Potential Enabling Technologies for 6G Mobile Communication Networks: A Recent Review

Duc-Nghia Vu*, Nhu-Ngoc Dao†, Dongwook Won*, Sungrae Cho*
*School of Computer Science and Engineering, Chung-Ang University, Korea.
†Department of Computer Science and Engineering, Sejong University, Korea.
Email: dnvu@uclab.re.kr, nndao@sejong.ac.kr, dwwon@uclab.re.kr, srcho@cau.ac.kr.

***Abstract*—The evolution of wireless networks has transformed the way people interact and communicate with each other. The next generation of wireless technology, 6G, promises to take this evolution to the next level. In this paper, we present an overview of the key technologies that are likely to shape the future of 6G mobile networks such as terahertz communication, visible light communication, ultra-massive MIMO, artificial intelligence, quantum communication, blockchain, and intelligent reflective surface. We discuss the unique advantages and challenges associated with each technology and provide examples of ongoing research to overcome these challenges. By leveraging these technologies, 6G networks have the potential to provide ultra-high data rates, ultra-reliable low-latency communication, and massive connectivity to support a wide range of emerging applications, including virtual and augmented reality, autonomous vehicles, smart cities, and more. The integration of these technologies has the potential to enable new use cases, unlock new opportunities, and bring us closer to realizing the full potential of the 6G vision.**

***Index Terms*—Potential technology, key technology, 6G, mobile networks.**

I. Introduction

The development of mobile communication networks has revolutionized the way people connect and communicate with each other. Originating from first generation (1G), mobile network is continuously developed through 2G, 3G, 4G, and until recent generation, 5G. Although the data rate, reality, capacity, coverage, and serviceability have been significantly improved in each generation, the exponential growth of data usage, emerging technologies, and new applications demands more advanced networks to support future needs [1].

The latest generation of mobile networks, 5G, show the great performance when providing high-speed internet access, low latency, new applications and services for massive IoT devices. However, it can not satisfy the increasing requirements of the new smart applications in digital information technology era. This demands the next communication network generation to overcome 5G network limits and support the future needs [2]. Researchers are already looking ahead to the next generation of mobile networks. The 6G is the next frontier of mobile communication technology that is set to deliver unprecedented connectivity, higher data rates, and lower latency compared to its predecessors [3]. The 6G mobile network will build upon the strengths of the 5G network while also incorporating innovative and advanced technologies to enable new applications and use cases.

The future of mobile communication networks is exciting, and the possibilities that 6G networks will bring are limitless. It emerges a new era, intelligent Internet of Everything (IoE), where the IoE will become even more intelligent and the interconnectedness of people, things, data, and processes enabled by the communication network infrastructure such as smart cities, autonomous vehicles, telemedicine, smart healthcare, and so on. We will examine the potential impact of 6G networks on various sectors, including transportation, healthcare, entertainment, and education. In this paper, we will present an overview of the requirements and the potential key technologies that will drive the development of 6G mobile networks. These technologies include terahertz communication, visible light communication, ultra-massive MIMO, artificial intelligence, quantum communication, block chain, intelligent reflective surface, and so on. Each of these technologies has unique advantages and challenges, and we will explore how they can be integrated into 6G networks to unlock their full potential.

II. 6G Mobile Network Requirements

The 6G mobile communication networks is expected to be a revolutionary technology that provides ultra-high-speed connectivity, low latency, and massive device connectivity. The KPIs for 6G is inherited from 5G and update according to the emergence of new applications and the development of technologies [4]. The following are some of the key requirements for 6G mobile networks:

- High data rates: 6G networks are expected to deliver data rates of up to 1 terabit per second (Tbps) [5], which is several times faster than 5G networks [6].
- Low latency: 6G networks will provide an ultra-low latency of fewer than 1 millisecond (ms) to support real-time applications and services such as virtual reality and augmented reality (AR/VR), telemedicine, and autonomous vehicles [7][8].
- Massive connectivity: 6G networks are supposed to support a ultra-massive number of devices, up to the millions of devices per one kilometer [9].
- Energy efficiency: 6G networks are intended to be more energy-efficient, about 100 times compared to previous generations to minimize the carbon footprint of wireless networks and lower energy consumption [10].

- Security and privacy: 6G networks must provide robust security and privacy protection to safeguard user data and information against cyber threats [11].
- Interoperability: 6G networks must be interoperable with existing and future wireless networks to ensure seamless connectivity and user experience [12].

Meeting these requirements will require the application of advanced technology such as terahertz communication, visible light communication, ultra-massive MIMO, artificial intelligence, quantum communication, blockchain, and intelligent reflective surface. Achieving these requirements will enable new applications and use cases that will transform various sectors, including healthcare, transportation, entertainment, and education.

III. Potential Key Technology For 6G Mobile Communcation Networks

The next mobile network generation is released roughly every ten years. The 5G network has been a significant breakthrough, providing high-speed, low latency, and seamless connectivity, which has paved the way for the emergence and evolution of new technologies and applications. However, research and development for the next generation of mobile communication networks, 6G, is already underway and in the early stage of exploration [13]. The 6G mobile network is expected to be commercialized from 2028. This research paper explores the potential key technologies for 6G mobile communication networks.

A. Terahertz Communication

One of the potential enabling technologies for 6G mobile communication networks is Terahertz (THz) communication. The THz frequency range is above 100 GHz, and it enables high-speed data transfer rates of up to several terabits per second [14]. This technology could support advanced applications such as (AR/VR), real-time remote treatment, and holographic displays. THz technology is very promising to be used in nanoscale devices, such as ultra-high-speed on-chip communication, military, health, and environmental pollution monitoring. THz communication could also support the development of smart cities, where various systems such as transportation, energy, and healthcare would be connected and optimized for maximum efficiency [15][16].

However, THz communication faces significant challenges such as limited transmission distance and high power consumption, requiring innovative solutions for successful implementation. Aiming at making THz applications the reality, researchers are exploring different approaches to address these challenges, including developing THz antennas and transceivers with higher efficiency, and using adaptive modulation techniques to optimize the system performance [17][18].

B. Visible Light Communication

Visible Light Communication (VLC) is a potential technology in the context of 6G networks, where data is transmitted through visible light. VLC is a novel kind of optical wireless communication which uses visible light spectrum 400-800 THz. It also can provide high-speed data transfer rates and can be used in areas where traditional wireless communication is not feasible, such as underwater and in outer space. Additionally, VLC can be used for vehicular communications, indoor navigation and location-based services [19][20].

Although there are outstanding advantages, VLC has challenges such as the requirement of a line-of-sight, and interference from external light sources. Significant researches are carried out to address these challenges, including developing hybrid communication systems that combine VLC with traditional wireless communication and using advanced signal processing techniques to mitigate interference, and use nano-optical antennas and Fresnel lenses [19].

C. Ultra-massive MIMO

Massive multiple-input, multiple-output (MIMO) technology is expected as a core 6G network enabler. Massive MIMO uses large arrays of antennas to increase the capacity and efficiency of wireless networks. Massive MIMO is defined as number of antennas serving each user is greater than 10 and when number of antenna arrays become larger, up to hundreds or even thousands of antennas, it is ultra-massive MIMO [13]. The ultra-massive MIMO can provide spatial beams and it is feasible for THz frequency bands [21]. This technology could be used to support high-density urban areas and other environments with high demand for wireless data.

The main challenges in implementing ultra-massive MIMO for 6G is the hardware complexity and cost, increased energy consumption and the need for specialized infrastructure must be addressed for successful implementation. The huge number of antennas requires significant processing power, high-speed data converters, and sophisticated signal processing algorithms. Moreover, the antennas should be placed in a dense array to reduce the mutual coupling between them, which increases the overall size and weight of the system [22]. To overcome these challenges, numerous researches are conducted, focusing on characteristics, channel, modulation techniques, and so on to develop more energy-efficient massive MIMO systems and to enable their integration with existing infrastructure [23][13].

D. Artificial Intelligence

Artificial Intelligence (AI) is another promising key technology for 6G networks. AI could play a crucial role in the development of 6G networks by enabling more intelligent network management and optimization, as well as supporting advanced applications such as autonomous vehicles and smart cities [24]. AI and 6G communication technology will be revolutionized from connecting the things to connecting intelligence, result in emergence of intelligent IoE. AI including Federated learning, Machine learning, Deep learning, Big Data and many more aspects are brought out together to prepare for an intelligent communication network 6G [25]. AI can help in

predicting network traffic, analyzing user behavior, and optimizing network resources to provide seamless connectivity, high reliability, and low latency. Additionally, AI can facilitate real-time decision-making in various applications, enabling faster and more efficient communication [13][26].

However, challenges such as high energy consumption and the lack of standardization and regulation must be addressed for successful implementation and applying AI to air interface design. It also requires significant computational power, particularly for tasks such as training large neural networks. Ensuring that 6G networks have the necessary computational resources to support AI applications will be a key challenge. AI requires access to large amounts of data to train and optimize models, but this data often contains sensitive information. Ensuring data privacy will be a critical challenge for 6G networks that rely on AI, particularly as regulations around data protection become increasingly strict [25]. Researchers are exploring ways to develop more energy-efficient AI algorithms and improve the interoperability of different AI and ML systems such as federated learning, interpretable machine learning, and so on to ensure their effective integration with 6G networks [27].

E. Quantum Communication

As one of the promising technologies for 6G networks, quantum communication utilizes the principles of quantum mechanics to enable secure and high-speed communication that is resistant to hacking or eavesdropping. Quantum communication and computing technologies will revolutionize network security by providing un-hackable communication channels in 6G [28][29]. This technology could be used for applications such as military communications, financial transactions, and other sensitive data transfer [30]. The quantum paradigm considered as a core 6G enabler.

Despite of very promising, quantum communication remains significant difficulties to really deploy in 6G mobile network. Quantum communication systems typically have a limited range due to the effects of optical fiber attenuation and signal degradation. This means that the deployment of quantum communication systems in large-scale 6G networks may be challenging, and new technologies such as quantum repeaters and amplifiers will be required to extend the range. Number of researches with different approaches are conducted to address these challenges, including developing compact and low-cost quantum communication devices and leveraging existing fiber-optic networks to enable quantum communication over longer distances [31].

F. Block chain

The blockchain and distributed ledger technology is emerging as one of the enablers facilitate the functional standards of 6G [32]. A blockchain is a decentralised distributed ledger maintained by an underlying peer-to-peer (P2P) network of nodes. A distributed ledger is a database that is spread across a network of computers, rather than being stored on a single, centralized server. Blockchain, on the other hand, is a specific type of distributed ledger that uses a chain of blocks to record and verify transactions. Each block in the chain contains a cryptographic hash of the previous block, making it tamper-proof and immutable [29][33]. Blockchain can provide a secure and transparent way for devices and networks to share data in 6G wireless communication systems. This can be particularly useful in scenarios where privacy, security, and trust are critical, such as in healthcare, finance, and government [34]. It also can be used to manage identities and access permissions in 6G networks, enabling secure and decentralized authentication and authorization. This can help to prevent unauthorized access and cyberattacks, while also ensuring the privacy and confidentiality of user data.

While blockchain has potential benefits for 6G wireless communication systems, there are also several challenges. Number of approaches are explored to address them before blockchain can be fully integrated into large-scale 6G networks. Blockchain-based systems can be slow and computationally intensive, which can make them challenging to scale up to handle the large volumes of data and high-speed transactions that are expected in 6G networks. New consensus mechanisms, such as sharding or proof-of-stake, may be needed to improve blockchain scalability. Blockchain-based systems may not be fully interoperable with existing communication protocols and systems, which can create barriers to adoption and integration into 6G networks. New standards and protocols, such as Interledger or Hyperledger Fabric, may be needed to enable interoperability [35].

G. Intelligent Reflective Surface

Intelligent Reflective Surface (IRS) is a promising technology that can significantly enhance the performance of 6G mobile communication systems. An IRS is a surface made up of passive reflecting elements programming to reflect incoming signals in a desired direction. Reconfigurable intelligent surfaces (RIS) are considered as the MIMO 2.0 in 6G [29]. IRS can increase the capacity of 6G networks by enabling multiple users to simultaneously transmit and receive signals on same frequency as well as reduce the power consumption of 6G networks by efficiently enabling utilization of the available spectrum. IRS could be used to enhance signal coverage and reduce interference. By reflecting and manipulating signals in real-time, Intelligent Reflective Surfaces could help to overcome obstacles and improve signal strength, even in challenging environments such as urban areas or indoor spaces. [36].

The deployment of IRS in 6G networks presents several challenges such as complexity of design, deployment and integration, dynamic environments, etc. To overcome these challenges, number of approaches are emerged such as use machine learning algorithms to optimize the design of IRS, use wireless sensors and advanced positioning systems to accurately position the reflecting elements, or use wireless sensors and advanced positioning systems to accurately position the reflecting elements, and so on [37].

H. Other potential key technologies

The 6G networks development is already underway. Researchers are exploring various potential key technologies that could shape the future of mobile communication. With the key enabling technologies listed above, there are a lot of technologies that are promising and potential for 6G such as Orbital Angular Momentum (OAM) [38], Holographic Beamforming [39], Edge Computing [40][41], In-Band Full-Duplex [42], Dynamic Network Slicing, New Waveforms, Satellite-terrestrial integrated networks and more [13]. These technologies will bring to the future network 6G the ultra-high data rates, ultra-reliable low-latency communication, more intelligence, massive connectivity, more security, and support a wide range of emerging applications. They are the key successor for 6G.

IV. Concluding Remarks

As the world continues to embrace the advancements in wireless communication technologies, the focus has now shifted to the development of the next generation of mobile communication network - 6G. 6G is expected to bring about a massive transformation in the wireless industry, with a potential to support ultra-high-speed data transfer rates, ultra-low latency, and a large range of applications such as AR/VR, holographic communications, and intelligent transportation systems. This paper presents the potential enabling technologies that are promising to be the building the future 6G networks. These includes terahertz communication, visible light communication, ultra-massive MIMO, artificial intelligence, quantum communication, block chain, intelligent reflective surface and more. We presents the advantages and challenges acorrding to each technology and ongoing researches to address these challenges. Overall, 6G mobile communication network is just in the early stages, but the advancements in technology are promising. With the potential to support massive emerging applications and provide unprecedented levels of connectivity, 6G networks can change the way we communicate with the world.

Acknowledgment

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2023-RS-2022-00156353) supervised by the IITP (Institute for Information and Communications Technology Planning and Evaluation)

References

[1] A. S. Shah, "A survey from 1g to 5g including the advent of 6g: Architectures, multiple access techniques, and emerging technologies," in *2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC)*. IEEE, 2022, pp. 1117–1123.

[2] Z. Qadir, K. N. Le, N. Saeed, and H. S. Munawar, "Towards 6g internet of things: Recent advances, use cases, and open challenges," *ICT Express*, 2022.

[3] M. Moussaoui, E. Bertin, and N. Crespi, "5g shortcomings and beyond-5g/6g requirements," in *2022 1st International Conference on 6G Networking (6GNet)*. IEEE, 2022, pp. 1–8.

[4] ITU-R, "Framework and overall objectives of the future development of imt for 2020 and beyond," *Available: https://www.itu.int/dms pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-.pdf*, 2015.

[5] B. Rong, "6g: The next horizon: From connected people and things to connected intelligence," *IEEE Wireless Communications*, vol. 28, no. 5, pp. 8–8, 2021.

[6] S. Chen, Y.-C. Liang, S. Sun, S. Kang, W. Cheng, and M. Peng, "Vision, requirements, and technology trend of 6g: How to tackle the challenges of system coverage, capacity, user data-rate and movement speed," *IEEE Wireless Communications*, vol. 27, no. 2, pp. 218–228, 2020.

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

[8] J. R. Bhat and S. A. Alqahtani, "6g ecosystem: Current status and future perspective," *IEEE Access*, vol. 9, pp. 43 134–43 167, 2021.

[9] G. Flagship, "Key drivers and research challenges for 6g ubiquitous wireless intelligence," *Available: https://www.mobilewirelesstesting.com/wp-content/uploads/2019/10/5G-evolution-on-the-path-to-6G- wp en 3608-3326-52 v0100.pdf*, 2019.

[10] U. M. Malik, M. A. Javed, S. Zeadally, and S. ul Islam, "Energy efficient fog computing for 6g enabled massive iot: Recent trends and future opportunities," *IEEE Internet of Things Journal*, 2021.

[11] B. Mao, J. Liu, Y. Wu, and N. Kato, "Security and privacy on 6g network edge: A survey," *IEEE Communications Surveys & Tutorials*, 2023.

[12] S. Kharche and P. Dere, "Interoperability issues and challenges in 6g networks," *Journal of Mobile Multimedia*, vol. 18, no. 5, pp. 1445–1470, 2022.

[13] C.-X. Wang, X. You, X. Gao, X. Zhu, Z. Li, C. Zhang, H. Wang, Y. Huang, Y. Chen, H. Haas *et al.*, "On the road to 6g: Visions, requirements, key technologies and testbeds," *IEEE Communications Surveys & Tutorials*, 2023.

[14] T. S. Rappaport, Y. Xing, O. Kanhere, S. Ju, A. Madanayake, S. Mandal, A. Alkhateeb, and G. C. Trichopoulos, "Wireless communications and applications above 100 ghz: Opportunities and challenges for 6g and beyond," *IEEE access*, vol. 7, pp. 78 729–78 757, 2019.

[15] G. Szabó, S. Rácz, N. Reider, H. A. Munz, and J. Pető, "Digital twin: Network provisioning of mission critical communication in cyber physical production systems," in *2019 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT)*. IEEE, 2019, pp. 37–43.

[16] K. Tekbıyık, A. R. Ekti, G. K. Kurt, and A. Görçin, "Terahertz band communication systems: Challenges, novelties and standardization efforts," *Physical Communication*, vol. 35, p. 100700, 2019.

[17] Z. R. Hajiyat, A. Ismail, A. Sali, and M. N. Hamidon, "Antenna in 6g wireless communication system: Specifications, challenges, and research directions," *Optik*, vol. 231, p. 166415, 2021.

[18] C.-X. Wang, J. Wang, S. Hu, Z. H. Jiang, J. Tao, and F. Yan, "Key technologies in 6g terahertz wireless communication systems: A survey," *IEEE Vehicular Technology Magazine*, vol. 16, no. 4, pp. 27–37, 2021.

[19] N. Chi, Y. Zhou, Y. Wei, and F. Hu, "Visible light communication in 6g: Advances, challenges, and prospects," *IEEE Vehicular Technology Magazine*, vol. 15, no. 4, pp. 93–102, 2020.

[20] M. Katz and I. Ahmed, "Opportunities and challenges for visible light communications in 6g," *2020 2nd 6G wireless summit (6G SUMMIT)*, pp. 1–5, 2020.

[21] R. Dilli, R. Ch, D. Jordhana *et al.*, "Ultra-massive multiple input multiple output technologies for 6g wireless networks," *Engineered Science*, vol. 16, pp. 308–318, 2021.

[22] F. A. P. de Figueiredo, "An overview of massive mimo for 5g and 6g," *IEEE Latin America Transactions*, vol. 20, no. 6, pp. 931–940, 2022.

[23] V. Dala Pegorara Souto, P. S. Dester, M. Soares Pereira Facina, D. Gomes Silva, F. A. P. de Figueiredo, G. Rodrigues de Lima Tejerina, J. C. Silveira Santos Filho, J. Silveira Ferreira, L. L. Mendes, R. D. Souza *et al.*, "Emerging mimo technologies for 6g networks," *Sensors*, vol. 23, no. 4, p. 1921, 2023.

[24] D. Gupta, M. Ragab, R. F. Mansour, A. Khamparia, and A. Khanna, *AI-enabled 6G Networks and Applications*. Wiley Online Library, 2023.

[25] Y. Siriwardhana, P. Porambage, M. Liyanage, and M. Ylianttila, "Ai and 6g security: Opportunities and challenges," in *2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*. IEEE, 2021, pp. 616–621.

[26] G. Zhu, Z. Lyu, X. Jiao, P. Liu, M. Chen, J. Xu, S. Cui, and P. Zhang, "Pushing ai to wireless network edge: an overview on integrated sensing, communication, and computation towards 6g," *Science China Information Sciences*, vol. 66, no. 3, p. 130301, 2023.

[27] A. M. Al-Ansi, A. Al-Ansi *et al.*, "An overview of artificial intelligence (ai) in 6g: Types, advantages, challenges and recent applications," *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 5, no. 1, pp. 67–75, 2023.

[28] S. Dang, O. Amin, B. Shihada, and M.-S. Alouini, "What should 6g be?" *Nature Electronics*, vol. 3, no. 1, pp. 20–29, 2020.
[29] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6g wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open Journal of the Communications Society*, vol. 1, pp. 957–975, 2020.
[30] K. Prateek, N. K. Ojha, F. Altaf, and S. Maity, "Quantum secured 6g technology-based applications in internet of everything," *Telecommunication Systems*, vol. 82, no. 2, pp. 315–344, 2023.
[31] C. Wang and A. Rahman, "Quantum-enabled 6g wireless networks: Opportunities and challenges," *IEEE Wireless Communications*, vol. 29, no. 1, pp. 58–69, 2022.
[32] T. Hewa, G. Gür, A. Kalla, M. Ylianttila, A. Bracken, and M. Liyanage, "The role of blockchain in 6g: Challenges, opportunities and research directions," *2020 2nd 6G Wireless Summit (6G SUMMIT)*, pp. 1–5, 2020.
[33] H.-N. Dai, Z. Zheng, and Y. Zhang, "Blockchain for internet of things: A survey," *IEEE Internet of Things Journal*, vol. 6, no. 5, pp. 8076–8094, 2019.
[34] H. H. Pajooh, S. Demidenko, S. Aslam, and M. Harris, "Blockchain and 6g-enabled iot," *Inventions*, vol. 7, no. 4, p. 109, 2022.
[35] A. Kalla, C. De Alwis, P. Porambage, G. Gür, and M. Liyanage, "A survey on the use of blockchain for future 6g: Technical aspects, use cases, challenges and research directions," *Journal of Industrial Information Integration*, p. 100404, 2022.
[36] B. Ji, Y. Han, S. Liu, F. Tao, G. Zhang, Z. Fu, and C. Li, "Several key technologies for 6g: Challenges and opportunities," *IEEE Communications Standards Magazine*, vol. 5, no. 2, pp. 44–51, 2021.
[37] S. Basharat, S. A. Hassan, H. Pervaiz, A. Mahmood, Z. Ding, and M. Gidlund, "Reconfigurable intelligent surfaces: Potentials, applications, and challenges for 6g wireless networks," *IEEE Wireless Communications*, vol. 28, no. 6, pp. 184–191, 2021.
[38] R. Chen, M. Chen, X. Xiao, W. Zhang, and J. Li, "Multi-user orbital angular momentum based terahertz communications," *IEEE Transactions on Wireless Communications*, 2023.
[39] C. Huang, S. Hu, G. C. Alexandropoulos, A. Zappone, C. Yuen, R. Zhang, M. Di Renzo, and M. Debbah, "Holographic mimo surfaces for 6g wireless networks: Opportunities, challenges, and trends," *IEEE Wireless Communications*, vol. 27, no. 5, pp. 118–125, 2020.
[40] D.-N. Vu, N.-N. Dao, W. Na, and S. Cho, "Dynamic resource orchestration for service capability maximization in fog-enabled connected vehicle networks," *IEEE Transactions on Cloud Computing*, vol. 10, no. 3, pp. 1726–1737, 2020.
[41] D.-N. Vu, N.-N. Dao, Y. Jang, W. Na, Y.-B. Kwon, H. Kang, J. J. Jung, and S. Cho, "Joint energy and latency optimization for upstream iot offloading services in fog radio access networks," *Transactions on Emerging Telecommunications Technologies*, vol. 30, no. 4, p. e3497, 2019.
[42] B. Smida, A. Sabharwal, G. Fodor, G. C. Alexandropoulos, H. A. Suraweera, and C.-B. Chae, "Full-duplex wireless for 6g: Progress brings new opportunities and challenges," *arXiv preprint arXiv:2304.08789*, 2023.