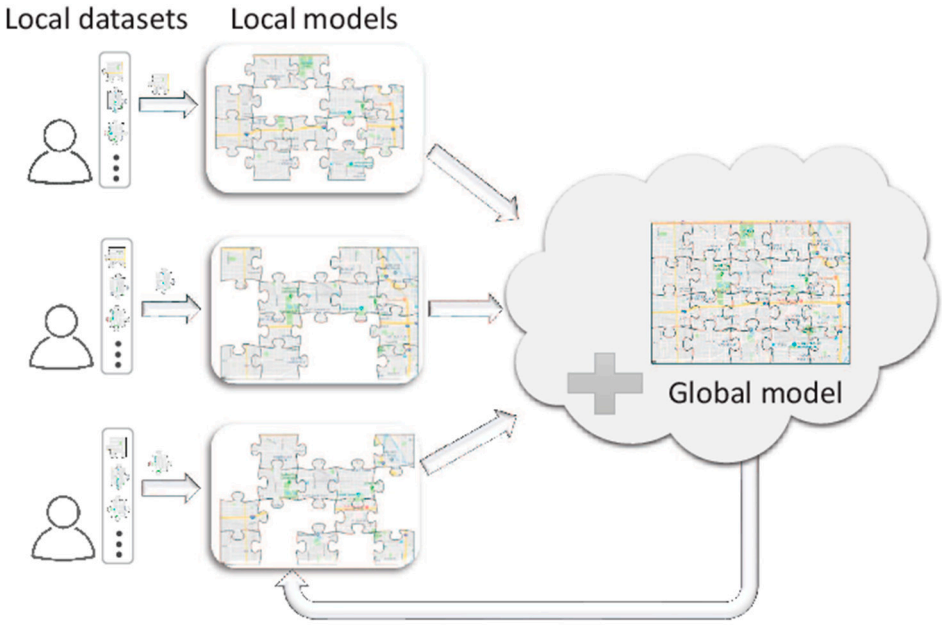

Figure 2. An illustration of the concept of Federated Learning [1].

3.3. Real-Life Uses

Some of the examples of federated learning being used in real life are:

- Group knowledge transfer: increased CNN size improves model accuracy, but it is challenging for training on resource-constrained edge devices. FedGKT, a group knowledge transfer training algorithm, addresses this issue by addressing edge node compute capability limitations.
- Federated Learning for Mobile Keyboard Prediction (Google).
- Frameworks like "Flower: A Friendly Federated Learning Framework", which supports heterogeneous environments, including mobile and edge devices, and scales to many distributed clients.

3.4. Challenges in Federated Learning

While having so many extraordinary advantages, Federated Learning has its fair share of challenges to overcome. Some of them are Communication Overhead, Privacy and Security Concerns, Expensive Communication, etc.

- Communication Overhead: FLs iterative nature does not completely solve network congestion due to data offloading from the edge to the cloud. Communication overhead is significant for complicated models, big-scale applications, and high-frequency updates, making it challenging to handle [3].
- Privacy and Security Concerns: Federated Learning models are susceptible to attacks, similar to any machine learning model. These attacks can be initiated by individuals, a compromised central server, or local devices. Common attacks include Membership Interference, Data poisoning, Model poisoning, and Backdoor attacks [4].

- Expensive Communication: Federated Learning generally involves multiple devices for model training. Some studies prior to this [5–12] show some work conducted to improve communication efficiency. To minimize the communication overhead, we take two things into account: (i) minimizing the total number of communication rounds, or (ii) minimizing the number of gradients used in each round [13].

4. Security in 6G and Blockchain

This section about 6G will focus on the security threats faced/expected in 6G, the current 5G security protocols and where they stand, and the inclusion of blockchain in overcoming those. However, as no solution can be considered the final solution for existing problems, blockchain also comes with its own set of threats. This is discussed in the last section.

4.1. Security Threats

Over the studies conducted, Privacy-preserving, Location-based privacy, Eavesdropping, Traceability, Extraction, Replay, and DoS (Denial of Service) attacks are some common trends suspected [14]. These are accompanied by threats due to newer 6G requirements and architecture, all of which have to work on resource-constrained devices, as this network's possible 6G applications include a complete exchange between human senses and machines, wearable technologies including AR (Augmented reality), XR (comprises of augmented reality, virtual reality, and mixed reality), and VR (Virtual reality) [15].

1. Physical-Level Security Threats
   - Designing and implementing of resource isolation for base stations for full-duplex operations in the case of full-duplex radio stations.
2. New Requirements
   - To ensure service quality when using Enhanced Ultra-Reliable, Low-Latency Communication (ERLLC/eURLLC), security systems need to be implemented, taking latency into account.
   - Features and architecture guaranteeing high reliability need efficient security solutions protecting users, resources, and services.
   - Further improved Mobile Broadband (FeMBB) resulted in higher data rates, which caused traffic processing issues for attack detection, encryption, and traffic analysis.
   - The Internet of Everything (IoE) will render existing encryption models obsolete due to its extensive and diverse capabilities.
3. New Architecture
   - The advancement of AI chips has resulted in a breakthrough in which hardware can be isolated from transceiver algorithms, and they can configure and update themselves based on environmental inputs.
   - Intelligent radio today is expected to solve many problems of accurate channel modeling, dynamic spectrum access, improved network deployment, optimization, and autonomous orchestration that lead to malicious attacks/activities during communication systems.
   - Intelligent networks lead to DdoS (Distributed Denial-of-Service attacks) and MITM (Man in the Middle) attacks.
   - Intercepting information in the process of transmission.
   - Performance-Privacy balance.
   - This model is high on AI/ML dependency, where any contamination of data that is already in volumes can have a detrimental impact on the models we use.

4.2. Blockchain Solutions in the Security Domain

Blockchain is a decentralized ledged technology that originated with Bitcoin, but in recent years, the idea of blockchain is not just limited to currency but revolves around

the properties it holds: decentralization, accountability, transparency, security, permissionlessness, immutability, etc. Figure 3 show the KPI requirements and its impact on 6G networks [16].

KPI	Description	6G impact
Protection level	The guaranteed level of protection against certain threats and attacks	More stringent due to the pervasive utility of 6G and burgeoning risk level
Time to Respond (mean, max, ...)	Time for security functions to counteract in case of malicious activity	Much smaller due to compressed timescale of 6G networks, e.g., an attack can cause havoc at an order or faster
Coverage	The coverage of security functions over the 6G service elements and functions	More challenging due to diverse 6G technologies and ultra-distributed functions
Autonomicity level	A measure of how autonomic security controls can act	Expected to be easier to implement with pervasive AI, but also may be counter-beneficial due to AI security issues
AI robustness	The robustness of AI algorithms in the network hardened for security	More difficult to maintain consistently system-wide but more critical due to AI's role in 6G
Security AI model convergence time	Time for learning models working for security to converge	Although more advanced AI/ML models are emerging and hardware capabilities are improving, the data availability and complexity are challenging factors for this KPI.
Security Function Chain round-trip-time	Time for chained security functions to process for ingest, analyse, decide and act (related to "Time to respond" KPI)	Security architecture in 6G supposed to be more distributed, leading to challenges. But at the same time, device-centric and edge-centric solutions will help.
Cost to deploy security functions (mean, max, ...)	Various cost metrics for measuring the cost of deployment	Substantially increases due to complexity, thus harder to meet target KPI values

Figure 3. KPI vs. Requirement for 6G.

It involves every user being communal on the network who maintains and regulates it, along with tracking and tracing all further and previous transactions by means of hashing.

Solutions

IOTA Tangle, a distributed ledger technology for the Internet of Things, and Ethereum integration have been used to create fee-less transactions and crowdsourced indoor navigation systems. Smart contracts and consensus mechanisms enable transactions once all conditions are met [17]. 6G, an intelligent network, has an attacker model involving two levels of attackers, making verification challenging. Blockchain can be further developed in communication systems and distributed network environments, involving behaviors from all network protocol layers. With the advent of 5G communications, asymmetric public key infrastructure-based cryptography has been used, but none provides auditability for data. Adding blockchain to these systems, which use asymmetric PKI and privacy preservation frameworks, can improve data privacy and confidentiality. The presence of hash functions promotes auditability and data integrity [18].

PoW (Proof of Work) and PoS (Proof of Stake) are the biggest security providers on the network. Blockchain will aid 6G in data integrity, non-repudiation, and auditability. Previously, existing technologies used symmetric key cryptography, resulting in a lack of non-repudiation AKP and extensible authentication protocols (EAP) [19]. However, as the network decentralizes, it becomes harder for attackers to tamper with data or blocks. To avoid high data rates and processing costs, a local approach using distributed ledger technology is needed. Local processing and distributed security solutions can be implemented on edge and cloud platforms, enhancing security, errors, and transparency [20].

4.3. Challenges with Blockchain

- High costs: The average cost of a transaction, for example, Ethereum, is 150 USD per transaction. Ethereum because it is a highly used and decentralized network with ease of understanding.
- The average cost of storage is 100 dollars per GB, which is very cost-efficient given that large storage is mostly impossible on blockchain.
- SLAs-SLAs storage is carried out off-chain and requires constant monitoring and transparency among stakeholders, which often leads to delays and inefficiency.
- Common blockchain threats include 51% majority attacks, Sybil attacks, and selfish mining.

- Since data are with everyone, the aspect of transparency compromises privacy.

5. Conclusions

This paper compares 6G to 5G and analyzes its role in emerging technologies. 6G wireless communication enables URLLCs to make significant strides in mission-critical applications, integrating deep learning and URLLCs to resolve resource allocation and optimization issues.

Federated learning is crucial for 6G wireless communication, enabling dispersed learning across devices while maintaining data confidentiality and privacy. This enables faster, more accurate creation and enhancement of machine learning models without storing large amounts of private data.

However, 6G technology and requirements emphasize the importance of security, necessitating updates to existing protocols, frameworks, and measures. A decentralized network, such as blockchain, is needed to protect user privacy, integrity, and security, making it a promising use case for 6G.

Author Contributions: All the authors contributed to conceptualization, validation, formal analysis, investigation, original draft preparation, and review. Project supervision and administration were conducted by S.K. URLLCs review was done by S.A. and S.B. contributed to ward Federated Learning and K.A. worked on security in 6G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: No new data were created. Data sharing is not applicable to this article.

Acknowledgments: We would like to thank Anil Rana (Director) and Kumar Shama (HOD—Department of Electronics and Communication) at Manipal Institute of Technology for giving us the opportunity to work on this project.

Conflicts of Interest: Authors declare no conflicts of interest.

References

1. Pocovi, G.; Shariatmadari, H.; Berardinelli, G.; Pedersen, K.; Steiner, J.; Li, Z. Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements. *IEEE Netw.* **2018**, *32*, 8–15. [CrossRef]
2. She, C.; Sun, C.; Gu, Z.; Li, Y.; Yang, C.; Poor, H.V.; Vucetic, B. A Tutorial on Ultrareliable and Low-Latency Communications in 6G: Integrating Domain Knowledge Into Deep Learning. *Proc. IEEE* **2021**, *109*, 204–246. [CrossRef]
3. Shi, Z.; Xie, X.; Garg, S.; Lu, H.; Yang, H.; Xiong, Z. Deep Reinforcement Learning Based Big Data Resource Management for 5G/6G Communications. In Proceedings of the 2021 IEEE Global Communications Conference (GLOBECOM), Madrid, Spain, 7–11 December 2021; pp. 01–06. [CrossRef]
4. Chowdhury, M.Z.; Shahjalal, M.; Ahmed, S.; Jang, Y.M. 6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions. *IEEE Open J. Commun. Soc.* **2020**, *1*, 957–975. [CrossRef]
5. Salh, A.; Audah, L.; Shah, N.S.M.; Alhammadi, A.; Abdullah, Q.; Kim, Y.H.; Al-Gailani, S.A.; Hamzah, S.A.; Esmail, B.A.F. A Survey on Deep Learning for Ultra-Reliable and Low-Latency Communications Challenges on 6G Wireless Systems. *IEEE Access* **2021**, *9*, 55098–55131. [CrossRef]
6. Niknam, S.; Dhillon, H.S.; Reed, J.H. Federated Learning for Wireless Communications: Motivation, Opportunities, and Challenges. *IEEE Commun. Mag.* **2020**, *58*, 46–51. [CrossRef]
7. Caldarola, D.; Caputo, B.; Ciccone, M.; di Torino, P.; CINI. Improving Generalization in Federated Learning by Seeking Flat Minima. Available online: https://arxiv.org/abs/2203.11834 (accessed on 20 March 2022).
8. Al-Saedi, A.A.; Boeva, V.; Casalicchio, E. Reducing Communication Overhead of SFederated Learning through Clustering Analysis. In Proceedings of the 2021 IEEE Symposium on Computers and Communications (ISCC), Athens, Greece, 5–8 September 2021; pp. 1–7. [CrossRef]
9. Priyanka Mary Mammen, University of Massachusetts, Amherst. Federated Learning: Opportunities and Challenges. Available online: https://arxiv.org/abs/2101.05428 (accessed on 14 January 2021).
10. Konečný, J.; McMahan, H.B.; Yu, F.X.; Richtárik, P.; Suresh, A.T.; Bacon, D. Federated learning: Strategies for improving communication efficiency. *arXiv* **2016**, arXiv:1610.05492.

11. Tran, N.H.; Bao, W.; Zomaya, A.; Nguyen, M.N.H.; Hong, C.S. Federated learning over wireless networks: Optimization model design and analysis. In Proceedings of the IEEE Conference on Computer Communications, Paris, France, 29 April–2 May 2019; IEEE: Toulouse, France, 2019; pp. 1387–1395.
12. Bonawitz, K.; Eichner, H.; Grieskamp, W.; Huba, D.; Ingerman, A.; Ivanov, V.; Kiddon, C.; Konečný, J.; Mazzocchi, S.; McMahan, B.; et al. Towards Federated Learning at Scale: System Design. in SysML 201. [Online]. Available online: https://arxiv.org/abs/1902.01046 (accessed on 4 February 2019).
13. Liu, Y.; Yuan, X.; Xiong, Z.; Kang, J.; Wang, X.; Niyato, D. Federated learning for 6G communications: Challenges, methods, and future directions. *China Commun.* **2020**, *17*, 105–118. [CrossRef]
14. Siriwardhana, Y.; Porambage, P.; Liyanage, M.; Ylianttila, M. AI and 6G Security: Opportunities and Challenges. In Proceedings of the 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Porto, Portugal, 8–11 June 2021; pp. 616–621. [CrossRef]
15. Gracia, M.B.; Malele, V.; Ndlovu, S.P.; Mathonsi, T.E.; Maaka, L.; Muchenje, T. 6G Security Challenges and Opportunities. In Proceedings of the 2022 IEEE 13th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT), Cape Town, South Africa, 25–27 May 2022; pp. 339–343. [CrossRef]
16. Li, W.; Su, Z.; Li, R.; Zhang, K.; Wang, Y. Blockchain-Based Data Security for Artificial Intelligence Applications in 6G Networks. *IEEE Netw.* **2020**, *34*, 31–37. [CrossRef]
17. Singh, D. Features Architecture and Security Issues in 5G and 6G Communication. In Proceedings of the 2022 8th International Conference on Signal Processing and Communication (ICSC), Noida, India, 1–3 December 2022; pp. 117–120. [CrossRef]
18. Bindu, G.; S, I.T.J.; Kanakala, V.R.; Niharika, G.L.K.; Raj, B.E. Impact of Blockchain Technology in 6G Network: A Comprehensive survey. In Proceedings of the 2022 International Conference on Inventive Computation Technologies (ICICT), Lalitpur, Nepal, 20–22 July 2022; pp. 328–334. [CrossRef]
19. Hewa, T.; Gür, G.; Kalla, A.; Ylianttila, M.; Bracken, A.; Liyanage, M. The Role of Blockchain in 6G: Challenges, Opportunities and Research Directions. In Proceedings of the 2020 2nd 6G Wireless Summit (6G SUMMIT), Levi, Finland, 17–20 March 2020; pp. 1–5. [CrossRef]
20. Manoharan, V.S.R.; Ramachandran, S.; Rajasekar, V. Blockchain Based Privacy Preserving Framework for Emerging 6G Wireless Communications. *IEEE Trans. Ind. Inform.* **2022**, *18*, 4868–4874. [CrossRef]