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Technology Advancements in 6G Communications and Expected Consequences in Multiple Industries

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***Abstract*—**This research paper utilizes a systematic literature review methodology, drawing from the Scopus database and VOSViewer analysis, to investigate the current landscape of 6G telecommunications research and its potential implications. Our findings indicate that 6G technology is poised to revolutionize wireless communication, with significant ramifications for key sectors such as autonomous vehicles, transportation, and manufacturing, ushering in an era of unprecedented connectivity and operational efficiency. A notable trend is the growing interest among researchers in critical technical aspects, including bandwidth, latency, signal processing, spectrum management, spectral efficiency, Intelligent Reflecting Surfaces (IRS), meta-communication, and beamforming. Geographically, China and the United States lead in 6G research, reflecting a global competition to harness its transformative potential. Most researchers driving innovation in this field have engineering and computer science backgrounds. We anticipate the widespread deployment of 6G technology by 2030, with ongoing research efforts focusing on diverse implementation techniques across industries. Expected advancements encompass Machine-to-Machine (M2M) communication, Massive Multiple Input Multiple Output (mMIMO) systems, IRS utilization, novel waveform technologies, meta-communication, Orthogonal Time Frequency Space (OTFS) modulation, Generalized Frequency Division Multiplexing (GFDM), and the integration of Low-Density Parity-Check (LDPC) codes, all poised to enhance network speed and reduce latency significantly. Furthermore, the Metaverse is expected to experience exponential growth, driven by the capabilities of the 6G network. This paper contributes original insights to the burgeoning field of 6G telecommunications, offering a comprehensive overview of its current status and potential implications across various domains, particularly in management.

***Keywords*—**Autonomous vehicles, Bandwidth, Bean forming, IRS, Latency, Signal processing, and Spectrum, Virtual reality

I. INTRODUCTION

The excitement of 5G rollout in India has reached its pinnacle. The rollout is expected to augment the telecom services in India. The service expectations are not limited to watching a movie or playing a game on mobile but to enable high speed applications on mobile. Similar to all technological innovations, there is expectation from customers about the next wave of technology in the telecom sector. Telecom aficionados predict that the 6G evolution will deliver speedier and more effective telecom services. Though 5G implementation is still going on in certain countries, it was felt to have a more robust communication system that is faster, lower latency and consistent reliability. Telecom corporations were under pressure to set aside a percentage of their profits for R&D because future services will need reliable telecom equipment. According to predictions, internet 2.0 applications like virtual reality, augmented reality, autonomous vehicles, remote surgery, etc. will all be supported by 6G technology.

II. LITERATURE REVIEW

A. Virtual Reality (VR) in 6G Ecosystem

Virtual Reality (VR) is a simulated experience that provides an immersive experience of the virtual world (Wikipedia, 2023). The VR technology requires high speed internet as well as superior connectivity for real time collaboration. This is exactly the 6G architecture expected to be built. The 6G will allow customers to utilize it for social media immersive experience. Though customers currently browse social media, 6G will increase the speed of connectivity and provide a better experience. This also helps VR developers to build high resolution applications coupled with Artificial Intelligence (AI) to enhance customer experience. VR applications using Haptic technology are anticipated to change the shopping landscape in the future. In Haptic technology, customers wearing gloves can touch, understand the pressure, feel the temperature and know security nuances (Price et al, 2021). This brings physical shopping experience in the virtual world.

B. 6G and Autonomous Vehicles

Autonomous vehicles are the buzz world in the automobile world. The search results on the internet exhibit the craze for these vehicles. These vehicles utilize computer vision and LIDAR technology to have smooth rides (He, J., Yang, K., & Chen, H. H., 2020). However, the current 5G technology has serious limitations in providing seamless driving experience. These limitations may be overcome from 6G technology (Mahmoud, H. H. H., Amer, A. A., & Ismail, T., 2021). 6G communications will offer higher data speeds and lower latency. Thus improves the Machine to machine(M2M) communications (Yang, C., Xiang, Y., Li, W., & Wang, Z., 2020). Further, the success of autonomous vehicles was decided based on its ability to understand traffic lights and road sensors that empower real time complex navigation systems (Prathiba, S. B. et al., 2022). Added to this, lidar, radar, and cameras on which autonomous cars are built will boost with additional bandwidth in the 6G environment. This is expected to have lesser interference from other wireless signals. Autonomous vehicles face significant network challenges when they pass through tunnels and high mountains due to poor telecom connections. 6G is expected to cover such areas too (Wang, C. X. et al., 2022). The timely M2M among autonomous vehicles will reduce accidents. More than this faster and reliable communication from 6G infrastructure on weather and road conduction expected to reduce the fatality on roads.

C. 6G in Manufacturing

Industrial automation is happening at a brisk pace. These efforts are encircled around machines, robots and human beings. This has necessitated the need for seamless communication between various stakeholders. Hence, the need for 6G is felt in the manufacturing sector. The uninterrupted M2M communication ensures better predictive maintenance (Mezair, T et al, 2022). Further, a robust 6G communication supports remote operations of machines and is expected to improve the production efficiency (Lu, Y., & Zheng, X., 2020). More than these, 6G is expected to be a backbone of digital twins of production processes and allows for simulation and optimization processes in a real time.

D. 6G and Transport Sector

The improved M2M communication increases road efficiency of vehicles and in turn results in lesser number of accidents (Song, W et al, 2022). M2M also makes the vehicles more intelligent by enhancing the communication between vehicles, infrastructure and signals. Another path breaking development in transportation from customers perspective is HD live streaming and use of VR devices while commuting. People will also benefit from 6G in the transportation as they can watch HD live streaming and VR devices (Karaoğlan, B., & Şeker, C., 2021). Further, remote driver assistance for autonomous cars may pop up in the future. Added to this, logistics firms may adopt 6G for asset tracking in real time to have a better supply chain efficiency and productivity (Chen, M. Y., Fan, M. H., & Huang, L. X., 2021).

III. TECHNOLOGY PERSPECTIVES

A. 6G and Bandwidth

Data transfer rates over an internet connection are measured in terms of bandwidth. Ten times more bandwidth will be available from 6G networks than from 5G ones.

Table 1: Bandwidth Comparison between Communication Technology

Sr.No	Technology	Bandwidth	Frequency	Technique
1	4G	20-100Mbps	700MHz to 2600MHz	OFDM
2	5G	1Gbps	Low band- 600 MHz to 700 MHz, Middle Band-2.5 GHz to 3.7 GHz High Band- 24 GHz to 40 GHz	OFDM & mmWave
3	6G	10Gbps	0.1 THz to 10 THz	OFDM & mmWave

Source: Primary data.

The comparison of Table 1 depicts that increased bandwidth in a 6G network allows customers to transfer the data at a brisk pace. This will allow customers to use HD video streaming, VR and AR experience, and cloud computing. Greater bandwidth enables innovation. Additionally, programmers will create fresh Internet of things (IoT) and Massive Machine Type Communication (MMTC) apps. (Dutkiewicz et al., 2017).

B. Latency in 6G Communication

The time taken to either send a request or receive a message over a wireless network is known as latency. In addition to facilitating high data rates, 5G technology empowers extensive connectivity for the Internet of Everything (IoE) and accommodates ultra-low latency applications. (Panchapakesan, 2019). Thus, there is an effort to reduce the time taken in the telecom network. This will make real-time applications possible. Many 6G R&D teams are working hard to lower latency in order to support the expansion of the online gaming, VR & AR, and autonomous car industries. (Sun, W. et al., 2020). Table 2 describes the latency reduction in different generations of telecom services.

Table 2: Variation in Telecom Technologies and Latency

Sr. No.	Technology	Latency
1	3G	100-150 milliseconds
2	4G	30-50 milliseconds
3	5G	1-10 Milliseconds
4	6G	0.1 milliseconds

Source: Primary data.

To achieve better latency, use of advanced signal processing and network architecture to optimize network performance for transmission of data between devices. This entire latency reduction process conducted on the technique called network slicing. In this technology, network operators partition their networks into virtualized subnetworks. Further, these subnetworks have their own specific applications. Thus. reducing the latency factor time.

In another method of reducing latency, telecom companies are utilizing edge computing and AI. Edge computing reduces the amount of time it takes to process and analyze data by bringing processing and storage capabilities closer to the edge of the network (Zhao, L. et al., 2021). Yet another area where latency will be reduced in AI. The technology used to optimize network performance and anticipate user needs.

C. 6G and Signal Processing

Signal processing is the process of manipulation of signals to extract useful information and enhance the communication quality (Orfanidis, S. J., 1995). The technology improves the performance and efficiency of the communication network. Further, signal processing is built on waveform optimization in 6G networks. The advantage of waveform works differently for different forms of data. For instance, voice data and video signal usage are different. Apart from wave forming ques, companies are adopting beam forming. In addition to waveform optimization, 6G is anticipated to leverage additional cutting-edge signal processing methods like MIMO and intelligent reflecting surfaces (IRS) to further boost wireless communication performance and efficacy.

D. IRS and 6G Integration

By reflecting and directing radio waves, an Intelligent Reflecting Surface (IRS), a type of meta surface, can be utilized to enhance the performance of wireless communication systems. IRS is made up of several passive, subwavelength-sized components that may each be individually regulated to reflect incident signals in the desired amplitude, phase, and direction. An IRS can function as a programmable mirror that can focus, magnify, or direct incoming signals by modifying the arrangement of these components. IRS could be utilized in 6G systems to improve signal quality and lower wireless device power usage (Ji, B. et al., 2021). Some of the drawbacks of conventional wireless communication systems, such as signal attenuation, interference, and multipath fading, might be solved with the usage of IRS. It is possible to develop intelligent settings that respond to user needs and offer seamless connectivity for a variety of devices by strategically integrating IRS in the environment. (Naeem F. et al., 2022).

E. Meta and Sixth Generation Technology

Meta or metamaterials or materials not present naturally require material engineering. These include negative refractive index, cloaking, and sub-wavelength imaging. These materials are expected to bring significant differences in the field of optics, acoustics and electromagnetics. Further, future antennas are built on meta. They are more efficient and compact. They are expected to bring down the size of the device. Due to their characteristic, meta products will filter certain frequencies to reduce interference in signals and improve the quality (Xu, C., Ren, Z., Wei, J., & Lee, C., 2022).

F. 6G Spectrum

The spectrum is the range of frequencies used for operating the wireless communication. 6G uses higher frequencies than 5G. These high frequencies are termed as millimeter waves. These frequencies work on greater bandwidth and data capacity than lower frequency. There is an effort by telecom operators to maximize the spectrum usage available or achieve higher spectral efficiency. This is measured in bits per second per hertz. The higher the spectral efficiency means the more data transmitted using the same amount of spectrum. 6G adopts advanced modulation and coding techniques to have higher spectral efficiency. The advanced modulation technique researched in 6G is Orthogonal Time Frequency Space (OTFS) that allows the doppler effect to encode data in a way that is resistant to fading and interference. Hence, even in a challenging environment the data is transmitted effortlessly (Das, S. S., & Prasad, R., 2022). Another dimension to modulation research is Generalized Frequency Division Multiplexing (GFDM). In this flexible modulation, channel condition is used in real time to increase the efficiency (Kassam, J. et al., 2020). Further, this technology supports mMIMO and beamforming. Apart from the modulation emphasis is given on polar coding. These codes are a type of error correcting. Which transmits in a noisy channel through a set of inputs to a set of outputs. These codes are more reliable and possess very high encoding rates (Yue, C., Miloslavskaya, V., Shirvanimoghaddam, M., Vucetic, B., & Li, Y., 2022). These codes are applied in data transmission, channel estimation, and interference cancellations. This is used in high speed and low latency communication which are characteristics of 6G communication. Further, 6G communication is expected to adopt Low Density Parity Check (LDPC) codes to augment reliability and transmission rates These LDPC codes provide a few non-zero entries. This coding gives gains at a low complexity. Thus, making the communication faster (Fang, Y. et al., 2021). This is expected to work on ultra reliable and low latency communications, mMIMO and enhanced mobile broadband (Kulkarni, P., Gnanapragash, J., & Sadavar, M., 2021).

G. Beamforming

In 6G Beamforming, radio waves are focused on a spectrum rather than being disseminated in all directions. To maximise the utilisation of beamforming, machine learning is anticipated to be used.

Additionally, massive MIMO (multiple-input multiple-output) technology, which enables the use of multiple antennas at both the transmitter and receiver ends of a communication link, is anticipated to be employed in 6G beamforming. (Jiang, W., & Schotten, H. D., 2022). This allows for even more precise and efficient beamforming, as well as increased capacity and improved reliability (Ahn, Y. et al., 2022).

H. Niral Open Product Framework

Mobile Network Operators (MNOs) have traditionally depended on a few vendors, slowing upgrades and innovation. With the emergence of 5G and the upcoming 6G networks, the risk of vendor lock-in is growing. The Vendor Agnostic Open Product System by Niral Networks offers a solution. It enables MNOs to transition from vendor-controlled to operator-controlled systems, fostering competition and adaptability in the rapidly evolving 5G and future 6G landscapes.

III. RESEARCH METHODOLOGY

A. Bibliometric Analysis

Researchers conducted exploratory research to perform Systematic Literature Review (SLR) on 6G communication. They have selected a Scopus database which is reliable and valid in the management domain. Further, a keyword 6G wireless communication used to generate the articles published in the domain. A CSV file created from the Scopus website. The CSV file is uploaded into the VOS viewer software which is popular to conduct bibliometric analysis. According to Science direct topics: Bibliometric analysis scientific computer-assisted review methodology that can identify core research or authors, as well as their relationship, by covering all the publications related to a given topic or field . Further, VOS viewer software is used for Co-Occurrence analysis for identifying relationships between terms or concepts based on their co-occurrence within a given corpus of documents, such as academic publications or web pages.

Entity-Relationship Diagram (ERD): To complement the textual analysis, an Entity-Relationship Diagram (ERD) was constructed, serving as a visual representation of the intricate 6G technology landscape. The ERD was structured into three primary segments: Technologies, Relationships, and Benefits.

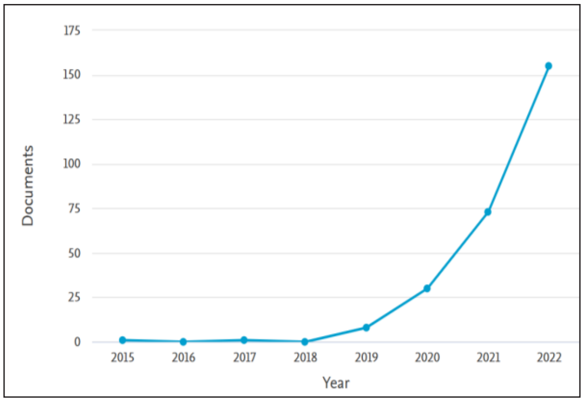
Interpretive Structural Modelling (ISM): Complementing the ERD, ISM was employed to delve deeper into the hierarchies and interconnections among key elements within the 6G ecosystem. ISM facilitated a systematic categorization of these elements into three pivotal sections: Infrastructure, Applications, and Services.

IV. DATA ANALYSIS AND FINDINGS

Researchers searched the Scopus database with keywords 6G and wireless and communication keywords. The data file sliced to computer engineering to get more precise articles. The dicing is done with English words with the condition of 6G word presence. Scopus documents extracted using following code:

TITLE-ABS-KEY (6g AND wireless AND communication) AND (LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “ENGI”)) AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (LANGUAGE , “English”)) AND (LIMIT-TO (EXACT KEYWORD , “6G”))

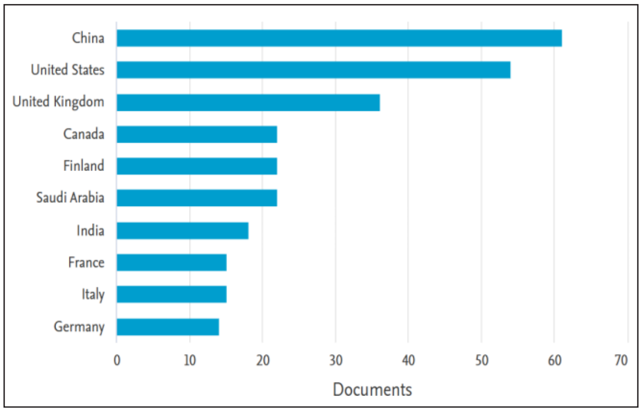
The bibliometric analysis provided first evidence of 6G literature in Scopus in 2010. However, authors limited the period from 2015 to 2022.The Fig. 1 depicts the growing academic literature in the 6G communication. Thus, validating the researcher interest and identification of trend in the research topic.



(Source: Vos Viewer analysis)

Fig. 1: Documents versus Year of Publications in 6G Communications

Fig. 2 drills down the research articles to a particular country. China, the USA, and the UK are leading the 6G research. Though India is progressing in the academic research pertaining to 6G technology, it has to catch up with other countries. Thus, the research gap is identified by researchers. It is also noticed that China, the manufacturing hub of the world investing more money on the research and development of 6G communications is leading the research publications.

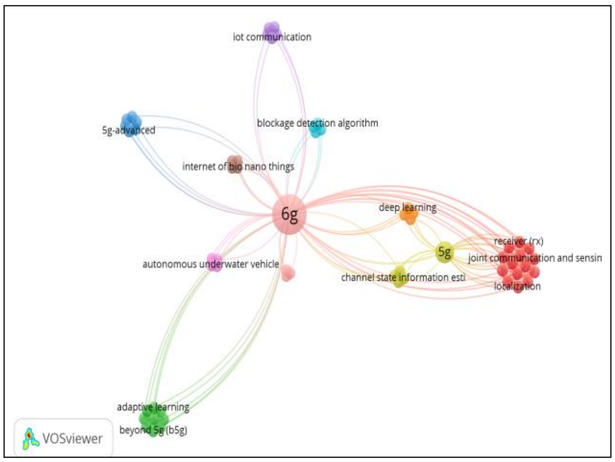


(Source: VoSviewer analysis)

Fig. 2: Documents by Countries

Co-Occurrence Analysis

The VoSviewer analysis co-occurrence analysis, also shown in Fig. 3, formed different clusters. In the first cluster, deep learning, localization and joint communication and sensing is formed. This entrusts the use of AI in the local environment to speed up the 6G implementation. In the second cluster, 5G and channel estimates were formed. These publications throw light on limitations of 5G networks in deployment and channel integration. Third cluster highlights on autonomous vehicles and IoT devices. It shows the need and importance of 6G communication for both sectors. The fifth cluster elements such as adaptive learning and beyond 5G picks articles speaking about next generation telecom requirements and applications. In the final cluster, advanced 5G and algorithms discussed by authors to overcome the limitations of 5G communications.



(Source: VoSviewer analysis)

Fig. 3: Co Occurrence Analysis of 6G Communications

Entity – Relationship Diagram

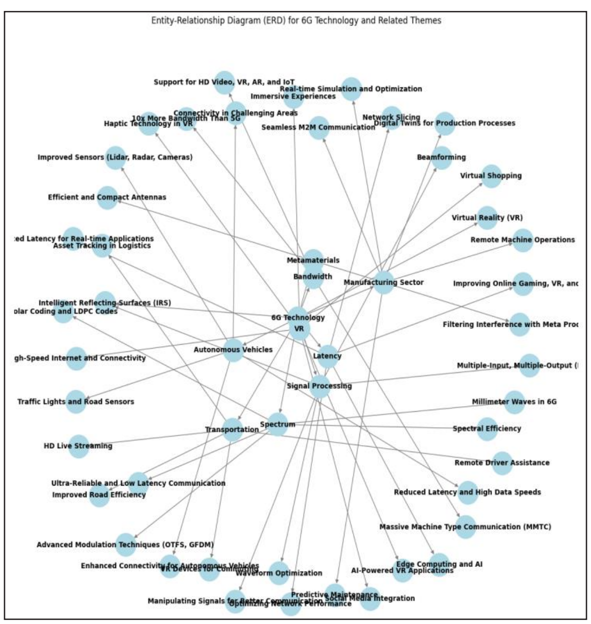


Fig. 4: Entity Relationship Diagram for 6G

Technology and Related Themes

The provided Entity-Relationship Diagram (ERD) serves as a comprehensive depiction of 6G technology and its associated domains, elucidating the intricate interplay of various technologies and concepts that constitute this pioneering realm of innovation. The ERD can be systematically categorized into three primary segments, each offering valuable insights into the landscape of 6G:

Technologies: At its core, this segment encompasses a diverse spectrum of technologies integral to 6G. These encompass crucial elements such as support for high-definition (HD) video, virtual reality (VR), augmented reality (AR), and the Internet of Things (IoT). Additionally, it includes pivotal facets like real-time simulation and optimization, immersive experiences, connectivity solutions in challenging environments, the promise of delivering 10 times more bandwidth than 5G, haptic technology within VR, seamless machine-to-machine (M2M) communication, network slicing, the concept of digital twins for optimizing production processes, advancements in sensors (lidar, radar, cameras), beamforming, virtual shopping experiences, efficient and compact antenna designs, reduced latency for real-time applications, and asset tracking within logistics. Collectively, these technologies form the foundational building blocks of the 6G ecosystem.

Relationships: The intermediary section of the ERD unveils the intricate connections and dependencies that exist among these diverse technologies. For example, the arrow bridging "Support for HD Video, VR, AR, and IoT" to "Immersive Experiences" signifies the indispensable role played by the former in crafting immersive digital encounters.

Benefits: The final segment outlines the potential advantages ushered in by 6G technology. Notably, the arrow extending from "6G Technology" to "Improved Road Efficiency" underscores the capacity of 6G to enhance road infrastructure and management.

Collectively, the ERD effectively portrays 6G technology as a multifaceted ecosystem characterized by intricate interconnections among its constituent elements. Furthermore, it accentuates the revolutionary potential of 6G technology across diverse industries and facets of human existence. To illustrate this transformative potential, consider specific instances where elements from the ERD converge to fuel the development of 6G applications:

Support for HD Video, VR, AR, and IoT: These technologies collectively pave the way for novel immersive experiences, ranging from virtual concerts to advanced sporting events. Simultaneously, they empower IoT applications like self-driving cars and smart homes to operate with heightened sophistication.

Real-Time Simulation and Optimization: This capability can be harnessed to optimize industrial processes, fostering efficiency gains and serving as a foundation for innovative training tools for professionals, including surgeons.

Immersive Experiences: Leveraging this technology can lead to the creation of new paradigms in entertainment and education. Virtual worlds for training and collaborative ventures become more attainable and realistic.

Connectivity in Challenging Areas: This technology can bridge the digital divide by providing internet access to remote regions and enabling connectivity in challenging environments.

Reduced Latency for Real-Time Applications: By minimizing latency, 6G technology can catalyze the development of real-time applications like remote surgery and augmented reality, ushering in a new era of possibilities. In essence, the ERD illuminates the intricate tapestry of 6G technology, highlighting its potential to redefine industries, empower applications, and shape the future of technological innovation.

Interpretive Structural Modelling (ISM): The ISM diagram presented offers a comprehensive representation of the 6G ecosystem, providing insights into the various components and interactions within this dynamic field. The diagram can be divided into three primary sections, each addressing essential aspects of the 6G landscape:

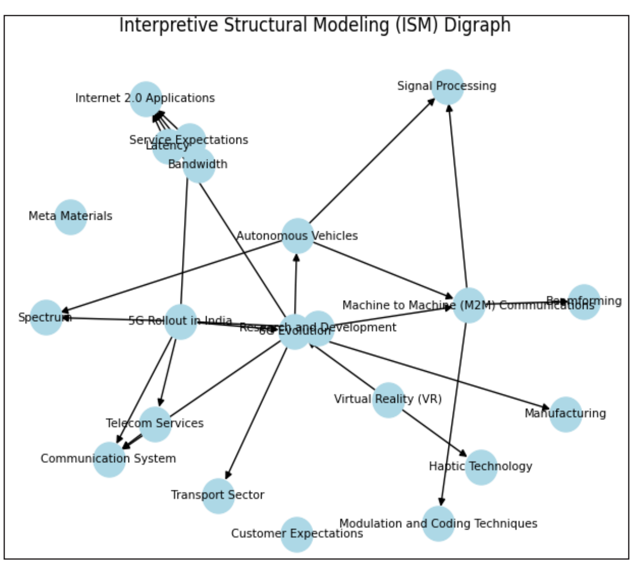


Fig. 5: Interpretive Structural Modelling (ISM) Digraph

Infrastructure: This foundational section encompasses the core technologies that underpin the 6G functionality. Key components include the internet itself, which serves as the fundamental connectivity medium, cloud computing, which offers the necessary storage and processing capabilities, and big data infrastructure, vital for the analysis of the vast volume of data generated.

Applications: This segment delves into the diverse range of 6G applications that can be used. Notable examples include smart homes, where 6G automate and manage various household functions like lighting, temperature, and security. Additionally, smart cities will leverage 6G technology to gather data for improving city services such as transportation, energy management, and waste disposal. Industrial automation is another critical application domain, utilizing 6G to streamline and monitor industrial processes effectively.

Services: The services section explores the various support services integral to the 6G ecosystem. Data analytics plays a pivotal role in extracting valuable insights from the copious amounts of data collected, enhancing the performance and efficiency of 6G applications and services. The directional arrows within the diagram depict the intricate relationships between these elements. For instance, the arrow connecting "Infrastructure" to "Applications" signifies that 6G applications rely heavily on the underlying infrastructure for their operation.

This detailed analysis underscores the complexity of the 6G ecosystem, where various technologies, devices, and services are interconnected and mutually dependent. Moreover, the diagram emphasizes that the 6G is still in its nascent stages of development, continually evolving with the emergence of new technologies and applications.

V. IMPLICATIONS

A. Managerial Implications

Telecom companies are in fierce battle with each other and exert pressure themselves to reduce the cost, provide the quality service and augment the customer experience. The reduction latency, improvement in signal processing, antenna technologies, coding, meta material usages, artificial intelligence applications and IoT devices are improving communication efficiency. This phenomenon continues to boost in the 6G technology. IoT also coupled with managerial implications such as allocation of resources for spectrum buying, establishing physical infrastructure, and spending money on research and development. Above all this, the talk of 7G began in the engineering world. Thus, managers must glance at the cost implications of each of their strategies.

B. Societal Impact

The advancement in 6G development comes out with advantages and challenges to society. The society largely benefited from autonomous vehicles that were expected to reduce the number of accidents. Further, the technology is expected to augment customer service using VR, AR and IoT technologies. Added to this, 6G is expected to reach tunnels and mountains where 5G has the limitations, Thus, providing better connectivity. The improved performance of the 6G network will boost productivity in transportation, healthcare, and logistics sectors. However, massive implementation of hardware devices may cause sustainability concerns. Thus, there is a need for more green communication efforts from telecom companies.

VI. LIMITATIONS AND FUTURE RELEVANCE

The research is exploratory in nature and needs conclusive evidence to support the initial research conducted by several authors in different countries. There is very little contribution from Indian authors in the 6G field and there exists the scope to conduct the research. Most technology products in the current scenario face disruption. Hence, these digital technologies' life span and impact on investment to be studied. All research conducted and quoted in 6G technology is based on preliminary investigation and needs substantial evidence to prove the hypothesis of the research.

VII. CONCLUSION

6G is expected to bring transformation in telecom technologies and broadening its applications to various sectors. Thus, it is inevitable for all industries to glance through the repercussions of 6G technology on their sector. Further, researchers identified its implications to managers and businesses and society in whole.

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