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A Detailed Overview of 6G and Related Technologies

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ABSTRACT

While fifth-generation wireless communication system (5G) implementation is an ongoing process and many devices are coming up that support 5G, the next generation of communication technology research, sixth-generation wireless communication system (6G), is already underway. 6G is not only going to be 100 times faster than the current generation of wireless communication network, 5G, but is also going to open a world of possibilities for other technologies, and it can prove to be a platform for future technologies to be developed and enhanced on. However, there are also some challenges related to the implementation of 6G, and in this paper, we will be discussing those challenges and the possible solutions.

***Index Terms*—**6G, artificial intelligence, communication networks, mixed reality, neurosciences, self-driving cars

I. INTRODUCTION

In the next decade, we might be seeing probably the biggest technology revolution ever, and the revolution will be caused by faster data transfer rates. Right now, a common man has connectivity to fourth-generation wireless communication system (4G) and 4G long-term evolution internet speeds. However, fifth-generation wireless communication system (5G) is being implemented gradually, while some developed countries already have access to the 5G technology. We also have various technologies which will work on the 5G communication framework. These devices include robots, smartphones, car infotainment, self-driving systems, and so on [1]. However, now that the implementation process of 5G is underway, research on the next communication technology, sixth-generation wireless communication system (6G), is happening and researchers have covered a lot of ground in a massive amount of work [2]. Speaking of the 6G network communication technology, several very significant requirements are needed to be considered. 6G needs to be exponentially fast as compared to previous generations, to provide a base for future technologies like self-driving vehicles, advanced augmented reality and virtual reality applications, advanced robotics, Internet of Everything (IoE), unmanned aerial vehicles (UAV), and many other highly anticipated technologies [3]. For that, 6G has to move away from the millimeter (mm) waves that were used in the propagation of 5G to terahertz waves. Speaking of the speeds, we can expect data transfer rates to be more than 20 GB/s [4]. To put that into perspective, the data speeds in 6G will be around 100–1000 times faster than the speeds offered by 5G, a technology that is nearing its release and implementation. Also, 6G offers extremely low latency and much higher reliability as compared to 5G [5,6]. A comparison between 4G, 5G, and 6G is shown in Table I.

A. 6G and Artificial Intelligence

The reason why 6G would be extremely different than previous data communication technologies is due to the fact that artificial intelligence (AI) is one of the most significant components of its entire framework [7,8]. Also, 6G will help power many AI- and Big Data-based applications in the coming future [7]. But, the important question is that why is AI so important for the development and deployment of the 6G networks? In 5G networks, there are a number of new configurable parameters defined. However, when we talk about the 6G network and radio, the technical requirements for its development and deployments are going to be so complex that there are going to be many new configurable parameters that are based on the latest technical requirements [9]. To fulfill future necessities related to 6G networks, the configurable waveform parameters vary, depending on the requirements [10]. We have discussed how 6G will be using

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TABLE I. A COMPARISON BETWEEN 4G, 5G AND 6G NETWORKS [16]

Issue	4G	5G	5G
Per Device Peak Data Rate	1 Gbps	10 Gbps	1 Tbps
End-to-End (E2E) Latency	100 ms	10 ms	1 ms
Maximum Spectral Efficiency	15 bps/Hz	30 bps/Hz	100 bps/Hz
Mobility Support	Up to 350 km/hr	Up to 500 km/hr	Up to 1000 km/hr
Satellite Integration	No	No	Fully
AI	No	Partial	Fully
Autonomous Vehicle	No	Partial	Fully
XR	No	Partial	Fully
Haptic Communication	No	Partial	Fully
THz Communication	No	Very Limited	Widely
Service Level	Video	VR, AR	Tactile
Architecture	MIMO	Massive MEMO	Intelligent Surface
Maximum Frequency	6 GHz	90 GHz	10 THz

terahertz waves for its transmission and propagation. However, due to the extremely low range of these types of waves, the need for complex signal-processing algorithms is rather obvious [11]. Also, signal processing must be done in collaboration with deep learning in order to improve reliability, range, data rates, adaptability, and convergence [12].

The use of deep learning can also help in lowering the computational requirements for 6G communication in order to make this revolutionary communication technology accessible for everyone [2,13].

II. 6G APPLICATIONS

6G is not just about fast data rates or fast internet speeds, it also brings a wide array of technologies with it, and in this portion [14], we will be discussing the technologies that we might be able to see with the advent of 6G communication.

A. 6G and Self-Driving Cars

One aim of 6G networks is to improve machine-to-machine communication [15]. Also, many engineers and entrepreneurs dream that one day, our traffic will become completely autonomous. It is a very expansive form of device-to-device communication and it has to be very reliable [16]. This system can prove to be very beneficial, as a person who was supposed to drive his car can just sit behind, do his work, make his commute productive, and the car can drive itself and reach its destination. Even though we have self-driving or autopilot mechanisms in many cars, such as Tesla Motors, however, they still require driver input as most cars on the road are incompatible with the respective technology, and even if they are, they are unable to harmonize. As a result, engineers have started working on ways to create this ecosystem, where every car is coordinated via a network spectrum, therefore, the traffic flows at a stable pace and which will also reduce the risk of accidents. This is the vision of autonomous driving that many entrepreneurs work on day and night. This can also facilitate terrestrial trade, in which vehicles would not need drivers, and transportation of vehicles can happen 24 hours a day without any interruption. However, the current technology limitations do not allow this coordination. For such rapid and real-time communication between vehicles, there needs to be an extremely fast and reliable network that has very low latency and very high reliability [17]. The reason why it is so important is that if there is ever a drop in connectivity, this can lead to many car accidents as all cars in traffic become autonomous. This makes this autonomous transportation system impossible in either 4G or 5G, which does have much higher reliability compared to 4G, but the latency and reliability are not enough to make this system completely autonomous and implementable [1]. This is the reason why 6G is going to bring a revolution in daily transportation to fulfill the vision of a completely autonomous traffic system. 6G has just 10th of the latency of 5G, and it is 100 times more reliable than 5G. Also, 6G has the capacity to support 10 times more devices per area than 5G, which means that a vast quantity of data can be collected from a huge amount of devices and stored. Through such advanced and real-time Internet of Things (IoT), cars can coordinate with each other, and therefore, with 6G, we can realize the vision of a fully autonomous vehicle transportation system that saves a lot of manpower and will be much more organized as compared to human-driven car traffic.

B. Mixed Reality and 6G

Virtual reality (VR), has been around for some time now. The VR technology we are seeing today is far from its true potential, and we can have a good idea of how great VR can be. It imitates a scenario or a background right before our eyes through VR headsets that give us a 360° view of the scenario through the help of a gyroscope sensor, which is integrated into smartphones and headsets which support VR. On the other hand, we have augmented reality (AR), which can visualize certain imaginary objects in real scenarios. We have seen many smartphones having basic augmented reality (AR) features in their cameras. But, AR and VR, which can be called mixed reality (MR), are much more capable and useful. Mixed reality can change the way we shop, with headsets that can scan certain products in a shop through its barcodes and search the internet for their price and reviews, and display it in real-time. Mixed reality can also help us recognize people in real time as the headset will scan their faces and will tell you the necessary information about them. Other than that, MR can also make driving easy, if we are not opting for autonomous driving. It can show us map directions right before our eyes while driving, and in this way, we would not have to take our eyes off the road in order to check the map for directions. It can also change the entertainment and gaming industry. With the advancement of MR through the fast data rates and extremely low latency of 6G networks, the way people play games can be changed. Games will be permanently shifted to MR to provide a much more realistic experience. Also, movies can be switched to VR in order to avoid noise pollution. In that way, 6G can be used to create a sustainable environment. Last but not the least; MR can be integrated with our smartphone so that we can just scan a certain object to know its name, price (if it is a product), and other specifications. We also have certain apps that use AR to do that, and this technology will only be improved with the advent of 6G communication technology [18].

C. Smartphone and 6G

One of the biggest selling points of 6G is its incredibly fast speed, which is over 100 times faster than 5G, which is still in the early

stages of implementation [19]. But, data speed is not the main topic of conversation. The smartphones we use may no longer be the same as well. Holographic screens have been tried out by companies in the past where they have tried to replace touch screens with holographic displays. However, due to the high latency of 4G, holographic displays could not work out in the past. But with 6G, latency can be as low as 0.1 ms, which is 10 times lower than the latency of the fastest 5G network [20]. Therefore, we might be able to see holographic displays to work as well as normal Organic Light Emitting Diodes (OLED) or Liquid Crystal Display (LCD) touch displays that are used today [21]. 6G can also possibly use blockchain-based communication and because blockchain is already poised to play a huge role in digital currency as well, this is a technology that we can look forward to [22,23]. Considering the fact that we want the network to be secure from any kind of data tampering, we can consider edge caching involving cutting-edge technologies like blockchain and physical layer security that can help prevent the corruption of data and can contribute to a more reliable, secure solution [24].

D. 6G and Neurosciences

Brain computing is the future, although a large number of the population refuses to acknowledge its need. Brain computing can be revolutionary in the field of medical sciences, where brain-controlled robots can perform surgical procedures if the surgeon is unavailable. Also, it can help paralyzed individuals live a better life. Advances have been made by scientists all around the world, and there are also modules that can perform basic tasks and can highlight the potential of this technology. However, we are living in the 4G era, as of now, 5G implementation is encountering many limitations, which is the reason why the current communication technology is not available for most of the users. Another issue with 4G is its very high latency, which will be problematic for something like brain computing that requires extremely low latency and very high data rates. 5G will bring a lot of great advancements to brain computing, but this cannot be achieved due to the limitations related to the transmission of millimeter waves and comparatively lower latency for a real-time brain-related robotic experience. With ultralow latencies offered by 6G networks, we will be able to see the true power of brain computing and how it can revolutionize brain-controlled robotics and systems. The latency is going to be the tenth of what is being offered by 5G, making it almost instant and real-time which implies near-zero response time [25]. In Fig. 1, we can see the massive array of possibilities that can occur in the era of low-latency 6G networks.

III. CHALLENGES RELATED TO 6G NETWORK'S IMPLEMENTATION

Even though 6G and Beyond-5G (B5G) are going to bring a massive technology revolution, but, for that to happen, the technology must be implemented in such a way that it is easily accessible for a common user [26]. Right now, we have many limitations and challenges in the implementation of 5G and the problem is exacerbated only if no suitable solution is found to properly implement the next-generation network which is B5G and 6G [27]. As discussed in this paper previously, the 5G communication is based on millimeter waves or gigahertz waves, which is the reason why the implementation of 5G is taking much longer than it was supposed to take [28]. Many countries which are densely populated and cannot afford the amount of investment 5G requires might not even get access to the technology, a very alarming possibility. A common phenomenon of physics states that the higher the frequency is, the lower the range of propagation that particular signal gets [29]. Also, the higher the frequency is, the easier it is for objects to block the signals. This is the reason why in densely populated areas, implementation of 5G is almost impossible through conventional methods. To test the range of 5G, companies like Ericsson and Qualcomm conducted many experiments to test the range of millimeter waves, which will be the waves that will transfer the data at a high data rate, which is around 10–20 Gbps on its maximum capability [30]. However, the results received from these experiments were not satisfactory due to some reasons [31]. The signals traveled from just 3 km to 6 km, depending on the density of that particular area. Even if we exaggerate the numbers to be optimistic about 5G, which is being implemented at the moment, the range will not extend beyond 10 km in any way. Therefore, lots of antennas will have to be installed in urban cities in order to implement 5G to some extent. But, that would not be feasible, convenient, or cost-effective [32]. With the current methods of 5G propagation, only developed, organized, and advanced research-oriented countries can get access to 5G. The abovementioned solution is not very feasible, convenient, or cost-effective that leads to the unavailability of 5G all the time. To put that into perspective, the smartphones these days that support 5G have a variable chipset, which means that if the signals are not strong enough for 5G, the phone will switch to 4G or even 3G. These limitations in the implementation of 5G not only limits us from future technologies like low-latency robots, self-driving system, brain computing, and MR to name a few, it also shows that the implementation of B5G and 6G will be extremely difficult if a proper implementation solution is not found [33]. 6G will be working on signals that have frequency bands ranging from 100 GHz to 1 THz. This shows that 6G will lie in the terahertz range. In comparison, 5G and B5G use millimeter or sub-millimeter waves for data communication [34]. In this range, very high data rates can be achieved, which are expected to have 100 times the data rate than the fastest 5G connection, 10 times lower latency, 10 times more device density which is going to take IoT to the next level, and 100 times the current reliability. But, as we discussed previously 5G is encountering range issues and a huge part of the world would probably never be able to use 5G. As a matter of fact, to avoid the power loss for millimeter waves, companies chose the solution of lowering the bandwidth below millimeter waves as power losses from rain, oxygen molecules, and humidity would not affect lower bands, which has frequency bands of 600 MHz, 800 MHz, and 900 MHz, and medium bands, which has frequency bands of 2.5 GHz, 3.5 GHz, and 4.2 GHz [35,36]. However, lowering the bandwidth has its consequences. Therefore, with so many limitations for 5G, we can confirm that antenna-based implementation of 6G networks and even B5G with a frequency band lower than millimeter waves is not an ideal approach.

Another challenge that comes with every generation of wireless technology is its lack of support for the rural areas. In the rural areas of many developed and developing countries, users do not even have proper access to 4G, and with the implementation of 5G, the people in rural areas are two generations behind the current technology trend. They have to travel to network towers in order to get internet signals. Browsing the web is not a very feasible thing for them to do. Most of the people living in rural areas around the world have never spoken to someone on a video call. The rural areas have the potential to develop if they are given access to technologies, but implementing technologies like 5G over there is a huge investment and companies never seem interested to develop an underdeveloped area with situations as described. With 6G, it is important to

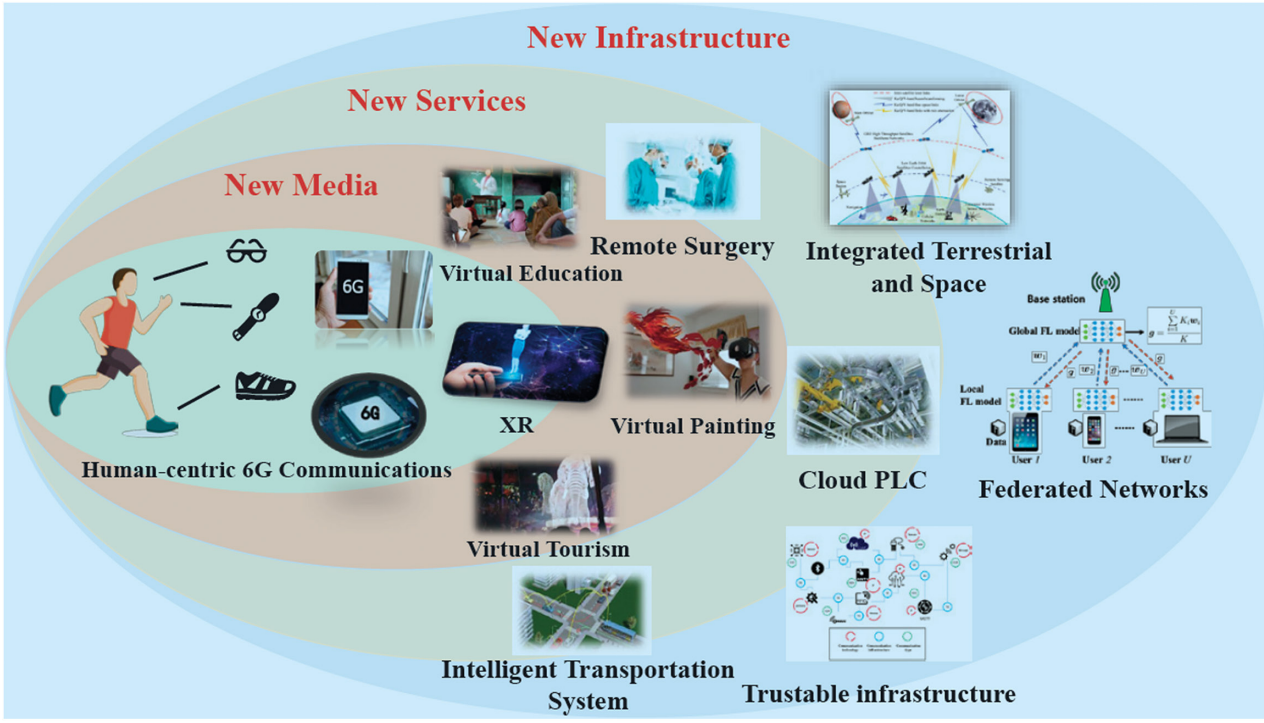

Fig. 1. Different potential applications of 6G [10].

develop the rural areas and bring technology advancements in fields like agriculture and ease the work of farmers through surveying their crops while standing at one place with the help of a UAV network which will be a part of a non-terrestrial 6G system [26]. 6G will also help farmers to get introduced to new agricultural techniques as it is really important to make agriculture more efficient. The power of the internet not only improves farming efficiency but also allows children to homeschool, eliminating the need to drive a lot to schools, which is a major problem in countries like India, Bangladesh, and Pakistan to name a few.

IV. 6G IMPLEMENTATION SOLUTIONS

We discussed the limitations with the implementation of 5G and how 6G's implementation would become impossible if it is implemented in the same way as 5G and 4G are being implemented. Therefore, in this portion of this paper, possible solutions for the efficient and effective implementation of 6G will be discussed. Firstly, the paper will be discussing terrestrial implementation solutions.

A. Wireless Mobile Radio Implementation

Rural areas have always missed out on proper stable broadband connections, which is why they are not able to download and upload an unlimited amount of data on the internet. They have always had to rely on mobile networks, which provide them with a limited amount of data, and due to their financial limitations, they can rarely use the internet. With the implementation of 6G in urban and especially in rural areas, it is important to implement a solution through which even hardly accessible areas can access high-speed data transfers. One immediate solution could be multiple 6G transmitters installed on tall structures like a TV tower which can provide signals to that particular rural area [28]. Code index modulation and spatial modulation can be used in this transmission to achieve high data rate and energy efficiency [37]. These transmission spots can be used as mega coverage cells which can transmit 6G signals to the whole rural area. This would not require as much investment as there is no structure being built for the network and an already existent tall structure can be used for the setup of that mega cell [38]. Considering the low population and low data usage in rural areas, data can also be stored using caching and slicing for future use. This can be used by the user and it can also be used for IoT purposes [39]. Also, for rural areas, there can be flexible frequency bandwidths which will improve connectivity in such rural areas [40,41].

Now, a non-terrestrial way of implementation of 6G will be discussed.

B. Satellites

For proper 6G propagation not only in rural but also in urban areas, satellites can be a very feasible solution to look forward to. China has already sent out its first satellite to experiment with the non-terrestrial spread of 6G terahertz waves. There are many ways in which the non-terrestrial spread of the terahertz waves can be achieved; one of them is that the satellite can act as a mega cell that is connected to several UAV nodes in the orbit, making a global terahertz spectrum as shown in Fig. 2 [42]. The way the 6G satellite network can work is by having multiple cell levels. As shown in Fig. 3, we can divide the system into four subcells: pico-cell, microcell, macro-cell, and the outermost level will be the satellite cell. Currently, there is no proper satellite-based transmission system for 5G, this is just a concept and as mentioned above, China is investing and experimenting with this method [43].

C. Artificial Intelligence to Air Interface

Artificial intelligence is one of the most important technologies to talk about whenever the base and framework of 6G is discussed.

Considering the huge limitations in the implementation of not only 6G, but also B5G, which will be a sub-upgrade in the global wireless data communication system, collaborative AI is going to play an important role [44]. The goal is to turn devices like smartphones and other electronic devices into transceivers so that the terahertz waves of 6G can be received and used without sacrificing much on data rates. The devices like smartphones can have a board in them which will help in the radio transmission of 6G signals. In the future, graphics processing units (GPUs) in smartphones are going to be very powerful; hence, these GPUs will contribute to running intensive machine learning algorithms. This board can also contain its central processing unit, GPU, and field-programmable gate array for independent processing. In that way, phones could act both as transceivers and receivers.

D. Reconfigurable Intelligent Surfaces and Meta-Surfaces

One of the limitations of terahertz waves is that it has a very narrow effective beam, which is why a line of sight is required between the sender and receiver. This can be done by implementing reflectors that can reflect beams around blockages, improving the transmission range in the process. In this way, we will be able to improve terahertz wave propagation in an indoor environment massively. To avoid the obstacles, we will be using meta-surface tunnels [45]. Meta-surfaces are artificial sheets having a sub-wavelength thickness. It can be both structured and unstructured. Meta-surfaces help in the effective propagation of waves. We can have a top view camera that can highlight various signal blockages through image segmentation, like water droplets, vapors, or any other gas which is blocking the path of the wave. Then, with the help of reflectors, these blockages can be avoided to promote better indoor wave propagation [46]. Another way in which wave propagation can be improved is by including intelligent reconfigurable surfaces in the architecture of future buildings. We know how the surrounding object's interaction with radio waves deteriorates the received signal. This problem worsens with the increase in frequency. A considerable solution to this problem is to install reconfigurable intelligent surfaces all around the indoor area, as it can control all the wavefront like phase, frequency, and so on, and improve wave propagation with low power loss [47,48].

V. CONCLUSION

In this paper, we learned about terahertz waves which will enable astronomically high data rates. We also studied the plethora of possibilities and applications which can be seen after the development and deployment of the 6G communication network in the upcoming future. 6G is going to do wonders in the fields of robotics, AI, IoT, IoE, telecommunication, and brain computing. However, the issues we are facing during the ongoing 5G network implementation need to be solved and measures must be taken to improve network propagation solutions so that the upcoming communication technologies like B5G and 6G can be implemented properly and become accessible to the masses. 6G is still a technology that is under research and even though billions of dollars have been invested in it, its research is still in an initial state and there will be many possibilities and challenges that will get unfolded as we proceed in the research of 6G. 6G

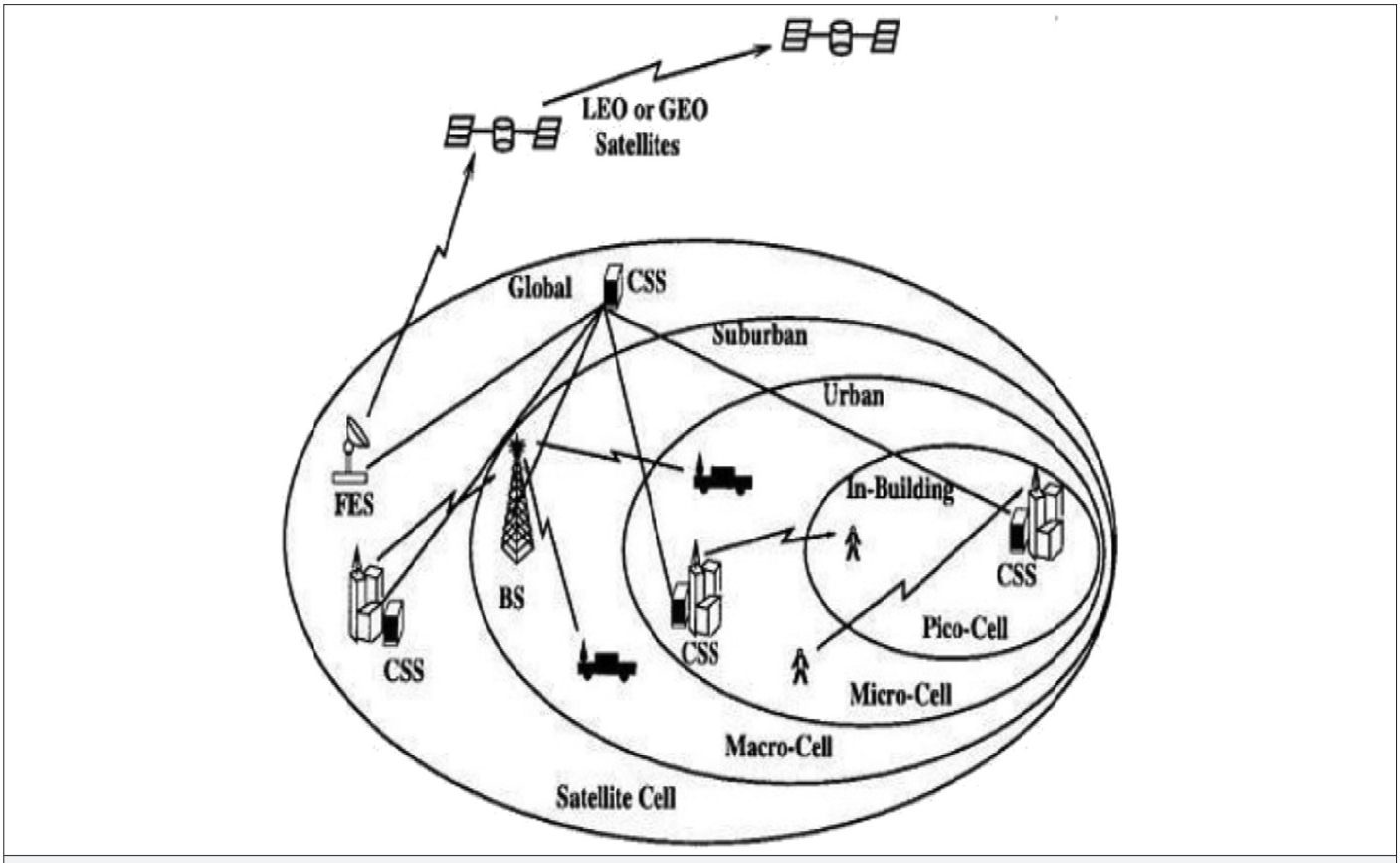

Fig. 2. 6G implementation using satellite-based network [43].

is a technology that will define how the decade between 2030 and 2040 will be like. We can get an idea about the possible technologies we will be able to see 15–25 years from now.

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REFERENCES

1. L. U. Khan, I. Yaqoob, M. Imran, Z. Han, and C. S. Hong, "6G wireless systems: A vision, architectural elements, and future directions," *IEEE Access*, vol. 8, pp. 147029–147044, 2020. [CrossRef]
2. H. Viswanathan and P. E. Mogensen, "Communications in the 6G era," *IEEE Access*, vol. 8, pp. 57063–57074, 2020. [CrossRef]
3. L. Zhang, Y. Liang, and D. Niyato, "6G Visions: Mobile ultra-broadband, super internet-of-things, and artificial intelligence," *China Commun.*, vol. 16, no. 8, pp. 1–14, 2019. [CrossRef]
4. G. Gui, M. Liu, F. Tang, N. Kato, and F. Adachi, "6G: Opening new horizons for integration of comfort, security, and intelligence," *IEEE Wirel. Commun.*, vol. 27, no. 5, pp. 126–132, 2020. [CrossRef]
5. S. Zhang, C. Xiang, and S. Xu, "6G: Connecting everything by 1000 times price reduction," *IEEE Open J. Veh. Technol.*, vol. 1, 107–115, 2020.
6. I. F. Akyildiz, A. Kak, and S. Nie, "6G and beyond: The future of wireless communications systems," *IEEE Access*, vol. 8, pp. 133995–134030, 2020. [CrossRef]
7. K. B. Letaief, W. Chen, Y. Shi, J. Zhang, and Y. A. Zhang, "The roadmap to 6G: AI empowered wireless networks," *IEEE Commun. Mag.*, vol. 57, no. 8, pp. 84–90, 2019.
8. T. B. Ahammed and R. Patgiri, "6G and AI: The emergence of future forefront technology," *Adv. Commun. Tech. Signal Process. (ACTS)*, vol. 2020, pp. 1–6, 2020. [CrossRef]
9. A. Yazar and H. Arslan, "A waveform parameter assignment framework for 6G with the role of machine learning," *IEEE Open J. Veh. Technol.*, vol. 1, pp. 156–172, 2020. [CrossRef]
10. Y. Liu, X. Yuan, Z. Xiong, J. Kang, X. Wang, and D. Niyato, "Federated learning for 6G communications: Challenges, methods, and future directions," *China Commun.*, vol. 17, no. 9, pp. 105–118, 2020. [CrossRef]
11. S. Wang, T. Sun, H. Yang, X. Duan, and L. Lu, "6G network: Towards a distributed and autonomous system," in 2nd 6G Wireless Summit (6G SUMMIT), vol. 2020, 2020, pp. 1–5. [CrossRef]
12. A. Jagannath, J. Jagannath, and T. Melodia, "Redefining wireless communication for 6G: Signal processing meets deep learning," *arXiv*, p. 2004.10715, 2020 [Online]. Available: http://arxiv.org/abs/2004.10715.
13. C. She et al., "A tutorial on ultrareliable and low-latency communications in 6G: Integrating domain knowledge into deep learning," *Proc. IEEE*, vol. 109, no. 3, pp. 204–246, 2021. [CrossRef]
14. C. Yizhan, W. Zhong, H. Da, and L. Ruosen, "6G is coming: Discussion on key candidate technologies and application scenarios," in Int. Conf. Comput. Commun. Network Security (CCNS), vol. 2020, 2020, pp. 59–62. [CrossRef]
15. N. H. Mahmood, H. Alves, O. A. López, M. Shehab, D. P. M. Osorio, and M. Latva-Aho, "Six key features of machine type communication in 6G," in 2nd 6G Wireless Summit (6G SUMMIT), vol. 2020, 2020, pp. 1–5. [CrossRef]
16. S. Zhang, J. Liu, H. Guo, M. Qi, and N. Kato, "Envisioning device-to-device communications in 6G," *IEEE Network*, vol. 34, no. 3, pp. 86–91, 2020. [CrossRef]
17. S. Liao and L. Ou, "High-speed millimeter-wave 5G/6G image transmission via artificial intelligence," in IEEE Asia Pac. Microwave Conf. (APMC), vol. 2020, 2020, pp. 655–657. [CrossRef]
18. M. E. Leinonen, M. Jokinen, N. Tervo, O. Kursu, and A. Pärssinen, "Radio interoperability in 5G and 6G multiradio base station," in 92nd Veh. Technol. Conference (VTC2020-Fall), Victoria, BC, Canada, vol. 2020. IEEE Publications, 2020, pp. 1–5. [CrossRef]
19. J. Zhu, M. Zhao, S. Zhang, and W. Zhou, "Exploring the road to 6G: ABC — Foundation for intelligent mobile networks," *China Commun.*, vol. 17, no. 6, pp. 51–67, 2020. [CrossRef]
20. W. Saad, M. Bennis, and M. Chen, "A vision of 6G wireless systems: Applications, trends, technologies, and open research problems," *IEEE Network*, vol. 34, no. 3, pp. 134–142, 2020. [CrossRef]
21. M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 957–975, 2020. [CrossRef]
22. R. Sekaran, R. Patan, A. Raveendran, F. Al-Turjman, M. Ramachandran, and L. Mostarda, "Survival study on Blockchain based 6G-enabled mobile edge computation for IoT automation," *IEEE Access*, vol. 8, pp. 143453–143463, 2020. [CrossRef]
23. T. Nguyen, N. Tran, L. Loven, J. Partala, M. Kechadi, and S. Pirttikangas, "Privacy-aware Blockchain innovation for 6G: Challenges and opportunities," in 2nd 6G Wireless Summit (6G SUMMIT), Levi, Finland, vol. 2020, 2020, pp. 1–5. [CrossRef]
24. W. Sun, S. Li, and Y. Zhang, "Edge caching in blockchain empowered 6G," *China Commun.*, vol. 18, no. 1, pp. 1–17, 2021. [CrossRef]
25. R. C. Moioli et al., "Neurosciences and 6G: Lessons from and needs of communicative brains," *arXiv*, p. 2004.01834, 2020.
26. W. Jiang, B. Han, M. A. Habibi, and H. D. Schotten, "The road towards 6G: A comprehensive survey," *IEEE Open J. Commun. Soc.*, vol. 2, pp. 334–366, 2021. [CrossRef]
27. G. Wikström et al., "Challenges and technologies for 6G," in 2nd 6G Wireless Summit (6G SUMMIT), vol. 2020, 2020, pp. 1–5. [CrossRef]
28. M. S. Sim, Y. Lim, S. H. Park, L. Dai, and C. Chae, "Deep learning-based mmWave beam selection for 5G NR/6G with Sub-6 GHz channel information: Algorithms and prototype validation," *IEEE Access*, vol. 8, pp. 51634–51646, 2020. [CrossRef]
29. A. Ramírez-Arroyo, P. H. Zapata-Cano, A. Palomares-Caballero, J. Carmona-Murillo, F. Luna-Valero, and J. F. Valenzuela-Valdés, "Multilayer network optimization for 5G & 6G," *IEEE Access*, vol. 8, pp. 204295–204308, 2020. [CrossRef]
30. S. Zhang, G. Wang, and C. I, "Is mmWave ready for cellular deployment?," *IEEE Access*, vol. 5, pp. 14369–14379, 2017. [CrossRef]
31. Ericsson, "Ericsson, Qualcomm and U.S. Cellular achieve extended-range 5G data call over mmWave," SEP. 17, 2020. Available: https://www.ericsson.com/en/press-releases/2020/9/ericsson-qualcomm-and-u.s.-cellular-achieve-extended-range-5g-data-call-over-mmwave.
32. P. Chatzimisios, D. Soldani, A. Jamalipour, A. Manzalini, and S. K. Das, "Special issue on 6G wireless systems," *J. Commun. Netw.*, vol. 22, no. 6, pp. 440–443, 2020. [CrossRef]
33. V. Raghavan and J. Li, "Evolution of physical-layer communications research in the post-5G era," *IEEE Access*, vol. 7, pp. 10392–10401, 2019. [CrossRef]
34. L. Zhu, Z. Xiao, X. Xia, and D. Oliver Wu, "Millimeter-wave communications with non-orthogonal multiple access for B5G/6G," *IEEE Access*, vol. 7, pp. 116123–116132, 2019. [CrossRef]
35. J. Heinonen, P. Korja, T. Partti, H. Flinck, and P. Pöyhönen, "Mobility management enhancements for 5G low latency services," in IEEE Int. Conf. Commun. Work. (ICC), vol. 2016, 2016, pp. 68–73. [CrossRef]
36. W. Hong et al., "The role of millimeter-wave technologies in 5G/6G wireless communications," *IEEE J. Microw.*, vol. 1, no. 1, pp. 101–122, 2021. [CrossRef]
37. F. Cogen, E. Aydin, N. Kabaoglu, E. Basar, and H. Ilhan, "Generalized code index modulation and spatial modulation for high rate and energy-efficient MIMO systems on Rayleigh block-fading channel," *IEEE Syst. J.*, vol. 15, no. 1, pp. 538–545, 2021. [CrossRef]
38. S. Chen, S. Sun, and S. Kang, "System integration of terrestrial mobile communication and satellite communication—The trends, challenges and key technologies in B5G and 6G," *China Commun.*, vol. 17, no. 12, pp. 156–171. 2020. [CrossRef]
39. E. Yaacoub and M. Alouini, "A key 6G challenge and opportunity—Connecting the base of the pyramid: A survey on rural connectivity," *Proc. IEEE*, vol. 108, no. 4, pp. 533–582, 2020. [CrossRef]
40. Y. L. Lee, D. Qin, L. -C. Wang, and G. H. Sim, "6G massive radio access networks: Key applications, requirements and challenges," *IEEE Open J. Veh. Technol.*, vol. 2, pp. 54–66, 2021. [CrossRef]
41. S. Yan, X. Cao, Z. Liu, and X. Liu, "Interference management in 6G space and terrestrial integrated networks: Challenges and approaches," *Intell. Converged Netw.*, vol. 1, no. 3, pp. 271–280, 2020. [CrossRef]

42. G. Charbit, D. Lin, K. Medles, L. Li, and I. Fu, "Space-terrestrial radio network integration for IoT," in 2nd 6G Wireless Summit (6G SUMMIT), vol. 2020, 2020, pp. 1–5. [CrossRef]
43. D. Kalbande, Z. Khan, S. Haji, and R. Haji, "6G-next Gen mobile wireless communication approach," in 3rd Int. Conf. Electron. Commun. Aerospace Tech. (ICECA), vol. 2019, 2019, pp. 1–6. [CrossRef]
44. S. Han et al., "Artificial-intelligence-enabled air interface for 6G: Solutions, challenges, and standardization impacts," *IEEE Commun. Mag.*, vol. 58, no. 10, pp. 73–79, 2020. [CrossRef]
45. C. Liaskos, S. Nie, A. Tsioliaridou, A. Pitsillides, S. Ioannidis, and I. Akyildiz, "A new wireless communication paradigm through software-controlled metasurfaces," *IEEE Commun. Mag.*, vol. 56, no. 9, pp. 162–169, 2018. [CrossRef]
46. M. Pengnoo, M. T. Barros, L. Wuttisittikulkij, B. Butler, A. Davy, and S. Balasubramaniam, "Digital twin for metasurface reflector management in 6G terahertz communications," *IEEE Access*, vol. 8, pp. 114580–114596, 2020. [CrossRef]
47. E. Basar, "Reconfigurable intelligent surface-based index modulation: A new beyond MIMO paradigm for 6G," *IEEE Trans. Commun.*, vol. 68, no. 5, pp. 3187–3196, 2020.
48. E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M. Alouini, and R. Zhang, "Wireless communications through reconfigurable intelligent surfaces," *IEEE Access*, vol. 7, pp. 116753–116773, 2019. [CrossRef]

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