Understanding 6G

Developments and Challenges

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Abbreviations

3GPP:	Third Generation Partnership Project
5G:	5th Generation
6G:	6th Generation
ACMA:	Australian Communication and Media Authority
AI:	Artificial Intelligence
AICCTP:	Australia-India Cyber and Critical Technology Partnership
AR:	Augmented Reality
BS:	Base Station
CBA:	Cost-Benefit Analysis
C-DoT:	Centre for Development of Telematics
CERT:	Computer Emergency Response Teams
DoT:	Department of Telecommunications
EMBB:	Enhanced Mobile Broadband
EU:	European Union
GDP:	Gross Domestic Product
GHz:	Gigahertz
GSMA:	Global System for Mobile Communications Association
IEEE:	Institute of Electrical and Electronics Engineers
IMSI:	International Mobile Subscriber Identity
ITU:	International Telecommunications Union
KAIST:	Korea Advanced Institute of Science and Technology
LEO:	Low Earth Orbit
LTE:	Long Term Evolution
MC:	Molecular Communications
MHz:	Megahertz
ML:	Machine Learning
MMTC:	Massive Machine-Type Communications
mn:	million
MSME:	Medium, Small, and Micro Enterprise

PPP:	Public Private Partnership
PQC:	Post-Quantum Cryptography
QC:	Quantum Communication
QKD:	Quantum Key Distribution
R&D:	Research and Development
RAN:	Radio Access Network
SDG:	Sustainable Development Goal
SNS JU:	Smart Networks and Services Joint Undertaking
SWOT:	Strength Weakness Opportunity Threat
THz:	Terahertz
TIG:	Technology Innovation Group
tn:	trillion
TSDSI:	Telecommunications Standards Development Society, India
UN:	United Nations
UNESCAP:	United Nations Economic and Social Commission for Asia and the Pacific
URLLC:	Ultra-Reliable Low Latency Communications
US:	United States of America
UTS:	University of Technology Sydney
VLC:	Visible Light Communication
VR:	Virtual Reality

Executive Summary

Wireless communication, marked by the ongoing deployment of 5G, holds a significant societal impact, and this transformative trajectory is set to extend with the advent of 6G networks. Currently, in the research phase, 6G focuses on technology components, anticipating a subsequent systemisation phase before formal standardisation initiates.

Notably, industry standards organisations such as 3GPP have not yet begun coordinating work on 6G. Early stages of 6G definition witness various regions and countries vying to be the first to define its scope, new use cases, requirements, and underlying technologies. While healthy competition fosters innovation, it is crucial to avoid disrupting the global scale of the industry, crucial for recovering substantial R&D investments.

6G is poised to usher in advancements akin to those propelling 5G into discussions among business leaders and policymakers. Diverging from the sporadic global rollout of 5G, 6G envisions a world where every physical object, not just everyone, can continuously connect and communicate. Technically, 6G is projected to extensively use millimetre waves and higher terahertz frequency bands (100GHz-10THz), surpassing those employed by 5G. Anticipated benefits include superior coverage, cost efficiency, and opportunities for network intelligence.

Augmented reality experiences will be more efficient, and 6G video teleconferences may feature holograms and AI-powered in-call suggestions. By offering enhanced human-machine and machine-machine connectivity, superior low latency, and faster speeds than 5G, 6G is anticipated to reshape consumer experiences, economies, and societal structures.

However, the increased capacity and processing power of 6G will necessitate broader radio frequency bandwidths and specialised chips for devices. While 6G networks enable the flow of more information, they also introduce heightened security risks as critical infrastructure becomes digitised, making them vulnerable to attacks.

Amidst the centrality of national security in the global landscape, 6G emerges as both a geopolitical and commercial battleground. Success in 6G unlocks opportunities for

information technology development and establishes corresponding global influence. Nations with allied upstream telecommunications and networking players leading in 6G intellectual property and operational deployments stand to reshape global telecommunications rules, gaining international market share and influence. It also introduces challenges related to the environment, cybersecurity, data protection, and potential standardisation fragmentation.

This report aims to provide information to policymakers, industry leaders, and civil society regarding the necessary technological, infrastructural, regulatory, and policy advancements required for the development of 6G. The report presents recommendations to guide the creation, modification, and improvement of related laws, regulations, and policies pertaining to 6G.

Key Recommendations:

- **Economic Sustainability:** The deployment of 6G introduces new business prospects across various sectors, enhancing operational profitability. To ensure the widespread accessibility of such groundbreaking technology, affordability must be a primary consideration for both end consumers and business users.
- **Social Sustainability:** The advancements facilitated by 6G should actively contribute to increasing social capital. This involves prioritising initiatives that improve public health, providing opportunities for skills and education development, enhancing privacy and cybersecurity measures, addressing the digital divide to ensure comprehensive societal inclusion, and leaving no one behind.
- **Environmental Sustainability:** The deployment of 6G technologies should actively focus on reducing the anticipated carbon footprint associated with their operations. Emphasis should be placed on optimising energy consumption through the implementation of energy-efficient technologies, renewable energy sources, and sustainable infrastructure practices.
- **India-Australia Partnership:** Recognising the potential of India-Australia collaboration in the realm of critical technologies, particularly 6G, efforts should extend beyond supporting each other's digital development to encompass shared initiatives in the broader Indo-Pacific region. A coordinated approach to digital engagements with regional countries is essential.

  Establishing a Joint Working Group on Digital Engagement can serve as a platform for India and Australia to collaborate, share expertise, and align their efforts in fostering digital advancements within the region. This collaborative approach can strengthen diplomatic ties, promote regional stability, and collectively address digital challenges faced by countries in the Indo-Pacific.

About the Project

The project, titled "Ethical 6G: Identifying Elements of an Ethical Framework for 6G and Creating Opportunities for India and Australia," is a collaborative effort between CUTS International, the Australian Risk Policy Institute (ARPI), and the International Institute of Information Technology, Bangalore (IIITB). This initiative is supported by the Department of Foreign Affairs and Trade (DFAT), Australia, under the Australia-India Cyber and Critical Technology Partnership (AICCTP) Grant.

Recognising the critical importance of cyber technologies and their growing influence on international relations, the AICCTP was formed with the primary aim of fostering an open, secure, free, accessible, stable, peaceful, and interoperable cyberspace. Emerging technologies like Artificial Intelligence, next-generation telecommunications, the Internet of Things, quantum computing, synthetic biology, blockchain, and big data are central to this partnership.

The project is grounded in the comprehensive strategic partnership between India and Australia, signed in June 2020. It focuses on fostering cooperation between both countries, particularly developing next-generation networks such as 5G and 6G, emphasising on security, resilience, and diverse technology supply chains.

The project aims to identify elements for an ethical framework for future 6G technology, create an enabling environment for Indian and Australian institutions to participate in the 6G standard-making process, and develop opportunities for firms in both nations to invest in and promote 6G in the Indo-Pacific region.

The research outputs are divided into four components:

1. Understanding 6G: Development and Challenges
2. Strategic Opportunities for Australia and India from 6G
3. Standardising Standard Setting for 6G
4. Identifying Elements of an Ethical Framework for 6G.

Methodology

- Detailed review and analysis of research papers, industry reports and government regulations and policies.
- Exhaustive structured interviews with experts in the Telecom Industry (telcos, Network Equipment Manufacturers), Academia, Government, Standard-Setting Organisations (TSDSI), and Industry organisations (COAI).

1 Introduction

1.1. Background

Many countries worldwide have either deployed or are in the process of deploying 5th Generation (5G) mobile communication technology. The technology is poised to unlock many novel use cases for society and the industry through its three chief characteristics – Enhanced Mobile Broadband (EMBB), Massive Machine-Type Communications (MMTC), and Ultra-Reliable and Low-Latency Communications (URLLC). These are given in Table 1 below.[1]

Table 1: Use Cases to be Unlocked by 5G

	EMBB	MMTC	URLLC
Technology Advancement	It enables 5G to theoretically offer lightning speeds up to 100x faster than 4G.	It enhances 5G's capabilities to support a high density of devices (up to millions per sq.km.)	It reduces latency in 5G, up to a factor of 10, down to single-digit milliseconds.
Benefits for Society	Augmented Reality (AR), Virtual Reality (VR), hotspots for high user density, etc.	Bolster IoT, smart home, etc.	Autonomous vehicles, telehealth, etc.
Benefits for Industry	Enterprise collaboration, remote training, etc.	Smart agriculture, smart cities, energy monitoring, wireless control of industrial manufacturing, etc.	Smart grids, remote patient monitoring, drones, industrial automation, etc.

Source: Authors' representation

[1] Setting the Scene for 5G: Opportunities & Challenges, available at: https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-BB.5G_01-2018-PDF-E.pdf

Considering such use cases, the 5G revolution is being seen as more than just a telecom service for consumers, but instead, as an advanced technology acting as the backbone for enabling several other technologies and industry use cases. Estimates suggest that 5G will generate US$7tn of economic value by 2030,[2] and enable US$12.3tn of global economic activity by 2035.[3]

Safe to say that the advancement of telecom technology has, and will continue to play a crucial role in bolstering the digital economy by providing the fundamental building blocks required for it, i.e., access, interconnectivity, and applications. Accordingly, the current and potential value stemming from the digitalisation of different sectors/ industries is dependent on the telecom industry delivering essential infrastructure, applications, and productivity improvements in many areas.[4]

Recognising such potential of telecom technology advancement, countries worldwide have already begun work on the next generation of telecom technology–6G. 6G is anticipated to surpass 5G in numerous technical aspects, such as peak data rates, traffic capacity, connection density, spectral efficiency, and latency. This technological leap is set to enhance Artificial Intelligence (AI) and Machine Learning (ML) applications.

Furthermore, it will seamlessly merge the physical and digital realms, instigating unprecedented sensory experiences. 6G will also ensure exceptional performance and extensive coverage and foster advancements in network-enabled robotics and autonomous systems, among other benefits.[5]

This report constitutes the first research component (RC1) of the project titled "Understanding 6G: Developments and Challenges". The primary objective of this report is to deepen the understanding of the technology, infrastructure, regulations, and policies necessary for the development and deployment of 6G. It presents recommendations and analyses challenges associated with 6G technology, especially in India and Australia.

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2 State of 5G Report: Enabling The Boundless Generation, available at: https://www.interdigital.com/white_papers/state-of-5g-report-enabling-the-boundless-generation?utm_source=PR&utm_medium=Website&utm_campaign=State_of_5G_2022

3 The 5G economy: How 5G technology will contribute to the global economy, available at: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf

4 Telecommunications: helping other industries unlock value from digitalization, available at: https://reports.weforum.org/digital-transformation/telecommunications-helping-other-industries-unlock-value-from-digitalization/#:~:text=%C2%B9%20The%20telecommunications%20(telecom)%20industry,digital%20revolution%20to%20take%20place

5 6G explained, available at: https://www.nokia.com/about-us/newsroom/articles/6g-explained/

These recommendations aim to guide the development, amendment, and refinement of pertinent laws, regulations, and policies related to the inception and integration of 6G into our digital infrastructure.

1.2. 6G: Differences from 5G and Potential Impacts

6G will help unlock many novel benefits and use cases, such as public safety and critical asset protection (threat detection, air quality measurements, gas, and toxicity sensing, etc.), support emerging technologies (unmanned mobility, eHealth, smart cities, autonomous vehicles etc.), holographic telepresence, revolutionaries' industry 4.0 and robotics (digital transformation of manufacturing, real-time industrial operations etc.).[6]

Apart from the above, 6G is also poised to help countries monitor their progress in achieving the United Nations (UN) Sustainable Development Goals (SDGs). Experts opine that future 6G systems will have their communication capabilities merged with sensing, location, imaging, and other capabilities, which could help governments gather a variety of data to report on the achievement of the UN SDGs at a highly local granularity level. This would help countries overcome the challenge they face in reporting indicator-level data on achieving the UN SDGs targets.[7]

It is safe to say that 6G will not just be another industry vertical but will serve as a fundamental foundation for almost all other sectors. Experts expect the technology to be the new "electricity," and everything ranging from manufacturing and logistics to autonomous transportation and precision agriculture will depend upon it,[8] which will be useful for developing and developed countries. Detailed benefits and use cases of 6G have been given in **chapter two**.

However, it is to be noted that there are several challenges/ roadblocks in realising such benefits and use cases of 6G. These include infrastructure requirements, standard setting for a global interoperable network, spectrum regulation, scalability, and battery lifetime of sensors, among many others. Furthermore, 6G is expected to fuel existing risks of and to telecom technology. These include network security, privacy and data

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6 What is 6G? Overview of 6G networks & technology, available at: https://www.techtarget.com/searchnetworking/definition/6G; 6G Use Cases and Analysis, available at: https://www.ngmn.org/wp-content/uploads/220222-NGMN-6G-Use-Cases-and-Analysis-1.pdf; and Towards 6G Networks: Use Cases and Technologies, available at: https://par.nsf.gov/servlets/purl/10192293

7 6G and the UN SDGs: Where is the Connection? available at: https://link.springer.com/article/10.1007/s11277-021-09058-y

8 What Is 6G? available at: https://www.forbes.com/sites/mungchiang/2021/09/30/what-is-6g/?sh=106b07cf33db

protection, unethical use of 6G technology use cases, etc. Such challenges/ roadblocks and risks have been detailed in **chapter four**.

1.3. 6G Arrival and Current Developments

The International Telecommunications Union (ITU) and the Third Generation Partnership Project (3GPP) are expected to complete their standardisation process by the end of 2030 for 6G. Many stakeholders (government, industry, academia) from different countries have also started taking initiatives towards the future of telecom technology.

India has recently announced its intentions to develop and implement 6G networks and technologies by 2030. The country has already initiated the necessary actions to achieve this goal. Prime Minister Narendra Modi introduced the Bharat 6G Vision Document and inaugurated the 6G research and development test bed. The Indian government believes that the vision document will play a vital role in promoting the rapid adoption of new technologies throughout the country.[9]

Countries are spending large amounts of money on Research and Development (R&D) of the 6G technology and have already begun filing for its patents. China and the United States (US) are leading the race with 40.3 percent and 35.2 percent of the global filings for 6G patents. They are followed by Japan, Europe, and South Korea, with 9.9 percent, 8.9 percent and 4.2 percent fillings respectively.[10]

Indian Union Minister for Communications, Ashwini Vaishnaw, has recently claimed that India has secured more than 127 global patents for 6G technology.[11] Initiatives being taken in these countries have been non-exhaustively given in **Annexure 2**.

Notably, 6G will have various implications for the cyber-security and geo-political stability of the volatile Indo-Pacific region. The threat gets amplified with China leading the 6G race now. Accordingly, other nations in the region must collaborate on the R&D of the technology to ensure an open and secure Indo-Pacific.

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9 Bharat 6G Vision Statement. Available at https://dot.gov.in/sites/default/files/Bharat%206G%20Vision%20Statement%20-%20full.pdf

10 The Global Race towards 6G, available at: https://www.communicationstoday.co.in/the-global-race-toward-6g/

11 "India currently holds 127 patents for 6G," says Telecom Minister Vaishnaw. Available at https://www.livemint.com/technology/india-currently-holds-127-patents-for-6g-says-telecom-minister-vaishnaw-11679563655795.html

Given that the US and Japan are front runners in the race for 6G, there appears to be an opportunity for other members of the Quad countries, i.e., India and Australia, to work together on the technology in partnership with other like-minded democratic countries in the region, like South Korea. Details on the issue have been elaborated in **chapter three**.

Chapter Five concludes the report with actionable recommendations (especially for India and Australia) on steps to be taken to realise the vision of 6G by overcoming the challenges in its path.

2 Harnessing the Power: A Snapshot into 6G

5G telecommunication technology is still being deployed in various parts of the world. However, discussions around 6G technology and its development have already begun. As the 6G technology is being developed, it becomes important to understand the technical prowess of 6G technology over 5G before delving into what the next-generation technology will bring for us.

2.1 Comparing 5G and 6G Technologies

A comparison of 5G and 6G technologies based on different parameters[12] has been tabulated below.

Table 2: Comparison of 5G and 6G

Parameter	5G Technology	6G Technology
Data Rate/ Speed	Downlink Data Rate: 20 Gbps Uplink Data Rate: 10 Gbps	~1 Tbps
Latency	1 millisecond	10-100 micro sec
Frequency Spectrum	Low band frequency: sub 6 gigahertz (GHz) High band frequency: 24-25 GHz Millimetre wave (mm-wave) in 30-300 GHz for fixed access	THz bands (above 140 GHz), Non-RF bands including Visible Light Communication
Traffic density per unit of area/ volume	10 Mb/s per m^2	1–10 Gb/s/ per m^3
Connection density	1 mn devices per square km	10 mn devices per square km

[12] '1G Vs. 2G Vs. 3G Vs. 4G Vs. 5G', Net-Informatics, *available at*: http://net-informations.com/q/diff/generations.html

Parameter	5G Technology	6G Technology
Localisation precision	10 cm on 2 Dimension (2D)	1 cm on 3 Dimension (3D)
Mobility	500 Km/h	>1000 Km/h
Spectral Efficiency	3 x	≥ 15 x
Network Energy Efficiency	≥ 10 x	≥ 100 x

Source: Various sources[13]

2.2 Achieving Sustainable Development Goals with Advanced Telecom Technologies

The advancement in telecommunication technology has the potential to aid the growth of an economy, as it has a multiplier effect.[14] The adoption of newer generation technology leads to an increase in economic activities as more and more people get connected to achieve various economic goals. For instance, 5G technology is helping to create supply chains and is also being utilised in the manufacturing sector, remote healthcare, precision agriculture, and digitised logistics, among others.[15]

Further, not just positively affecting the growth of the economy, telecommunication technology also has the potential to impact the social and economic well-being of the masses.

The role of mobile communications is fundamental for attaining many of the United Nations Sustainable Development Goals (UN SDGs) through its following three layers[16]:

1) deployment of infrastructure and networks forming the needed foundation for the digital economy;

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13 'What is 6G? How is it different from 5G?', Rant Cell, *available at:* https://www.rantcell.com/how-is-6g-mobile-network-different-from-5g.html

14 'Telecom a force-multiplier for all sectors, is an essential service: COAI', Business Standard, available at: https://www.business-standard.com/article/companies/telecom-a-force-multiplier-for-all-sectors-is-an-essential-service-coai-120101400834_1.html

15 'What is 5G | Everything You Need to Know About 5G', Qualcomm, available at: https://www.qualcomm.com/5g/what-is-5g; 'The Impact of 5G on the European Economy', Accenture, *available at*: https://www.accenture.com/_acnmedia/PDF-144/Accenture-5G-WP-EU-Feb26.pdf

16 "Sustainability and spectrum management in the 6G era". available at: http://jultika.oulu.fi/files/nbnfi-fe202201179002.pdf

2) access and connectivity by providing people the opportunity to use mobile communications; and
3) enabling services and relevant content that provides life-enhancing services for people.

6G technology has the potential to contribute to all three levels and can be used for achieving societal goals[17] in economic, social, and environmental areas, thus helping achieve sustainable development.[18] It can be a critical driver for achieving the UN SDGs. Studies have highlighted that achieving the SDGs requires greater mobile communications.[19] The International Telecommunication Union (ITU) has prepared the 'Connect 2030 Agenda' which identifies the contribution of information and communications technologies (ICTs) made towards the SDGs.[20]

The ITU Radiocommunication Assembly 2023 (RA-23) concluded its proceedings in Dubai, United Arab Emirates, setting the course for the future of radio communication systems. The Assembly approved a resolution that will guide the development of standards and radio interface technologies for the upcoming 6th generation of mobile systems. Notably, RA-23 also endorsed a resolution on gender equality, aiming to enhance, expedite, and broaden the active participation of women in the activities of the ITU Radiocommunication Sector (ITU-R).[21]

In its strategic blueprint,[22] the Indian government underscores the pivotal role of 6G technology in diminishing the disparity in electronic service accessibility between urban and rural demographics. The document acknowledges the substantial contributions that 6G technology is expected to make towards achieving the UN SDGs, significantly enhancing life quality, and creating equitable opportunities for all.

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17 'Next G Alliance Report: 6G Applications and Use Cases' available at: https://www.nextgalliance.org/wp-content/uploads/dlm_uploads/2022/05/Next_G_Alliance_6G_Applications_and_Use_Cases_7-1.pdf

18 'Sustainability And Spectrum Management in the 6g Era' available at: http://jultika.oulu.fi/files/nbnfi-fe202201179002.pdf

19 'Mobile Industry Impact Report: Sustainable Development Goals' available at: https://www.gsma.com/betterfuture/wp-content/uploads/2021/12/2020-Mobile-Industry-Impact-Report-SDGs.pdf

20 Available at: https://www.itu.int/highlights-report-activities/highlights-report-activities/connect2030/

21 https://www.itu.int/ra-23/

22 Supra Note 9

In the context of India's unique regional and socioeconomic needs, particularly in rural vicinities, this advanced telecommunication platform can provide a solution to the challenges posed by geographical isolation.

Furthermore, the integration of 6G technologies promises to create opportunities for Indian entrepreneurs. These opportunities are anchored in the potential to innovate and generate novel products based on their proprietary intellectual property (IP). Such technological innovation, targeted at fulfilling domestic needs, could also strategically position India on the global stage as a pioneer in offering transformative solutions capable of improving lives and livelihoods worldwide.

In essence, this approach underscores the potential for India to take the lead in the conception, development, and deployment of technologically advanced solutions with far-reaching implications for societal progress.

2.3 6G: Enabling the Future

It is believed that 6G technology will act as an enabler and bolster other emerging technologies such as the Internet of Things (IoT), machining learning (ML), artificial intelligence (AI), edge computing, haptic technology, and blockchain, among others. This can result in newer use cases and experiences for the industry as well as consumers. Broadly, they can be divided into two categories:

1. Use cases where interaction of humans with machines happens, and
2. Use cases where interaction of humans with humans with the help of machines happens.

This section looks at how 6G will interact with and impact these technologies and corresponding potential use cases and further evaluates the changes which may happen for the economy and society.

2.3.1 Building a Smart Environment: How 6G Enhances Interaction Between Humans and Machines

The future entails an intelligent ecosystem where technologies like IoT,[23] edge and fog computing,[24] and distributed AI, among others, will be integrated, and their

[23] IoT is a network of computing devices (things) where these devices interact with one another using the internet to carry out predefined tasks. It finds its application in household as well as industrial settings.

[24] IoT utilises cloud computing, where storage and processing of data happens on the cloud i.e., remote servers. However, increasingly, for storage and processing purposes in IoT, edge computing and fog computing are being adopted wherein, storage and processing is done on the

communication and smooth functioning will be enabled by 6G telecommunication technology. This intelligent ecosystem will facilitate human-machine interactions in an unprecedented fashion by enabling massive IoT networks, which 5G telecommunication systems may not be able to do.

For IoT, 5G has multiple limitations in terms of data rate, latency, and reliability, amongst others. On the other hand, 6G can ensure reliable connectivity in dense networks,[25] and it is expected to have a high connection density of over 10^7 devices/km^2.

Further, the Internet of Everything (IoE) is envisioned as the next logical step of IoT which will be an integrated and hyper-connected world where people and machines will be intelligently connected. Applications of IoE take IoT a step further and include connecting homes to hospitals which can help in saving more lives and connecting homes for a comfortable living, among others. Thus, while 5G may facilitate IoT to grow, 6G will help unlock the true potential of IoT and help it to transition and become IoE.[26]

Furthermore, the IoE ecosystem will transition from a smart ecosystem to an intelligent ecosystem.[27] In the IoE ecosystem, AI and ML technologies will be needed to process enormous amounts of data and meaningfully utilise them. Here, there will be a need to have 6G telecommunications technology to have real-time access to powerful computational facilities.[28]

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edge i.e., on the device itself or in between the device and the cloud, respectively. Due to its decentralised nature, edge and fog computing have several benefits. Data processing happens at the data generation source which helps in improving performance, efficiency, and data security. However, it must be noted that utilising edge and fog computing does not fully eliminate the requirement of using cloud computing for IoT purposes. For further details, please check: 'Difference Between Edge Computing and Cloud Computing', Java Point, available at: https://www.javatpoint.com/edge-computing-vs-cloud-computing; 'Understanding Fog Computing vs Edge Computing', OnLogic, available at: https://www.onlogic.com/company/io-hub/fog-computing-vs-edge-computing

25 'Survey on 6G Frontiers: Trends, Applications, Requirements, Technologies and Future Research', IEEE Open Journal of the Communications Society, available at: https://ieeexplore.ieee.org/document/9397776

26 *Ibid*

27 'A vision on the artificial intelligence for 6G communication', ICT Express, *available at:* https://www.sciencedirect.com/science/article/pii/S2405959522000741

28 Supra Note 25

With the use of 6G technology, it will become possible to perform AI techniques such as AI, ML, deep learning etc., on edge devices, so that they can transform to become intelligent edges.[29]

For instance, 6G will facilitate federated learning, a distributed AI[30] model utilising machine learning techniques, which allows learning to happen on edge devices. Thus, 6G will help enable the transition to distributed architectures and facilitate the creation of Real-Time Intelligent Edges (RT-IE).[31]

In such an ecosystem, intelligent edges (devices), capable of executing distributed AI and ML techniques locally on large datasets produced through sensors, will make real-time decisions.

Enabling massive IoT networks for both consumers and the industry through the synchronised usage of technologies enabled by 6G telecommunication technology has the potential to create a wide range of new use cases and applications. Specific use cases useful for and impacting the industry directly include autonomous vehicles and smart grids, among others.[32]

Wide-ranging production and industrial use cases where IoT will be utilised will be facilitated by 6G technology. Consumers can benefit directly from use cases such as caregiving for the elderly, telemedicine healthcare services, smart transportation, and public safety.

Multi-Platform Next Generation Networks, the task force constituted by the Department of Telecommunication, specifically convened to deliberate on multi-platform, next-generation networks, prevailing international perspectives regarding the advancement of telecom networks expected in 2030 and beyond. These varied

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29 '6G White Paper on Edge Intelligence', University of Oulu, available at: http://jultika.oulu.fi/files/isbn9789526226774.pdf

30 Distributed AI models create a decentralised structure, as opposed to the traditional system where training happens on a centralised system, say at the local server. More details available at: 'Distributed Artificial Intelligence-as-a-Service (DAIaaS) for Smarter IoE and 6G Environments', MDPI Sensors, available at: https://pdfs.semanticscholar.org/c252/f9632c9ca4d21d15cb00ab075fc2907e5882.pdf

31 Supra Note 21

32 'Enabling Massive IoT Toward 6G: A Comprehensive Survey', IEEE Internet of Things, *available at:* https://ieeexplore.ieee.org/document/9369324; '6G Opportunities Arising from Internet of Things Use Cases: A Review Paper', Future Internet, *available at:* https://www.mdpi.com/1999-5903/13/6/159/htm; 'Towards 6G Internet of Things: Recent advances, use cases, and open challenges', ICT Express, *available at:* https://www.sciencedirect.com/science/article/pii/S2405959522000959

perspectives were situated against the backdrop of India's unique future requirements and projected growth trajectory in the coming decade.

Depending on the applicability and relevance of each perspective to the Indian context, the task force underscored certain potential evolutionary paths more than others. In their evaluation, they prioritised trajectories that appeared most pragmatic and promising within a ten-year timeframe.

The task force stated the criticality of a robust optical network extending to residential and professional spaces. While the construction of the wireless network requires time and resources, it satisfies the needs of not only mobile users but also those who are nomadic or static.

Looking ahead, an integrated network combining optical and wireless elements—with fibre-like wireless segments included where suitable—is considered essential. This necessitates a dedicated focus on the engineering of Gigabit Passive Optical Networks (GPON) in rural regions. The advent of 6G is anticipated to significantly expand the horizons of communication technology by introducing bandwidths of 1Tbps—approximately a hundredfold increase over its predecessor, 5G.

This technology, with sub-millisecond latencies, has the potential to profoundly transform various modes of interaction, encompassing human-to-human, machine-to-machine, and human-to-machine communications. It promises to radically modify the future landscape of data storage, processing, and utilisation.

It is expected that 6G technology will integrate 'sensing' as a service, which will have a significant impact on the design and delivery of innovative technologies and services across various sectors such as education, healthcare, and gaming.

The Indian government has set up a task force called Innovative Solutions, which emphasises the need to identify and develop a strategic roadmap to fully comprehend the implications of these emerging capabilities. This roadmap should be designed to explore a wide range of potential use cases, uncovering the full potential of 6G technology while ensuring that it caters to the diverse needs stipulated by anticipated future use cases.

Box 1: 6G will Ease 'Living' as well as 'Doing Business'

The government and industry both have recognised that the deployment of 5G telecommunication systems will facilitate Ease of Living (EoL) and Ease of Doing Business (EoDB).[33] In this regard, 6G will take it a step even further and make it possible for the world to experience newer solutions which improve living standards and ease the living of people by extrapolating the usage of IoT to make our cities smart.[34]

Applications of 6G technology are anticipated to enhance the standard of day-to-day living. Potential examples include service robots that could offer health care services, caregiving, localised indoor deliveries, and sophisticated travel assistance.

With the advanced proficiency of omnipresent sensors and smart network infrastructure, humans, as the ultimate recipients of 6G services, stand to gain substantial enhancements to their quality of life. Whether in the comfort of their residential spaces or during transit, individuals will experience this improvement via the ubiquity of ambient intelligence that can adapt and learn from their patterns and needs. Further, in the future, in industrial settings such as the manufacturing sector, the role of 6G technology will only increase and increase the ease of doing business.

Through mechanisms like edge intelligence for 6G-enabled industrial IoT and network-enabled robotics, one can imagine an automated robot unit making a car as per the pre-customised settings. Such autonomous systems can be imagined in large factories in the manufacturing sector.[35]

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33 '5G technology will bring positive changes in Governance, Ease of Living, and Ease of Doing Business in the country: PM Modi' available at: https://newsonair.gov.in/News?title=5G-technology-will-bring-positive-changes-in-Governance%2C-Ease-of-Living%2C-and-Ease-of-Doing-Business-in-the-country%3A-PM-Modi&id=441163; 5G launch a big step in ease-of-doing-business and ease of living: FICCI, available at: https://www.business-standard.com/article/news-cm/5g-launch-a-big-step-in-ease-of-doing-business-and-ease-of-living-ficci-122100300731_1.html

34 'Next G Alliance Report: 6G Applications and Use Cases' available at: https://www.nextgalliance.org/wp-content/uploads/dlm_uploads/2022/05/Next_G_Alliance_6G_Applications_and_Use_Cases_7-1.pdf

35 '6G use cases and analysis' available at: https://www.ngmn.org/wp-content/uploads/220222-NGMN-6G-Use-Cases-and-Analysis-1.pdf

2.3.2 Enabling Tactile and Telepresence: Human to Human Interactions Through Machines

6G telecommunication technology will enable tactile internet which is an internet, with ultra-low latency and high reliability and can enable real-time human-machine interaction.[36] Thus, 6G will help in extending IoT further and creating an ecosystem for holographic and haptic telepresence by utilising augmented reality (AR), virtual reality (VR), extended reality (XR) and other such technologies.[37]

While holographic technology will provide a visual experience, haptic technology can provide an experience of touch, thus giving an experience of telepresence of a person sitting far off. Creating highly immersive experiences offers opportunities to revolutionise education, healthcare, gaming, and other sectors.

Many other use cases in the entertainment and sports industry are speculated. For instance, since 6G can facilitate the operationalisation of ultra-realistic immersive experiences, interactive sports such as drone racing.[38] The experience of spectators of sports in stadiums can change totally as 6G will enable real-time replays using AR technology near spectators, thus giving a new experience. Further, the metaverse too will be hugely impacted by 6G.

Box 2: Metaverse in a 6G World

With the metaverse, immersive gaming and entertainment are likely to reach newer heights. It is projected that in the metaverse, data consumption will increase significantly. It will utilise the intelligent ecosystem where complementary technologies like distributed AI, edge, and cloud computing, blockchain, IoT, AR, VR and XR.[39]

One of the most crucial aspects of the metaverse is the requirement for extremely fast and low-latency connections. In this scenario, while 5G will support the

36 'What is Tactile Internet,' IGI Global, available at: https://www.igi-global.com/dictionary/internet-of-things-and-data-science-in-healthcare/79878

37 '6G and the Possibility of a Haptic, Holographic Internet', NAB Amplify, available at: https://amplify.nabshow.com/articles/6g-and-the-haptic-holographic-internet/

38 '6G Applications and Use Cases', Next G Alliance Report, available at: https://www.nextgalliance.org/wp-content/uploads/dlm_uploads/2022/05/Next_G_Alliance_6G_Applications_and_Use_Cases_7-1.pdf

39 'The real future of the metaverse is not for consumers,' available at: https://www.ft.com/content/af0c9de8-d36e-485b-9db5-5ee1e57716cb

metaverse ecosystem, 6G will likely enhance the metaverse and help in newer use cases.[40]

With the metaverse ecosystem being powered with the 6G technology, use cases pertaining to entertainment, media, and gaming are likely to find significant adoption as it will also enable aspects like holographic telepresence. Further, metaverse does not just find applications for consumers but for the enterprise as well as the industry where consumers co-design with the enterprise and manufacture it with the industry.[41]

Innovations like digital twins have the potential to revolutionise factory management, significantly boosting industrial productivity. Supporting advanced forms of media content that go beyond traditional formats and the emerging Metaverse concept is challenging. Incorporating VR, AR, MR, 360-degree video, immersive audio, haptic feedback, and holography into user-oriented media applications like teleconferencing requires specialised equipment for both end-users and content creators. It is crucial to achieve Key Performance Indicators (KPIs) that involve high bandwidth and low latency.

Additionally, establishing standardisation protocols is essential to facilitate the growth and widespread adoption of these advanced media types. The logical flow emphasises the potential of digital twins in the industry and then transitions to the challenges associated with advanced media content.

In addition to these, there are several other benefits and use cases that 6G technology may facilitate. For instance, in the field of healthcare, holographic medical imaging and haptic gloves can enable remote surgery. In the field of education, students can learn from immersive experiences. While 6G technology provides an opportunity with several use cases, there are a few potential challenges for 6G, as discussed in Chapter Four.

40 https://telecom.economictimes.indiatimes.com/news/why-6g-is-essential-to-bring-the-metaverse-vision-into-fruition/93591820

41 'The real future of the metaverse is not for consumers,' available at: https://www.ft.com/content/af0c9de8-d36e-485b-9db5-5ee1e57716cb

3 Status of 6G in India and Australia

Countries around the globe, including India and Australia, have begun to investigate the potential of 6G technology. Many countries are investing in 6G research and making themselves 6G ready. However, as mentioned previously, a few countries like China, the US, Japan, and South Korea, are in the race for contributing to 6G development and standardisation.

The statement emphasises the significant gap that exists between nations. Only a few countries possess the capability to develop and implement new and advanced technologies successfully. On the other hand, most nations lack sufficient resources and are compelled to rely on these sophisticated technological advancements to embrace digital transformation.

Such reliance exposes nations to the threat of digitally empowered authoritarian states reaping profits while asserting control through political and commercial hegemony.[42] This is precisely why many fragile democracies, especially in the Indo-Pacific, run the risk of becoming overly reliant on a few dominant powers, potentially undermining democratic national resilience.[43]

Globally countries are at varying levels of development on 6G and many countries have made ambitious plans to integrate 6G into their national systems much before 2030. The developmental status of the top contenders is as follows.

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42 'China's Digital Ambitions: A Global Strategy To Supplant The Liberal Order', available at: https://www.nbr.org/wp-content/uploads/woocommerce_uploads/sr97_chinas_digital_ambitions_mar2022.pdf

43 'Digital Southeast Asia: Opportunities for Australia–India Cooperation to Support the Region in The Post-COVID-19 Context', available at: https://www.orfonline.org/research/digital-southeast-asia/

Table 3: Initiatives towards 6G by Stakeholders in Select Countries

Countries	Government	Private Sector	Academia
China	China has a significant lead in the global 6G race. In November 2019, China officially launched 6G technology R&D efforts in collaboration with concerned ministries and national institutions. China's Ministry of Industry and Information Technology is investing in 6G R&D in the country. In 2020, the country launched a satellite to test the THz signal transmission, required for 6G.[44]	• Huawei, the leading Chinese ICT company, announced that it is now in the early stages of 6G research. It outlined a timeline for 6G development, including the vision for 6G by around 2023, standardisation by 2026, the rollout of relevant technologies by 2028, and preliminary commercial deployment by 2030. In 2020, telecom equipment giant ZTE and one of the three Chinese mobile operators China Unicom began working together on 6G technological innovation and standards.[45]	• Government-backed institute Purple Mountain Laboratories has claimed to have achieved a 6G transmission of speeds up to 206 Gbps. The tests were carried out in partnership with China Mobile and Fudan University.[46] The first 6G experimental satellite developed by China's University of Electronic Science and Technology was successfully launched in November 2020.[47]

44 'The Kick-Off Of 6G Research Worldwide: An Overview' available at: https://arxiv.org/ftp/arxiv/papers/2111/2111.10779.pdf

45 I*bid*

46 'Chinese Laboratory Hails 6G Breakthrough With Record Speed Test' available at: https://www.itpro.co.uk/infrastructure/network-internet/361927/chinese-laboratory-hails-6g-breakthrough-speed-test

47 Supra Note 44

Countries	Government	Private Sector	Academia
United States of America	The United States is attempting to reclaim its former glory as a global technological superpower and make up for lost technological ground through multi-stakeholder efforts. The Federal Communications Commission (FCC) announced in March 2019 that it had opened an experimental licence for the use of frequencies ranging from 95GHz to 3THz for 6G and beyond, facilitating THz communications testing. The FCC has also approved the first stage launch of 12,000 satellites, and another application for 30,000 more satellites is under consideration.[48]	The Alliance for Telecommunications Industry Solutions (ATIS), an American standards organisation, launched its Next G Alliance in October 2020, with founding members including AT&T, T-Mobile, Verizon, Qualcomm, Ericsson, Nokia, Apple, Google, Facebook, Microsoft, and others. The alliance will look at funding and research, manufacturing, and standards from a high-level strategic perspective, while also engaging the international community on standards, and how government and industry can work together. The goal of this private-sector-led industry initiative is to advance North American mobile technology leadership in 6G over the next decade.	
European Union	Europe is a world leader in the field of research, science, and	Hexa X is an important step toward bringing key industry	The University of Oulu in Finland has launched the 6

[48] Supra Note 44

Countries	Government	Private Sector	Academia
	engineering, accounting for 25% of all global ICT research. The EU has played a key role in establishing 5G standards through its 5G PPP under the Horizon 2020 research and science instrument. In December 2021, the EU established a Joint Undertaking on Smart Networks and Services for 6G (SNS JU), adopting its first Work Programme 2021-2022 with an earmarked public funding of approximately € 240 million.[49] The EU is also funding the Hexa X project through Horizon 2020, the European Union's research, and innovation funding programme. The EU has also released several strategies,	stakeholders in Europe together to take the lead in advancing 6G. The stakeholders represent the entire value chain of future connectivity solutions, including network vendors, communication service providers, verticals, and technology providers, as well as some of Europe's most prominent communications research institutes.[51] Finnish communications company Nokia is leading that project, which also includes Ericsson, a Swedish operator, and TIM in Italy. The group is expected to work on six primary issues of 6G: mass connectivity, sustainability, inclusion, affordability, extreme	Genesis research project with a budget of USD 300 mn, to develop a 6G vision for 2030. The university has also signed a collaboration agreement with Japan's Beyond 5G Promotion Consortium to coordinate the work of the Finnish 6G Flagship research on 6G technologies.[55]

[49] 'Europe Launches First Large-Scale 6G Research And Innovation Programme' available at: https://digital-strategy.ec.europa.eu/en/news/europe-launches-first-large-scale-6g-research-and-innovation-programme#:~:text=17%20December%202021-,Europe%20launches%20first%20large%2Dscale%206G%20Research%20and%20Innovation%20Programme,of%20about%20%E2%82%AC%20240%20million

[51] 'Nokia To Lead the EU's 6G Project Hexa-X' available at: https://www.nokia.com/about-us/news/releases/2020/12/07/nokia-to-lead-the-eus-6g-project-hexa-x/

[55] 6G Flagship, available at: https://www.6gflagship.com/

Countries	Government	Private Sector	Academia
	including the 2030 Digital Compass, the Strategic Compass, the Cyber Security Strategy, and the Standardisation Strategy, etc. To translate the ambitions of the EU's Digital Decade.[50] The EU has also funded consortiums such as RISE-6G, and NEW-6G, which will work on the technicalities of the 6G technology.	experiences, and trustworthiness. Many parallel projects on 6G and its technologies are also underway in the EU, including 6G BRAINS,[52] REINDEER led by Ericsson,[53] and 6G-ANNA,[54] to name a few.	
South Korea	South Korea intends to be the first country to launch commercial 6G services, with the first 6G trial scheduled for 2026. The country is expected to spend around $169 million developing key 6G technologies over the next five years, until 2025, with a special	As Huawei's products are increasingly being banned in various countries due to security concerns, Korean electronics giant, Samsung Electronics has accelerated its global ambition to become a major	South Korea's Electronics and Telecommunications Research Institute is researching the terahertz frequency band for 6G. It envisions data speeds 100 times faster than 4G Long-Term

50 'The Geopolitics Of Technology: How The EU Can Become A Global Player' available at: https://ecfr.eu/publication/the-geopolitics-of-technology-how-the-eu-can-become-a-global-player/

52 'Bringing Reinforcement Learning into Radio Light Network for Massive Connections (6G BRAINS)' available at: https://6g-brains.eu/

53 'Ericsson A Key Player in EU Drive to Develop 6G Multi-Antenna Technologies' available at:https://www.ericsson.com/en/news/2021/1/ericsson-in-eu-6g-drive

54 '6G-ANNA: Germany And The EU Reclaim Their Position As Technology Leaders With The Sixth Generation Of Mobile Communications' available at: https://www.fau.eu/2022/09/12/news/research/6g-anna-germany-and-the-eu-reclaim-their-position-as-technology-leaders-with-the-sixth-generation-of-mobile-communications/

Countries	Government	Private Sector	Academia
	focus on six critical areas, hyper-performance, hyper-bandwidth, hyper-precision, hyper-space, hyper-intelligence, and hyper-trust.[56] The Ministry of Science and ICT has unveiled a five-year project with a budget of USD 193mn for developing core technologies required for 6G.	telecommunications vendor. For this Samsung has established its dedicated Next-Generation Communication Research Centre. LG Electronics has also stated that it intends to lead the global 6G standardisation and create new business opportunities. LG opened its 6G Research Centre in January 2019 in collaboration with the Korea Advanced Institute of Science and Technology (KAIST).[57] Korea's finest technologists have formed a development partnership. LG, Samsung, and SK Telecom are all in the mix.	Evolution (LTE) networks and five times faster than 5G networks.[58]
Japan	Japan is taking individual initiatives to realise the vision of 6G and collaborating with other countries for it. The Japanese Ministry	Japan is said to be planning a $2 billion investment to encourage private-sector R&D of 6G technology.[60]	

56 '6G, Korea Takes The Lead Once Again' available at: https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=517&searchOpt=ALL&searchTxt=

57 Supra Note 44

58 Supra Note 6

60 *Ibid*

Countries	Government	Private Sector	Academia
	of Internal Affairs and Communications formed a working group to investigate next-generation wireless technologies in late 2017. In early 2020, the Japanese government established a dedicated panel of private sector and academic representatives to discuss technological development, potential use cases, and policy in future technologies.[59]	In December 2020, as a 6G-related initiative, Japan established the Beyond 5G Promotion Consortium in collaboration with industry, academia, and government. This consortium will also work to promote collaboration and cooperation with like-minded entities all over the world.[61] Toyota Motors, NEC, and other Japanese businesses are supporting Japan's efforts to lead the world in 6G standards. These private entities will join a government-backed group to study the technological requirements for 6G, giving Japan an early advantage.[62]	

Source: Multiple

59 Supra Note 44

61 'Beyond 5G: Japan's Collaborative Approach To Next-Gen Networks' available at:https://www.reuters.com/brandfeature/beyond-5g-japans-collaborative-approach-to-next-gen-networks

62 'Japan Eyes 6G Lead With Global Standards Backed By Toyota, Others' available at: https://asia.nikkei.com/Business/Telecommunication/Japan-eyes-6G-lead-with-global-standards-backed-by-Toyota-others

Table 4: Cross-Country Collaborations on 6G

Japan and Finland	Japan and Australia	Japan and the United States	South Korea and the United States
Industry groups of these countries have joined forces to conduct joint R&D of 6G communications technology.[63] Also in June 2022, Japan's leading mobile telecom carrier NTT DOCOMO and Finland's Nokia announced plans to conduct experimental trials of new mobile communications technologies in preparation for the targeted commercial launch of 6G services by around 2030.[64]	Osaka University in Japan and Australia's Adelaide University researchers have developed a silicon-based microchip with a special multiplex to divide data and enable more efficient management of terahertz waves. The new multiplexer covers more than 30 times the total spectrum allocated in Japan for 4G/LTE, and 5G, combined. Because bandwidth is proportional to data rate, the new multiplexer enables ultra-high-speed digital transmission.[65]	The countries have agreed to jointly contribute US$4.5bn to work together on R&D, testing and deployment of 6G through their Global Digital Connectivity Partnership.[66]	The two countries agreed at the Korea-US Summit 2021 to develop a future-oriented partnership in 6G and other future technologies and broaden cooperation to include joint research. The National Science Foundation (NSF) and the Institute for Information and Communication Technology Promotion (IITP) signed a Memorandum of Understanding (MOU) to collaborate on joint research in 6G, which will begin in 2021. The countries have developed the 6G R&D Implementation Plan, which outlines detailed action plans for becoming a global

63 'Japan Teams Up with Finland on 6G Development' available at: https://asia.nikkei.com/Business/Telecommunication/Japan-teams-up-with-Finland-on-6G-development

64 'Japan To Launch 6G Experimental Trials with Nokia' available at: https://asiatimes.com/2022/06/japan-to-launch-6g-experimental-trials-with-nokia/

65 'Silicon Chip Will Drive Next Generation Communications' available at: https://resou.osaka-u.ac.jp/en/research/2021/20210429_02

66 'US And Japan to Invest $4.5bn In Next-Gen 6G Race with China' available at: https://asia.nikkei.com/Business/Telecommunication/US-and-Japan-to-invest-4.5bn-in-next-gen-6G-race-with-China

Japan and Finland	Japan and Australia	Japan and the United States	South Korea and the United States
			leader in 6G technology, such as: 1) securing next-generation key original technologies; 2) dominating international standards and patents; and 3) laying the groundwork for 6G research and industry.[67]

Source: Multiple

3.1. The Case of Indo-Pacific, and India-Australia Partnership

The Indo-Pacific region boasts a vast market of consumers for online goods and services. The region has witnessed a significant increase in internet usage, primarily due to the popularity of mobile internet. Additionally, it has the largest number of technology start-ups. To take advantage of this technological revolution, many national governments in the area are implementing ambitious national digitalisation strategies.[68]

However, digital economic growth has been slow, uneven, and challenging in the region. While technology adoption is increasing, affordability, connectivity, and coverage remain significant challenges.

Digital development in the Indo-Pacific region has become the focus of geo-economic polarisation, with the US and China being the two main poles. This can be seen in international forums, including standards-setting bodies working on 6G. However, this is also leading to new partnerships being forged, and opportunities to deepen existing ones. The India-Australia relationship is one such example.[69]

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67 '6G, Korea Takes the Lead Once Again "6G R&D Implementation Plan' Established; available at: https://www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=18&bbsSeqNo=42&nttSeqNo=517&searchOpt=ALL&searchTxt=

68 'How Asia Can Boost Growth Through Technological Leapfrogging' available at: https://www.mckinsey.com/featured-insights/asia-pacific/how-asia-can-boost-growth-through-technological-leapfrogging

69 'Us-China Tension Can Give Way To India-Australia Partnerships On Critical Technology' available at: https://theprint.in/opinion/us-china-tension-can-give-way-to-india-australia-partnerships-on-critical-technology/524095/

India and Australia are in a geopolitically volatile region, given that it is experiencing an increase in mistrust, rivalry, and insecurity. Political problems are exacerbated by technological factors, such as uneven availability and potential misuse of technology, which may have implications for regional stability, especially considering the emerging 6G technology.[70] India and Australia are both emerging powers in the region, with complementary technological strengths. These have been discussed in the figure below.

Table 5: Snapshot of India and Australia's TECHNOLOGICAL STRENGTHS

India	Australia
Quickly becoming a global technology hub with its digital economy expected to be worth $1 trillion, by 2025. New investments in space and satellite technologies, smart cities, and a thriving start-up ecosystem are preparing India's economy to effectively capitalise on the digitalised world.[71] The world's second-largest telecommunications market, with approximately 1.16 billion mobile subscribers, which is expected to grow to 1.42 billion by 2024. The telecom industry's current contribution to Gross Domestic Product (GDP) is estimated to be 6.5 per cent and is expected to rise as the focus shifts to 5G deployments and other emerging technologies. A major power in the Indo-Pacific region and one of the factors contributing to its prominence is its large market. It is well-known as a trustworthy soft power in the region.	Australia has comparative global strengths in research, education, and training. The public sector in Australia is increasing its investment in technology policy expertise, and policymaking in that area is gradually becoming more strategic and long-term.[72] Australia's role as a first-mover in making sensitive critical technology policy decisions ahead of the rest of the world, such as banning 'high-risk' vendors from its 5G network in 2018, has resulted in governments worldwide looking to Australia for policy insight and advice.[73] Australia has been a world leader in mobile telecommunications for decades, with an innovative and competitive sector, an accommodating policy regime and a strong uptake of mobile innovations by Australian households.[74]

70 'Critical Technologies and The Indo-Pacific, A New India–Australia Partnership' available at: https://ad-aspi.s3.ap-southeast-2.amazonaws.com/2020-10/Critical%20technologies_0.pdf?VersionId=XWYJ1CHFPRHowYQcgeYRPD0LvmEEEGD7

71 *Ibid*

72 *Ibid*

73 *Ibid*

74 '5G Unleashed: Realising The Potential Of The Next Generation Of Mobile Technology' available at: https://amta.org.au/wp-content/uploads/2022/03/5G-Unleashed-Final-Report_combined-21-March-2022.pdf

Given the current state of geopolitics, India and Australia are the ideal partners for cooperation in the Indo-Pacific region due to their shared national interests and values. Both countries acknowledge their dedication to an open, secure, free, accessible, stable, peaceful, and interoperable Indo-Pacific cyberspace that abides by international law.

India and Australia share a commitment towards transparent and effective multilateral institutions and see each other as a key ally in establishing the global norms and standards that underpin the rules-based order. India and Australia have repeatedly expressed their interest in collaborating to advance their mutual interests through various multilateral fora, such as the UN and the ITU, in developing international standards, norms, and frameworks for cyberspace, as well as for critical and emerging technologies.[75]

In 2020, India and Australia elevated their strategic partnership, established in 2009, to a Comprehensive Strategic Partnership. Under the strategic partnership, the two countries have signed the Australia-India Cyber and Critical Technology Partnership (AICCTP) framework to collaborate on the development of next-generation telecom technologies, i.e., 5G and 6G, among other areas.[76]

3.2. Current Baseline Scenario in India and Australia with Respect to 5G

India: The 5G network is in the final stage of deployment in India. India launched its indigenously developed 5G Test Bed in May 2022. [77] Spectrum auction for 5G ended in August 2022. A total of 51.2 GHz of spectrum was sold of the total 72 GHz, approximately.[78] The government launched the first phase of its 5G services on October 1, 2022, under its National Broadband Mission.[79]

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75 Joint Statement on The Inaugural India-Australia Foreign Ministers' Cyber Framework Dialogue; available at: https://www.mea.gov.in/bilateral-documents.htm?dtl/34860/

76 'India, Australia reaffirm commitment to open, free and interoperable cyberspace, technologies' available at: https://www.thehindu.com/news/national/india-australia-reaffirm-commitment-to-open-free-and-interoperable-cyberspace-technologies/article38417554.ece

77 'Indigenous India 5G Test bed Project Launched; IIT Bombay Builds 5G Core' available at: https://www.timesnownews.com/technology-science/indigenous-india-5g-testbed-project-launched-iit-bombay-builds-5g-core-article-92538159

78 '5G Spectrum Auction Ends, Govt. Earns Over Rs 1.5 Lakh Cr.; Reliance Jio Top Bidder' available at: https://indianexpress.com/article/business/india-concludes-19-bln-5g-spectrum-auction-8064216/

79 'Launch of 5G services, This is not just India's decade, it is the century of India, says PM Modi' available at: https://www.thehindu.com/news/national/prime-minister-narendra-modi-launches-5g-services-in-india/article65958308.ece

Australia: Australia has been a world leader in terms of 5G rollout, which it started in 2019 and at present has three operational 5G networks (Telstra, Optus, and Vodafone).[80] Currently, it ranks third in the world in terms of 5G-connected devices per capita.[81] Australia has deployed significant 5G infrastructure, with around 4,000 5G base stations operational in 2021, and more were added in 2022. According to a PwC study, 5G in Australia has the potential to unlock billions of dollars in value-added uplift by 2030 across industries such as healthcare, mining, transportation, manufacturing, utilities, etc.[82]

Despite its early advantage in 5G deployment, Australia is expected to fall behind its international peers. According to GSMA Intelligence, Australia is predicted to drop from third to ninth place in 5G-connected devices per capita among 30 advanced economies by 2025. [83]

Given that India and Australia are at different stages of technological development, comparing the two countries' technological advancements is critical in determining what lessons they can learn from one another and what strengths they can each bring to the table to successfully pursue their symmetrical economic interests. India, which is currently deploying 5G services, can learn from Australia's 5G challenges and develop effective solutions to these problems in India, for instance, Australian businesses' inability to adopt 5G.[84]

Australia has been cautious and sensitive about its national security concerns, which led to the barring of Huawei and ZTE from participating in its 5G rollout in 2018[85], instead partnered with global industry leaders such as Ericsson, Nokia, and others. Considering India's ground-breaking advances in 5G developments, such as the

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80 Supra Note 74

81 'Introducing T25: Our Plan For Growth And Enhanced Customer Experiences' available at: https://exchange.telstra.com.au/introducing-t25-our-plan-for-growth-and-enhanced-customer-experiences/#:~:text=Our%20customers%20will%20keep%20enjoying,footprint%2C%20substantially%20increasing%20regional%20coverage.

82 'Insight – Australia's Multibillion-Dollar 5G Opportunities' available at: https://www.austrade.gov.au/news/insights/insight-australia-s-multibillion-dollar-5g-opportunities

83 Supra Note 74

84 *Ibid*

85 'Huawei and ZTE handed 5G network ban in Australia' available at: https://www.bbc.com/news/technology-45281495

development of indigenous test beds[86] and 5Gi standard[87], Australia can seek India's assistance in developing its national capacity for future technologies, particularly 6G, while maintaining national security.

3.3. India's 6G Vision

India has made substantial strides with over 700 million Indians, constituting 75% of rural and urban populations, using mobile and broadband services. This transformation has been integral in shaping India's vision of self-reliance and ensuring equal access to communication technology for both urban and rural citizens. Now, the global telecom sector is beginning to envision 6G. Although 6G is still in the conceptual stage, its promises of unified human-machine and machine-machine connectivity offer a glimpse into the future. It is projected to build upon 5G, offering more reliable, ultra-low latency, and affordable solutions that are nearly 100 times faster, promising to transform economies and lives across the globe.

Considering this, India must align its research with these upcoming technological advancements to facilitate a customised implementation of 6G, thereby improving access to resources, services, and information for all. This initiative can potentially alleviate regional and social infrastructure disparities, offering an alternative to mass urbanisation.

To guide this effort, the Technology Innovations Group in India has established six task forces to explore the potential impact of 6G. The recommended areas for research include mm Wave and Terahertz communications, fibre-broadband, Tactile Internet, and multi-sensor man-machine interfaces, among others.

With adequate funding, India is set to launch a 6G Mission, which will be divided into an ideation phase and a second phase dedicated to conceptualising and delivering solutions. The goal is not just a customised 6G implementation for India but acceptance and support from the global community, which could fast-track the commercialisation drive and open the way for further technological advancements.

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86 'Indigenous India 5G Testbed Project Launched; IIT Bombay Builds 5G Core' available at: https://www.timesnownews.com/technology-science/indigenous-india-5g-testbed-project-launched-iit-bombay-builds-5g-core-article-92538159

87 '5Gi Will Become Integral To 5G Standards For India And The World: TSDSI Chairman' available at: https://economictimes.indiatimes.com/industry/telecom/telecom-news/5gi-will-become-integral-to-5g-standards-for-india-and-the-world-tsdsi-chairman/articleshow/89188041.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

India's focus areas in this pursuit should include dense optical networks, AI/ML for network optimisation, tactile Internet, Intelligent network operation, and more. The standardisation of these technologies will further help streamline India's 6G roadmap, aiding efficient resource allocation.

Ultimately, 6G is expected to close the gap in the provision of e-services for urban and rural populations alike, aiding in the achievement of the UN-SDGs and improving the quality of life. This technology will also create opportunities for India's entrepreneurs to innovate and develop new products for the global market, transforming India into a world leader in providing transformative solutions.

Therefore, a comprehensive, mission-driven approach is crucial to leverage the benefits of 6G India's journey towards becoming a leading global provider of advanced, relevant, and affordable telecom systems and solutions can be propelled by ensuring engagement with all relevant stakeholders, including the research community and startups, with adequate financial backing.

Table 6: Status and Developments around 5G in India and Australia

India	Australia
Government Initiatives	
The Indian government established a High-Level Forum for 5G India 2020 in 2017. This forum was created to help India build its capacity in the design, development, and manufacturing of 5G-based technology, products, and applications.[88] Taking a step towards becoming self-reliant, the government of India developed indigenous 5G Testbeds and has offered free use to Indian Government	The Australian Government has launched the 5G Innovation Initiative to support projects that demonstrate the capability of 5G technologies in critical sectors like emergency services, resources, and public safety, among others.[96] So far, 5G technologies have been successfully tested for industrial use in agriculture, construction, meat processing, improved electricity grid reliability and safety, underground network wireless broadband technology, 5G-connected collaborative Robots, etc.[97] The initiative aims to assist

88 'Constitution of High Level Forum for 5G India 2020' available at: https://dot.gov.in/sites/default/files/Details%20of%20HLF%20for%205G%20India%202020_1.pdf#_blank

96 'Grants To Demonstrate The Value Of 5G To Businesses In Australia; available at: https://business.gov.au/grants-and-programs/australian-5g-innovation-initiative#:~:text=The%20%2420%20million%20Australian%205G,replicable%20testing%20of%205G%20technology

97 Australian Government Invests $20M For Innovative 5G Projects'; available at: https://publicspectrum.co/australian-government-invests-20m-for-innovative-5g-projects/

India	Australia
start-ups and MSMEs for six months from August 2022 to January 2023.[89] The Indian government has recently announced plans to establish 100 5G labs across the country, at least 12 of which will be converted into telecom incubation centres to train students and conduct experiments. Further, HFCL, a domestic telecom equipment manufacturer, has announced the launch of 5G Lab-as-a-Service to accelerate the deployment of 5G solutions and services. It will provide an automated testing environment in which the private sector, academia, and government can collaborate to bring product innovations from concept to reality.[90] The Indian government has invited Expressions of Interest for the "5G Vertical Engagement and Partnership Programme (VEPP)" initiative, which aims to build strong collaboration partnerships among stakeholders in the 5G use-case ecosystem. Under this initiative, the Department of Technology, Government of India, will assist the partners with the necessary approvals and regulatory clearances to enable use case prototyping,	businesses in increasing their productivity by leveraging innovative digital technologies, thereby creating jobs and supporting Australia's economy. The Australian Government under its 5G Innovation Initiative is supporting 19 projects across key sectors of the economy to explore novel uses of 5G. The projects range from tracking the transport of lifesaving medical supplies in remote areas to 5G-enabled livestock counting on farms.[98]

89 'Government Offers Use of Indigenous 5G Test Bed Free of Cost to Indian Government Recognized Start-Ups and MSMEs For the Next Six Months Up to Jan, 2023' available at: https://www.pib.gov.in/PressReleasePage.aspx?PRID=1849978

90 'Govt to set up 100 5G labs in country: Ashwini Vishnaw' available at: https://economictimes.indiatimes.com/industry/telecom/telecom-news/govt-to-set-up-100-5g-labs-in-country-ashwinivaishnaw/articleshow/94605334.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

98 Australian Government, Digital Economy Strategy, 2022 Update; available at: https://digitaleconomy.pmc.gov.au/sites/default/files/2022-03/digital-economy-strategy-2022-update.pdf

India	Australia
pilots, demos, and trials at the user or vertical industry premises.[91] India's own 5G core has been developed by the Centre for Development of Telematics (C-DOT), an autonomous Indian government-owned telecommunications technology development centre.[92] C-DOT is also allying with several industry and academic players to conduct 5G research and development collaboratively. C-DOT intends to deliver a full suite of 5G products over the next three years, for which the government has already allocated the budget.[93] The government of India is also heavily investing (nearly $30 billion), in developing effective telecommunication infrastructure for 4G and 5G in rural India to ensure last-mile network accessibility.[94] The government is running programmes like the Technology Incubation and Development of Entrepreneurs (TIDE) to help build national capacity in electronic	

91 '5G Vertical Engagement and Partnership Program (VEPP)' available at: https://www.mygov.in/task/5g-vertical-engagement-and-partnership-program-vepp/; and '5G Vertical Engagement and Partnership Program' available at: https://www.drishtiias.com/daily-updates/daily-news-analysis/5g-vertical-engagement-and-partnership-program

92 'C-DOT emerges as govt's biggest bet for India's ongoing 5G rollout' available at: https://www.business-standard.com/article/economy-policy/why-c-dot-is-govt-s-biggest-bet-for-india-s-ongoing-5g-network-rollout-122111001544_1.html

93 'C-DOT's "INDIA 5G ALLIANCE", Collaborative Development of 5G Technology for India' available at: https://www.cdot.in/cdotweb/web/5ghome.php?lang=en#:~:text=Therefore%2C%20C%2DDOT%20is%20forming,has%20been%20made%20for%20this.

94 'Govt investing $30 bn in creating 4G, 5G infra in rural India: IT Minister' available at: https://www.business-standard.com/article/economy-policy/govt-investing-30-bn-in-creating-4g-5g-infra-in-rural-india-it-minister-122092201263_1.html

India	Australia
and information technology fields. The Next Generation Incubation Scheme (NGIS) is another such programme designed to promote growth in the ICT sector. The government has also been implementing national policies to further strengthen manufacturing capacity in technology, such as the National Policy on Software Products, 2019; the government's scheme for promoting Electronics System Design and Manufacturing (ESDM); the Electronic Development Fund (EDF) and Promotion Linked Incentive (PLI) schemes, among others.[95]	
On Private Front	
There has been no significant representation from the private sector in the development of 5G in India. Though for the deployment of 5G services, Reliance Jio, Bharti Airtel, Vodafone Idea, and Adani Data Network Limited have emerged as the top players.[99] Bharti Airtel launched its 5G services in eight cities, including Delhi, Mumbai,	Trials of 5G technologies to be used in different industrial processes are being undertaken by the industry, under the 5G Innovation Initiative. These include: ● Telstra is extensively investing in the development of industry-specific advanced use cases of 5G (in Agri-Tech and Construction Business).[100] ● Nokia and the University of Technology, Sydney have developed the world's first private wireless and 5G connected digital microbrewery.[101]

95 'Consultation Paper on Promoting Networking and Telecom Equipment Manufacturing in India; available at: https://www.trai.gov.in/sites/default/files/CP_11022022.pdf

99 '5G Spectrum Auction Ends, Govt. Earns Over Rs 1.5 Lakh Cr.; Reliance Jio Top Bidder' available at: https://indianexpress.com/article/business/india-concludes-19-bln-5g-spectrum-auction-8064216/

100 'Telstra And Ericsson Supply Private 5G For Australian Agri-Tech Collective' available at: https://enterpriseiotinsights.com/20220201/channels/news/telstra-and-ericsson-supply-private-5g-for-australian-agri-tech-collective; and 'The 5G Future Has Arrived: Australian-Based Construction Company Successfully Trials 5G' available at: https://cradlepoint.com/press-release/the-5g-future-has-arrived-australian-based-construction-company-successfully-trials-5g/

101 'Nokia And University Of Technology Sydney Target The Perfect Pint With World's First 5G Connected Microbrewery' available at: https://www.nokia.com/about-us/news/releases/2022/05/15/nokia-and-university-of-technology-sydney-target-the-perfect-pint-with-worlds-first-5g-connected-microbrewery/

India	Australia
Varanasi, and Bengaluru, and plans to cover the entire country by March 2024. Reliance Jio notified that it will begin rolling out its 5G services on October 22 and committed to "deliver 5G to the entire country" by December 2023.	However, Australian businesses might lose out on potential productivity gains, as other countries adopt and capitalise on the benefits of 5G much faster than Australia. In fact, 73% of Australian businesses are yet to realise the full potential of 5G.[102]

3.4 The Way Forward with Respect to 6G

India and Australia, recognising the importance of mobile networks for economic prosperity and national security, have recently made significant progress in accelerating their 6G development processes. The advancement is being made both independently at the national level as well as through bilateral and multilateral engagements with like-minded states.

The countries will have to bilaterally cooperate to strengthen each other's technical prowess through developing R&D, effective regulatory framework, and standard-making capacity to better adapt and integrate 6G and other emerging technologies to capitalise on them.

As discussed above, India and Australia have complementary strengths that they can use to their advantage. For instance, India is one of the largest markets, and Australia may use India's enormous customer base to diversify its commerce. Further Australia has a comparative advantage in research, education, and training, which it can share with India by training educating, and leveraging to address Australia's skill shortage in the digital and technological sectors. India on the other hand, may collaborate with Australia, which has long been a global leader in mobile telecommunications to help build India the infrastructure needed to implement 6G technology.

India can also benefit from Australia, which has also been a leader in the adoption of new technologies and an accommodating policy regime for greater uptake of emerging technologies. Working together, both countries can develop niche solutions to country-specific problems, facilitating effective adoption of future technologies such as 6G, further strengthening their supply chains, and expanding trade and investment opportunities.

Table 7 summarises current developments in the emerging 6G technology.

[102] Supra Note 74

Table 7: Developments in India and Australia with Respect to 6G

India	Australia
Status	
The development of 6G in India is in a very early stage.	Australia strategised 6G development at an inception stage.
Government Initiatives	
In November 2021, The Department of Telecom (DoT) constituted a Technology Innovation Group (TIG) on 6G. Six academia-heavy task forces are formed under the TIG.[103] State-run telecom R&D organisation Centre for Development of Telematics (C-DOT) has begun developing 6G and other emerging technologies to catch up with the global market in time.[104] Notably, the government strives to develop 6G by 2030. Recently the Telecommunications Standards Development Society, India (TSDSI) has contributed to the IMT 2030, a document intended to address the "Motivation on driving factors for future technology trends towards 2030 and beyond" and drive the direction of 6G technologies. TSDSI submitted its 6G Vision to ITU-R with having focus on 4 key technology pillars:	The government is investing $10mn to establish a 6G R&D Programme under the Digital Economy Strategy, for undertaking skill development and training needed to make Australia a leading digital economy by 2030. Concurrently, the government is also exploring the viability, security, and regulatory implications of Open Radio Access Network (Open RAN) solutions within the Australian domestic context, to promote telecom market diversification. Australia is investing about $20mn to establish a 'Secure-G' Connectivity Test Lab, co-designed with the industry, enabling businesses to test measures, protocols, standards, and software that underpin secure 5G connectivity and other future networks (like 6G). Quantum computing, according to technological experts, will play a significant role in the transition from 5G to 6G communications systems, paving the way for smart systems and advanced computing.[105] In

[103] 'Government Sets Up Multiple Task Forces For 6G Development' available at: https://economictimes.indiatimes.com/industry/telecom/telecom-news/government-sets-up-multiple-task-forces-for-6g-development/articleshow/88618459.cms?from=mdr

[104] 'Telecom Secy. Asks Govt. Research Body To Start Work On 6G Technologies' available at: https://www.livemint.com/industry/telecom/telecom-secy-asks-govt-research-body-to-start-work-on-6g-technology-11633858207356.html

[105] 'Quantum Computing's Role in the Transition from 5G to 6G- it is Potential and Challenges' available at: https://ceur-ws.org/Vol-3080/14.pdf

India	Australia
• Technologies that aid the development of a ubiquitous intelligent mobile connected society; • Technologies to bridge the digital divide; • Support technologies that can personalise /localise services; and • Support technologies that can mimic real-world data ownership and hierarchies.	light of this, the Australian government will establish a Quantum Commercialisation Hub to work with other countries to commercialise Australia's quantum research.[106] AI is regarded as the new paradigm for the effective design and optimisation of future technologies such as 6G.[107] It is becoming increasingly clear that any country seeking to effectively exploit future technological avenues must develop a national capacity in AI. Keeping the foregoing in mind, the Australian government has developed an AI Action Plan, which is a shared vision for Australia to be a global leader in developing and implementing trusted, secure, and responsible artificial intelligence.[108] In 2022, the draft five-year spectrum outlook 2022–27 consultation sought stakeholder views on the Australian terahertz spectrum market and the need for regulatory arrangements. The ACMA is actively looking at various pricing mechanisms for terahertz spectrum[109]. The Australian government has updated its deregulation agenda to promote greater adoption of digital and emerging technologies like 6G while maintaining crucial safety nets. The agenda calls for the government to work on removing or updating all out-of-date regulations, with a focus on reducing barriers

106 'The Action Plan for Critical Technologies' available at: https://www.pmc.gov.au/sites/default/files/publications/ctpco-action-plan-critical-technology.pdf

107 'Artificial Intelligence-Enabled Intelligent 6G Networks' available at: https://arxiv.org/ftp/arxiv/papers/1912/1912.05744.pdf

108 'The Action Plan for Critical Technologies' available at: https://www.pmc.gov.au/sites/default/files/publications/ctpco-action-plan-critical-technology.pdf

109 'Terahertz use-cases and regulatory models Information paper' Available at: https://www.acma.gov.au/publications/2023-03/report/terahertz-use-cases-and-regulatory-models-information-paper

India	Australia
	to Australia's productivity growth and competitiveness. While updating regulations for new and emerging technologies, the government will ensure that they effectively reflect Australia's national values and interests.[110] Supply chains are becoming longer (more tiers), larger (more depth), and more complex as the world becomes more globalised and advanced technologies emerge, making them more vulnerable to disruptions. The fact that semiconductor is the fourth most traded product in the world after crude oil, refined oil, and automobiles demonstrates its significance and impact. In 2020, the world faced a semiconductor crisis. Learning from this, the Australian Government has created the Office of Supply Chain Resilience to identify and monitor vulnerabilities in critical supply chains. This is done to boost domestic manufacturing capability by diversifying the supply chain.[111]
On Private Front	
Many Indian firms such as Jio, Tech Mahindra and Wipro have been collaborating with international partners for the R&D of 6G. These include: ● In December 2019, Tech Mahindra signed an agreement with Business Finland for R&D on 5G and 6G. They will develop, and implement state-of-the-art digital products and services to	Nokia has announced a five-year deal with the University of Technology Sydney (UTS) to build and run a 5G innovation facility at the university's Tech Lab campus in Sydney, Australia. Researchers and commercial partners will undertake projects to explore the capabilities of 5G and 6G for Industry 4.0 applications. [115] The Australian Research Council and Ericsson are funding and partnering in the Terahertz

110 'Blueprint for Critical Technologies, Australian Government' available at: https://www.industry.gov.au/publications/blueprint-critical-technologies

111 'The Action Plan for Critical Technologies' available at: https://www.pmc.gov.au/sites/default/files/publications/ctpco-action-plan-critical-technology.pdf

115 'Nokia And University Of Technology Sydney Announce 5G Innovation Lab' available at: https://www.nokia.com/about-us/news/releases/2021/03/02/nokia-and-university-of-technology-sydney-announce-5g-innovation-lab/

India	Australia
foster growth, productivity, and innovations in 5G and 6G.[112] • Reliance Jio's Estonia unit has partnered with the University of Oulu to explore 6G, the upcoming next generation of telecom technology after 5G.[113] Furthermore, Nokia is betting on India to drive global standardisation for 5G advanced and 6G technologies and is expanding the scope and presence of its research arm, Bell Labs. Nokia is already working in rural areas of India to expand 5G applications.[114]	Radiation study conducted by the University of New South Wales (UNSW) Sydney. Terahertz (THz) radiation has a high bandwidth and strong penetrability, making it an ideal key technology for the next generation of non-intrusive imaging scanners and ultra-high bandwidth wireless communications beyond 100 GHz.[116] Researchers from Osaka University in Japan and the University of Adelaide in Australia collaborated to develop a multiplexer made from pure silicon for terahertz-range communications in the 300-GHz band. The multiplexer will handle terahertz waves, which are essential components of 6G, the next generation of communications, and beyond.[117]

112 'Tech M, Business Finland Ink Mou For R&D In 5G, 6G' available at:https://www.business-standard.com/article/pti-stories/tech-m-business-finland-ink-mou-for-r-d-in-5g-6g-119112101354_1.html

113 'Jio Partners With University Of Oulu Over Development Of 6G Technology' available at: https://indianexpress.com/article/technology/tech-news-technology/the-university-of-oulu-announces-its-6g-collaboration-with-jio-to-explore-digital-opportunities-7733762/

114 'Nokia Bets On India To Shape Global 6G Norms' available at: https://economictimes.indiatimes.com/industry/telecom/telecom-news/nokia-bets-on-india-to-shape-global-6g-norms/articleshow/91696215.cms

116 'Terahertz Innovation Group, School of Electrical Engineering and Telecommunications' available at: https://www2.ee.unsw.edu.au/terahertz/

117 'Ultra-Small 'Multiplexer' Silicon Chip Could Enable 6G And beyond' available at: https://interestingengineering.com/innovation/ultra-small-multiplexer-silicon-chip-could-enable-6g-and-beyond

4 Challenges Posed to and by 6G

Transitioning a network from one generation to another is a complicated process and poses multiple challenges, to which 6G might not be an exception.[118] This chapter attempts to identify challenges related to I) roadblocks in unlocking the potential of 6G and ii) risks posed and deepened by 6G.

4.1. Challenges in 6G Deployment

4.1.1 Lack of Infrastructure Readiness

The plethora of use cases and potential of 6G (as discussed in the previous chapter) requires extensive deployment of infrastructure that can support high data rates and low latency communications. Despite significant efforts, the previous generations of mobile communications have not been able to cover almost 2.9 billion people globally.[119]

According to an International Telecommunication Union (ITU) report, in the developed world the internet penetration rate is 87 percent but just 47 percent in developing countries and 19 percent in the least developed countries. 6G might exacerbate the urban-rural connectivity gap within developing and least developed countries as communication infrastructure is mostly concentrated in urban areas.[120;]

Lack of adequate rural telecom infrastructure will pose a complex challenge for 6G to be inclusive and scalable. Bulleted below are some of the infrastructural challenges in the path of 6G.

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[118] 'Towards 6G Internet of Things: Recent advances, use cases, and open challenges' *available at* https://www.sciencedirect.com/science/article/pii/S2405959522000959#b69

[119] 'Connected world: An evolution in connectivity beyond the 5G revolution' available at https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5g-revolution

[120] 'A Key 6G Challenge and Opportunity—Connecting the Base of the Pyramid: A Survey on Rural Connectivity', *available at* https://ieeexplore.ieee.org/document/904225; 'Connected world: An evolution in connectivity beyond the 5G revolution', available at https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5g-revolution

- Short range: 6G is expected to fall in millimetre waves (30 to 300 GHz) and terahertz radiation (300 to 3000 GHz). These frequencies will provide greater speed; however, the wave propagation (network coverage) will be much more sensitive to obstacles than the microwave frequencies which are being used in 5G and Wi-Fi. Due to the shorter wavelength/ range of 6G technology, deployment related to antennas would exacerbate the challenge of physical infrastructure.

  Such challenges are evident from the ongoing deployment of 5G in many parts of the world. This will be a major challenge for providing a 6G network in underdeveloped regions such as rural areas, especially in developing and least-developed countries, which may lack adequate communication infrastructure in such areas.

- Lack of fiberisation: Unlike 4G networks, 6G base stations containing many antennae will be used to coordinate the transmissions, minimise interference with each other, and send focused data to consumers. This will be connected via fibre optic cables or wireless microwaves and high and reliable connectivity will be dependent on it as 6G will carry large amounts of data. However, currently many networks are not fiberised.

  For example, in India, only 34 percent of the mobile towers are fiberised. This becomes particularly complex as private telecom operators are reluctant to expand their infrastructural capacities, particularly in rural settings.[121] To address these challenges, countries need to adopt a combination of different concepts such as better spectrum, deployment of microwaves and investment in infrastructural development.

- Backhaul limitations: Backhaul allows networks to interconnect massive devices from the core network. In terms of backhaul requirements, 4G has struggled with capacity, availability, deployment cost, and long-distance reach. However, this will be compounded in 6G with ultralow latency requirements and the ultra-dense nature of the network.

  Due to the dense antenna deployment and heavy traffic in 6G, a backhaul network will need to support hundreds of gigabytes of traffic from the core network, and current cellular backhaul networks are infeasible to meet these requirements in terms of higher capacity, faster speed, and increased network responsiveness for the diverse used cases.[122]

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[121] 'In-depth: Why India needs to urgently address backhaul problem?' available at https://telecom.economictimes.indiatimes.com/news/in-depth-why-india-needs-to-urgently-address-backhaul-problem/88972058

[122] 'Broadband Communications Networks' available at https://www.intechopen.com/books/6321

4.1.2 Spectrum Management

Spectrum availability and management is a growing concern due to tremendous growth in wireless-based systems and the evolution of radio communication technologies. The availability of adequate spectrum will be instrumental in the development and deployment of a 6G network. Bulleted below are some of the notable challenges of spectrum management for 6G.

- Tussles over allocation: Different parts of the spectrum are used for different technologies and applications and some spectrums often go unutilised due to undercapacity. This congestion has created a struggle between the public, private, space, and military sectors over frequency use. Private enterprises are advocating for direct spectrum allocation for private networks, allowing better network control and flexibility to manage solutions based on changing business needs.

  However, the whole set of technologies that come along with 5G technology, such as edge computing, IIoT applications and hybrid cloud need to be considered. Telecom companies will develop and deploy these, regardless of spectrum ownership. In this context, allocating spectrum to private enterprises will only limit their return on 5G investments.

  Tension for spectrum allocation will continue to gain paramount importance even within the licensed spectrum regimes to efficiently allow access to the spectrum locally and for coexistence with other users.[123]

  Telecom operators might not only need to share spectrum among themselves and with other private dedicated networks, but even within a single operator, multiple technologies will also co-exist and share a spectrum.[124] Accordingly, issues related to the efficient utilisation of the spectrum might get exacerbated.[125] The Indian task force on the spectrum also acknowledges the gaps in its management.[126]

- Congested bands: Since the 5G network started to deploy globally, over a couple of years, high amounts of new spectrum will be allocated for 5G and its

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123 Ibid

124 Ibid

125 '6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions', available at https://ieeexplore.ieee.org/document/9144301; 'Survey on Aerial Radio Access Networks: Toward a Comprehensive 6G Access Infrastructure', available at https://ieeexplore.ieee.org/document/9358097

126 Supra Note 9

evolutions.[127] For example, the broadcasters in India are citing multiple incidents of "disruptions" amid concerns over possible interference and potential outages once full-scale 5G services are launched across the country.[128] This poses a challenge as it might lead to a scarcity of spectrum as well as the issue of increasing interference; therefore, for 6G and its use cases, new spectrum-use methods will be critical.[129]

- Scarce availability, and reliance on lower frequency bands: Spectrum availability is scarce, and like 5G, 6G will use a range of frequency bands, i.e., low, and high-frequency bands. Although high-frequency bands offer high speed and low latency, their limited coverage range makes them less user-friendly. On the other hand, low-frequency bands will not offer great speed but they provide much-needed range, resulting in better network coverage.[130]

  Along with the high-band spectrum, the low-frequency spectrum will have a significant role to play as it provides wide-area coverage due to its superior propagation properties. As 6G is expected to transmit up to 1 Tbps per user; therefore, research on improved spectrum utilisation and management for both frequency bands will be important.

- Efficient utilisation of spectrum: Currently, multiple service providers are not utilising enough spectrum efficiently and effectively- thereby, re-farming, defragmentation, and harmonisation can act as corrective measures.[131] Recent policy discussions across the globe talk about these corrective measures which aim at repurposing spectrum bands to more efficient technologies and/or new services. Also, while efficient utilisation of spectrum is a global challenge, it is particularly complex in India. As compared to other countries, the availability of the licensed spectrum is significantly lower in India.[132]

- Cost of spectrum: This is another challenge in developing infrastructure for the 6G network in many developed and least developed countries across the globe.

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127 'Communications in the 6G Era', *available at* https://ieeexplore.ieee.org/document/9040431

128 'broadcasters cite 5G interference as guard band gets narrower', available at https://indianexpress.com/article/business/broadcasters-cite-5g-interference-as-guard-band-gets-narrower-8266693/

129 Ibid

130 Ibid

131 A bunch of radio wave holdings within a band into one contiguous block with the consensus of all telecom service providers.

132 'Setting Up Future-Ready India With 5G Roadmap: The Possibilities & Challenges' available at https://www.cnbctv18.com/technology/setting-up-future-ready-india-with-5g-roadmap-the-possibilities-challenges-14239622.htm

India is a good example in this regard, wherein telecom operators are struggling to make profits, and the high cost of spectrum compounds the issue further. **Governments have continuously aimed at gaining large amounts of revenue** through spectrum auctions.

Against this backdrop, there is a need to maintain a balance between the needs of the telecom operators, providing quality access to communication services to all, and continuing to boost government revenues through spectrum auctions.

4.1.3. Network Congestion

The upcoming 6G technology is expected to lead to a significant rise in mobile traffic, as it will connect an increasing number of personal devices. These devices include sensors, smart city devices, traffic, and industrial management systems, and more. This will further congest the network and make it difficult to provide stable connectivity to each device with consistent quality of service.

Due to this, the quality of service in 6G might be impacted as the network node will be carrying more data than it can handle, subsequently causing queueing delay, packet loss, or the blocking of new connections. If issues related to network congestion are not tackled, it might impact the telecom experience for consumers.

4.1.4. Need for Technical Standards

It is expected that 6G and 5G will coexist for a long period of time, as 6G will be an evolution of 5G and not a replacement technology.[133] Interoperability and integration of 6G networks and its related technologies will be increasingly dependent on technical standards.[134]

This will allow better integration and ensure greater access to emerging technologies to the end consumers. Accordingly, momentum for the standardisation of 6G has started to build, however, the development of technical standards needs to be carefully deliberated. The ITU is expected to develop the standard for 6G by 2030.[135] Thereby battles around patent rights and standard-making have begun among countries, given

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[133] 'What will the coexistence between 5G and 6G be like?' available at https://www.rcrwireless.com/20220829/architecture/what-will-coexistence-between-5g-6g-like

[134] 'Modern Trends Surrounding Information Technology Standards and Standardisation Within Organisations,' available at: https://www.igi-global.com/book/modern-trends-surrounding-information-technology/104754

[135] 'Make haste slowly - the long and winding road to 6G' available at: https://www.ericsson.com/en/blog/2022/2/the-long-winding-road-to-6g

that standards are the connective linkage between technology and the market, providing common designs for products and processes.

There has always been tension between telecom and software firms in the collaborative development of standards, and the latter seeks to roll out new features quickly, while the former aims towards global consensus building for these features. Historically, developing and least-developed countries around the world have been dependent on foreign mobile communication technology, due to a lack of Intellectual Property Rights (IPR) over technology. Policies that encourage harmonisation with global standards, technology generation and incentivising innovators to invest in R&D will be crucial.[136]

To do so, participating in and leveraging standards development holds immense importance as they will be instrumental in untapping the potential of the digital economy.

Box 3: Indian Experience

While actively participating in the development of international 5G standards via platforms such as 3GPP and ITU, India has accrued substantial relevant experience. Concurrently, Indian enterprises have developed distinct core competencies within specific domains.

During this ongoing process, there has been an enhanced comprehension of the Standards Development Lifecycle, particularly the procedures employed within the 3GPP, encompassing workflow and operational procedures. By capitalising on this acquired experience, India possesses the potential to contribute significantly to the development of 6G standards within various global entities, including but not limited to the 3GPP, ITU, IEC, IEEE, and one M2M. Such engagement could enable India to leave a substantial imprint in the realm of global standardisation, ensuring a notable quantity of key innovations originate from the nation.

Processes of standardisations are also important from the perspective of competition, intellectual property, and consumer welfare, as the mechanisms of processes lead to greater interoperability, connectivity, and the ability of the industry to generate network effects in terms of developing multiple associate technologies and allowing greater numbers of end consumers to access their services.

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[136] Supra Note 9

While the discourse around standard-making is often highly technical, they are gaining higher importance due to its strategic and economic implications. In 6G, emerging technologies such as the IoT and AI will be integral to its services and the future of the global economy, influencing global order.[137]

While in policy discussions around developing technological standards, national security considerations have become critical considerations, particularly after the controversy over Chinese technology companies.[138] This increasing realisation of uncertainty will be a challenge for developing a global standard for 6G.

4.2. Risks Deepened by 6G

4.2.1. Security

Security at all levels – end consumers as well within the operation of networks – of 6G will be critical.[139] These include the below.

- Security challenges in a cyber-physical world: In 6G, existing security mechanisms will not suffice because physical safety will increasingly depend on information technology and the networks we use for communication.[140] The diversity and interconnectedness of massive IoT devices and their control systems will continue to pose significant security risks. As development moves from 5G to 6G, additional security threat vectors will continue to rise.

  6G telecommunication will function on massive networks and billions of different devices, such as in-body sensors. These devices could provide a large attack surface for malicious actors and be used to initiate attacks. A multidisciplinary approach will be required in terms of technology, regulation, techno-economics, politics, and ethics to develop a trustworthy 6G.

- Quantum computing making cryptography irrelevant: The current 5G standard does not deal with the security issues raised by quantum computers because it

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137 'Connected world: An evolution in connectivity beyond the 5G revolution', available at; https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5g-revolution

138 'The US government's battle with Chinese telecom giant Huawei, explained', available at https://www.vox.com/technology/2018/12/11/18134440/huawei-executive-order-entity-list-china-trump

139 '6g White Paper: Research Challenges for Trust, Security and Privacy' available at http://jultika.oulu.fi/files/isbn9789526226804.pdf

140 '6G White Paper: Research Challenges for Trust, Security and Privacy' available at: http://jultika.oulu.fi/files/isbn9789526226804.pdf

relies on traditional cryptography. However, this will not be possible in 6G. Current cryptographic-based security mechanisms are vulnerable to attacks based on quantum computers. Authentication, access control, data transmission, and encryption, among others, are major security concerns in the 6G network.

- Enhanced vulnerable points of attack: Data collection by hyper-connected IoE to serve 6G applications will consist of huge interactions at different levels among users, sensors, applications, and networks through lots of data being produced and processed. Each device thereby increases the threat surface. Moreover, 6G depends on AI for fully autonomous networks- therefore, attacks on AI systems, especially ML systems, will affect the security mechanisms in 6G. The security threats ML systems face include poisoning attacks,[141] data injection,[142] data manipulation[143], model evasion, model inversion[144], model extraction[145], and membership inference attacks.[146]

- Cyberwarfare and attacks on critical infrastructure: Ransomware attacks on critical infrastructures were a major feature of 2021 (such as those against the Colonial Pipeline, the largest hydrocarbon network on the US East Coast; in another first, a ransom attack shut down the United States' largest meat processor's plants). The Department of Homeland Security puts the US ransom damages in the hundreds of billions of dollars for 2021. In the EU, Ireland's healthcare system suffered similarly from ransom attacks. The Internet is sufficiently opaque that its dark side can supply ransomware for hire[147].

  The attacks on critical infrastructure initiated by States on the other hand can lead to cyber warfare as witnessed between Ukraine and Russia. This

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141 Attacks where malicious users inject fake training data with the aim of corrupting the learned model.

142 Attempt to send data to an application in a way that will change the meaning of commands being sent to an interpreter.

143 An adversary makes subtle, stealth tweaks to data for some type of gain or effect.

144 Exploiting the imperfection of a trained model.

145 An adversary can collect data through query access to a victim model and train a substitute model with it to steal the functionality of the target model.

146 Allows an adversary to query a trained machine learning model to predict whether a particular example was contained in the model's training dataset.

147 ' 6G Means Redesigning Mobile Software Architecture for an Insecure World: Replacing the WWW and the Internet' available at: https://www.researchgate.net/profile/Antonios-Nestoras/publication/361736488_Europe's_Future_Connected_Policies_and_Challenges_for_5G_and_6G_Networks/links/62c2a6d71cbf3a1d12ac243f/Europes-Future-Connected-Policies-and-Challenges-for-5G-and-6G-Networks.pdf#page=92

requires extremely agile vulnerability detection and remedial actions to recover from such attacks, thereby minimising downtime and stopping the propagation of such attacks.

Annexure 4 provides details of the security threats envisioned in 6G networks and an overview of the solutions proposed for mitigating risk due to security vulnerabilities in 6G systems. A detailed report on risks and attacks on critical infrastructures is available here.

4.2.2. Privacy

From the end-user perspective, privacy concern is encapsulated around personal data related to identity, location tracking, reactions, emotions, etc. Striking a balance between privacy and intelligence would be critical in 6G communications. AI algorithms require access to personal and non-personal data to optimise network operations and provide high-quality services. Even with de-identified data sets, there are insights about consumers, consumers' relationships, habits, and preferences which will pose a significant threat to the consumers' privacy.

With 6G, more and more intimate data will be harvested which requires a progressive regulatory framework around data protection that takes a balanced approach for all stakeholders including people, businesses, and government. Further, International Mobile Subscriber Identity (IMSI) is prone to reveal the identity of mobile users.

4.2.3. Challenging the Fundamental of Net Neutrality

Mobile broadband services have gained critical importance in everyday socio-economic practices. The ongoing deployment of 5G telecommunication networks across the world has intensified the discourse around net neutrality due to its features such as network slicing and cloud computing.

Features such as network slicing allow telecom operators to provide different quality of services to different applications under different pricing standards which conflicts with the principle of equal access and non-discrimination. This might result in telecom operators charging different prices with uneven quality of service.

Net neutrality has long been a critical issue, which effectively ensures that mobile network operators treat every available data equally, fairly, and indiscriminately. These principles have played a substantive role in ensuring innovation, competition, and rights for consumers in accessing internet services by ensuring fair and non-discriminatory access to information.

In 6G this tension might be further aggravated. Therefore, ensuring net neutrality, as well as open and free internet, and balancing it with the business models of 6G will aggravate the complexity at the regulatory level.

4.2.4. Battery Life

More research is required to develop a sustainable future around 6G, as it is expected to enable data-intensive technologies that require a significant power supply.[148] In the development of 6G networks, telecommunication network researchers are paying considerable attention to the battery life of mobile devices and service classes[149], rather than data rate and latency.[150]

From a consumer standpoint, the battery of mobiles will be required to relook as data consumption will consume more and more power. Challenges related to the charging of smartphones and tablets become cumbersome in 4G/LTE networks and continue to be an issue in the 5G era. The way that we choose, use, reuse, and recycle materials in the production of products can greatly reduce the total cost of ownership, help extend network connectivity to remote areas, and provide access to networks in a sustainable and resource-efficient manner.

The research on the 6G communication networks is focusing on low energy consumption and long battery life to remove the constraints of daily charging. For this, it is being explored that the computing tasks of a user device can be off-loaded to smart Base Stations (BSs) with reliable power supply or pervasive smart radio space in 6G.[151] Various energy-garnering methodologies would be applied in 6G, which not only garner energy from ambient radios but also energy from micro-vibrations and sunlight[152]. Long-distance wireless power charging would also be a promising approach to extend battery life.[153] Cooperative relay communications and network

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148 'Terahertz Imaging and Sensing Applications with Silicon-Based Technologies,' available at: https://ieeexplore.ieee.org/document/8576551

149 '6G Vision and Requirements: Is There Any Need for Beyond 5G?' available at: https://ieeexplore.ieee.org/document/8412482

150 'Evolution of Physical-Layer Communications Research in the Post-5G Era'. available at: https://ieeexplore.ieee.org/document/8603730

151 'Ambient backscatter communications: A contemporary survey' available at: https://ieeexplore.ieee.org/document/8368232

152 'Energy harvesting wireless communications: A review of recent advances' available at: https://ieeexplore.ieee.org/document/7010878

153 'Keynote speakers: Wireless power transfer: From long-distance transmission to short-range charging,' available at: https://ieeexplore.ieee.org/document/6757202

densification are also being investigated to help reduce the transmit power of mobile devices by reducing the per-hop signal propagation distance.[154]

4.2.5. Environmental Implications

Along with challenges related to battery life, energy efficiency is a major factor that will determine the design of ultra-fast next-generation networks, as climate change has become a central agenda globally. The deployment of 5G networks has highlighted the fact that software-based systems consume more energy, thus requiring measures to improve energy efficiency. For example, the 5G networks deliver a higher bandwidth at the cost of higher power consumption in comparison to the 4G networks. 6G is expected to exacerbate this situation.

Since 6G is still in its initial development phase, its long-term effects on the environment are uncertain. However, there are already concerns that immersive technologies might compound the existing negative effects on the environment due to the requirement of multi-fold power consumption. ICT is responsible for about 4 percent of global electricity consumption and 1.4 percent of global carbon emissions. Data storage centres that handle and store our information use enormous amounts of energy—as much as 80 percent of total network energy.[155]

4.2.6. Health Related Risks

Concerns have been raised regarding the health impact of radiofrequency in the 6G network due to increasing antenna installation. It is being claimed that closer and more intense interaction with radiofrequency might increase the risk for glioma, a malignant type of brain cancer. These health-related claims need to be further investigated and tackled. Further physical layer security attacks on human body networks using biosensors could lead to catastrophe.

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[154] 'Energy-efficient cooperative relaying over fading channels with simple relay selection' available at: https://ieeexplore.ieee.org/document/4600214

[155] 'Beyond the Energy Techlash: The Real Climate Impacts of Information Technology' available at: https://itif.org/publications/2020/07/06/beyond-energy-techlash-real-climate-impacts-information-technology/

5 The Way Forward

The opportunities to be unlocked by 6G are immense. However, as mentioned in previous chapters, there are various roadblocks to achieving them. Broadly, it needs to be ensured that 6G is sustainable,[156] based on the three primary parameters as have been discussed below.[157]

5.1. Economic Sustainability

6G unlocks new business opportunities to help different sectors improve profitability in operations. It is important to ensure that emerging technologies are accessible to both individual consumers and businesses.

- Deploy an optimal mix of non-terrestrial and terrestrial modes: Terrestrial nodes are comparatively low in cost, in contrast to non-terrestrial nodes such as satellites, drones and other mobile nodes. Moreover, the 6G requires high-quality network nodes to maintain the highest QoS which is also costly. Accordingly, non-terrestrial nodes may be deployed sparingly, and only as a complementary technology to terrestrial nodes to keep the cost low.

- Keeping the price of 6G services and compatible hardware in check: Smart devices are costly and may not be affordable to everyone. Also, many countries are already suffering from high prices of mobile data services, which may further rise with the advent of 6G. To address such concerns, it is crucial to implement efficient regulations that focus on promoting competition and safeguarding consumer rights.

- Spectrum reuse and sharing: These can increase the efficiency of THz signals. Some techniques already exist for spectrum reuse, which helps multiple wireless systems to access the same spectrum. In the case of spectrum sharing, temporally underutilised or unlicensed spectrum is utilised to maintain

156 'Cannibals with forks: The triple bottom line of 21st-century business' available at: https://www.pdfdrive.com/cannibals-with-forks-the-triple-bottom-line-of-21st-century-business-e185853830.html

157 'Sustainability and spectrum management in the 6G era' available at: http://jultika.oulu.fi/files/nbnfi-fe202201179002.pdf

availability and reliability. More technical research is required to deploy spectrum reuse and sharing technologies.[158]

- Reassessment of spectrum Sharing practices: Encourage the shared use of spectrum, especially in higher frequency bands where propagation characteristics are like light. This approach can maximise the efficient utilisation of available spectrum resources while ensuring compatibility and minimising interference among users. By exploring shared spectrum models, we can unlock additional capacity and enable the deployment of innovative applications and services. Furthermore, conduct a thorough reassessment and rationalisation of congested spectrum bands. Identify areas where spectrum resources are underutilised or inefficiently allocated. We can improve spectrum utilisation, reduce congestion, and foster new use cases by reallocating or repurposing bands.

- Alternate spectrum signals: Given that the generation of THz signal is costly, and 6G is claimed as a low-cost communication service, there is a need to explore new communication alternatives such as Visible Light Communication (VLC),[159] Molecular Communications (MC),[160] and Quantum Communication (QC)[161]. Each of these has its own merits and demerits.[162] Further technical research and a cost-benefit analysis (CBA) are necessary to determine appropriate technology.

- Achieving high data rates: 6G requires a high data rate of 1 Tbsp to enable many of its high-reliability use cases like AR/ VR, smart healthcare, smart cars, etc. Highly efficient radio frequency will help in achieving high data rates. This

158 '6G Communication: Envisioning the Key Issues and Challenges' available at: https://eudl.eu/pdf/10.4108/eai.11-11-2020.166959

159 VLC uses cheap light emitting diodes (LED) to achieve higher frequency bands. However, the VLC has issues with coverage and noise interference from other sources of light. Thus, VLC is used in a confined arena that does not have any interference from other sources of light.

160 MC uses biochemical signals for data transmission. Biochemical signals are particles having size from a few nanometres to a few micrometres and propagate in a gaseous or aqueous medium. The advantages of MC signals are that they are biocompatible, consume less energy for production and transmission, and give high data rates. However, it creates challenges for security and effective interface between chemical and electrical domains.

161 Quantum particles or photons are utilised to encode data in a quantum state. It makes the data access and cloning by hackers difficult. The advantages are high security, high data rates and effective long-distance transmission. However, it is at an early stage of development and has a long way to go before being considered as an alternative to the THz signal.

162 '6G Communication: Envisioning the Key Issues and Challenges' available at: https://eudl.eu/pdf/10.4108/eai.11-11-2020.166959

requires a balance between radio frequency technologies, communication, and signal processing, which is dependent on the materials used in the transmitter and receiver antenna of 6G hardware. Research in ongoing on new materials such as nanomaterials, bio-based, foams, room-temperature fabricated materials and ultra-low permittivity.[163] The same needs to continue with public private and academic partnerships.

- Flexible and self-healing network: There is a need to construct a flexible and self-healing 6G network, which can provide stable network services, even when in case of network breakdowns. In other words, 6G networks should be able to provide service when part of its infrastructure is disabled due to natural disasters, local disturbances, deliberate malicious attacks, etc.[164] This will help in providing a reliable 6G service for its diverse applications in manufacturing operations, healthcare, autonomous vehicles etc.

- Interoperability: Given that the 6G network will be divided into heterogeneous sub-networks and will also need to integrate both non-terrestrial and terrestrial communication networks, interoperability will play a key role in 6G. Adopting global collaborative and harmonised standards would be essential in this regard.

- Influence Global Discourse on Standards: To ensure the widespread adoption and global impact of our innovations, it is important for India and Australia to actively participate and contribute to global standards forums. By engaging in these forums, both these countries can work towards establishing interoperability and compatibility between different systems and technologies.

  This collaboration will allow both these countries to align innovations with international standards, ensuring seamless integration and compatibility on a global scale. By actively contributing to these discussions, India and Australia can influence the development of standards that promote interoperability, security, and reliability. This ensures that innovations can effectively connect and communicate with other systems and devices, facilitating seamless global reach and widespread adoption.

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163 *Ibid*

164 '6G – Connecting a cyber-physical world' available at: https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g

5.2. Social Sustainability

New technologies unlocked by 6G must contribute to increasing the social capital, i.e. improve public health, provide skills and education development opportunities, enhance privacy and cyber security, decrease the digital divide to include all in society and leave no one behind.

- Reliance on Low-Earth Orbit (LEO) satellites for inclusive access: One of the key drivers of adopting LEO satellites is that they complement the coverage of terrestrial networks to help connect the unconnected, motivated by commercial potential, economic development, and humanitarian considerations of bridging the digital divide.[165] This could be especially useful in providing connectivity in challenging terrains like dense forests, mountains, remote rural areas, and islands.

- Confidential computing: it provides hardware-based isolation for the processing of data in cloud computing, which a cloud provider cannot tamper with, i.e. it prevents a bypass by the cloud provider owning the hardware. Confidential computing also has the potential to enhance the security of network slices. Its end goal is to create a system that offers privacy for all deployed software, as well as the protection of data from unauthorised access.[166]

  Other tools, such as Post-Quantum Cryptography (PQC) and Quantum Key Distribution (QKD), must also be explored and developed for building ultra-safe networks.[167] These enable communicators to generate and share a random and secure key to encrypt and decrypt messages to ensure communication security.[168]

- Fibre-Broadband Connectivity: Deploy fibre-broadband connections to every home, enabling high-speed and reliable internet access. By extending fibre-optic networks directly to residential premises, we can provide robust connectivity capable of supporting bandwidth-intensive applications and services. This approach ensures a future-proof infrastructure that can meet the growing demand for data and enable a connected society.

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165 'On the Path to 6G: Embracing the Next Wave of Low Earth Orbit Satellite Access' available at: https://arxiv.org/ftp/arxiv/papers/2104/2104.10533.pdf

166 '6G – Connecting a cyber-physical world' available at: https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g

167 'SoftBank outlines 12 challenges for 6G' available at: https://www.telecomtv.com/content/6g/softbank-outlines-12-challenges-for-6g-42096/

168 '10 Challenges Of 6G' available at: https://www.bt-pon.com/10-challenges-of-6g.html

- Global cyber-security assurance and certification: cyber security certification (such as EU's Cybersecurity Act, 2019) and assurance schemes (like GSMA Network Equipment Security Assurance Scheme) are receiving a lot of attention these days, and rightly so. As discussed previously, these will gain more prominence with the emergence of 6G and its use cases. These measures enhance the cybersecurity of digital products and services and provide security assurance for specific product versions.

  Moving forward, they should increase their ambition to consider all aspects of system security, including networks in operation, and not remain restricted to product security. However, such certifications and assurances must come with global standards after consensus of all stakeholders.[169]

- Propelling other privacy preserving technologies: THz communication is expected to make the 6G, eavesdropping and jamming proof. Blockchain is another prominent technology to achieve more privacy, secrecy, and security. Deploying federated AI also increases security. Although 6G will provide a high level of security, it must protect many vulnerable points, such as battery-draining attacks. Collaborative research is needed to guard 6G networks from such attacks, which may be based on the principle of privacy by design.

- Overcome health implications: attention needs to be paid to the possible health implications of using higher frequency ranges. Health concerns arising from the side effects of radiation, resulting in thermal hazards to the human body, such as eye and skin damage need to be watched out for. More research in this area is needed to create acceptable 6G standards, along with rigorous regulations for 6G device manufacturers.[170]

5.3. Environmental Sustainability

6G driven technologies should seek to reduce the expected carbon footprint by focusing on efficient energy consumption in operations.

- Improving energy efficiency of 6G devices: As discussed in the previous chapter, 6G devices will be high in energy consumption. To solve the issue of harvesting, charging and conservation of energy, there is a need to embed AI with 6G, AI algorithms are low compute-intensive and require less power. Research is

[169] '6G – Connecting a cyber-physical world' available at: https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g

[170] 'From 5G to 6G—Challenges, Technologies, and Applications' available at: https://encyclopedia.pub/entry/history/show/53890

ongoing on algorithms which integrate energy, computation, and communication.[171]

- Revisit telecom operations *wrt* environmental targets: Reporting on emissions and actions for achieving environmental targets is important to ensure a green 6G. The process should be open and allow contributions from researchers, academicians, and stakeholders, not just self-evaluation by industry players. Detailed data and actions on energy efficiency and energy consumption among other sustainability-related metrics should be made available to them, thereby allowing them to develop new methods to assess and reduce resource consumption based on real data, which today is a bottleneck.[172]

- Reduce dependency on batteries: given that 6G is likely to enhance the number of connected devices, the issue of toxic waste from electronics cannot be overlooked. Batteries contain hazardous chemicals that are not eco-friendly if left in nature to decompose. Accordingly, one of the expectations from 6G would be wider adoption of energy harvesting (ambient energy in the form of light, vibrations, temperature differences, or even radio waves and laser beams) to strive for battery-free devices.[173]

  Furthermore, batteries installed at base stations emit greenhouse gases. Carrying out R&D to make base stations carbon-free becomes important in this regard.

- Recycling 6G hardware waste: the exponential increase in connected devices would contribute to the annual electronic waste increase, which can harm the environment, given that they contain toxic materials such as mercury, arsenic, and chromium. It therefore becomes important to emphasise the need for electronics recycling in the international communication standards of 6G, improve the efficiency and performance of the disposal process, and spread awareness among consumers to participate in the recycling process.

  Also, the possibility of fabricating chips using green biological materials, such as microbes, allowing for the recycling process to take place with less-toxic materials may be explored.[174] One way to enable a circular economy is to track

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171 '6G Communication: Envisioning the Key Issues and Challenges' available at: https://eudl.eu/pdf/10.4108/eai.11-11-2020.166959

172 'Sustainability and spectrum management in the 6G era' available at: http://jultika.oulu.fi/files/nbnfi-fe202201179002.pdf

173 'From 5G to 6G—Challenges, Technologies, and Applications' available at: https://encyclopedia.pub/entry/history/show/53890

174 *Ibid*

goods throughout their entire lifecycle and use digital asset tracking, which may be possible with 6G.[175]

The issues discussed above are universally applicable in the development and deployment of 6G across the globe. However, as discussed in the previous chapter, there is a need and potential for India and Australia to work together on 6G. Given below are a few recommendations for the two countries, which may help them in exploring synergy amongst them on the subject.

5.4. Collaboration between India and Australia in the Indo-Pacific Region

India and Australia have the potential to partner in cyber and critical technologies, including 6G, to support digital development in the Indo-Pacific region. The two countries should take a coordinated approach to their digital engagements with countries in the region and consider establishing a Joint Working Group on Digital Engagement to bring together like-minded partners. Such collaboration should seek to address the following:[176]

- Digital knowledge and digital business skills shortage in the workforce: to release the full potential of 6G within individual countries as well as in the region as a collective, regional initiative may be taken by India and Australia, which seek to connect with existing local digital skilling programs. One area of focus is to support female entrepreneurship in the digital space and improve access to online courses and training for MSMEs.

- Fostering innovative ecosystem: To foster innovation and advancement, it is crucial to establish innovative funding mechanisms that support various sectors such as industry, startups, academia, and laboratories. Australia and India can collaborate to create mechanisms that enable them to engage in research and development (R&D) activities and pursue selected risky pathways in the pursuit of breakthrough discoveries.

  This partnership can play a vital role in facilitating the successful commercialisation of innovations, exploring uncharted territories, and taking calculated risks that have the potential to revolutionise industries and sectors. Collaboration between different stakeholders, including industry players,

[175] '6G – Connecting a cyber-physical world' available at: https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g

[176] 'Digital Southeast Asia: Opportunities for Australia–India cooperation to support the region in the post-COVID-19 context' available at: https://www.orfonline.org/research/digital-southeast-asia/

startups, academia, and national laboratories, fosters a collaborative ecosystem that leverages diverse expertise, resources, and networks.

- Improve cyber resilience: As has been established in the previous chapters, 6G is likely to come with various cyber-security vulnerabilities, especially in the Indo-Pacific region. This may be overcome by undertaking initiatives to strengthen relationships with national cyber security agencies and national Computer Emergency Response Teams (CERT) in the Indo-Pacific. Exploring ways to share collective resources, expertise, and experiences more effectively would be a good step in this regard.

  Furthermore, India and Australia countries should start sharing strategic assessments of the regional cyber threat landscape with Indo-Pacific partners. It has been alleged that the current digital engagements among Indo-Pacific countries are a mere patchwork of various initiatives that cover political, operational, infrastructure, and trade issues.

  However, they lack an overarching framework, which may include initiatives towards undertaking cyber risk awareness campaigns, arrangements for Public Private Partnerships (PPPs), and establishing a common, free, open-source threat intelligence sharing platform and security advisory.

- National level but regionally integrated broadband deployments: India and Australia must ensure universal broadband coverage in the region to make the 6G technology more inclusive. There appear to be significant opportunities for the two countries to leverage initiatives like the United Nations Economic and Social Commission for Asia and the Pacific's (UNESCAP) Asia-Pacific Information Superhighway and the UN Broadband Commission for technical deployment, financing arrangements, commercial uptake, and community awareness, on national level, but regionally integrated broadband networks amongst Indo-Pacific countries.

- Contributions to Standard Setting: India and Australia, being large countries in the ITU Region can collaborate and provide inputs to the standard-setting process, especially with respect to radio spectrum and Radio Access Networking technologies.

5.5. Areas for Further Research

Considering the above, there are many issues which require a detailed study for successfully developing and deploying 6G. Accordingly, Consumer Unity & Trust Society (CUTS), along with its project partners – the International Institute of Information Technology, Bangalore (IIIT-B), and Australian Risk Policy Institute (ARPI) propose to work on the issues mentioned below.

- Exploring strategic opportunities for India and Australia with respect to 6G: apart from the issues listed above, there is a need to explore opportunities for increased synergy between the two countries. This would require increased collaboration between different stakeholders from each country – academia, government, and industry (telecom and internet service providers, manufacturers, and equipment providers, among others).

  They would be required to adopt a cross-learning approach on various issues discussed in this report this may be based on a detailed Strength Weakness Opportunity Threat (SWOT) analysis of various indicators such as: the status of infrastructure available, spectrum management, contribution to standards, mature and robust regulatory landscape, investments in R&D, deployed use cases of 5G, uptake of 5G, influence on international discourse and in international forums, cooperation with other Indo-Pacific countries, among other areas.

- Standard setting for 6G: this is one of the most crucial issues in the discourse around 6G in global forums like the ITU and the Institute of Electrical and Electronics Engineers (IEEE). With patent filing already on the way from several countries, coupled with risks of fragmentation of technology standards in a politically polarised world, it is imperative to build global consensus on having harmonised standards for 6G.

  The role of India and Australia to build such consensus amongst other Quad countries and those falling within the broader Indo-Pacific region becomes important. Due attention would need to be given by the two countries to each other's national interests and priorities, status and direction of R&D efforts, and experience of participating and contributing to telecom technology standards, among other considerations wrt 6G.

- Developing an ethical framework for 6G: identifying and examining the elements of an ethical framework for 6G is another aspect which needs to be delved into. Considering the challenges identified in this report, such elements may include competition and consumer protection, security and privacy, inclusivity and trust, and interoperability, among others. Accordingly, adopting a principles-based approach during the development and deployment of 6G becomes an area requiring further research.

Annexures

Annexure 1: Contribution of ICTs to Sustainable Development Goals

S. No.	SDG	Contribution by ICT
1	No Poverty	ICT and telecom infrastructure can boost local economic growth in poor communities and provide access to digital financial services and employment opportunities.
2	Zero Hunger	Farmers can improve crop yields and productivity by utilising technologies like the Internet of Things (IoT) which are facilitated by next-generation telecommunication technologies.
3	Good Health and Well-being	ICTs can help connect patients to doctors using telemedicine, digitising medical records, and utilising AR/VR technology for medical training, etc.
4	Quality Education	With education going digital during the pandemic, high-speed internet connection through reliable telecom networks can facilitate students to learn from a distance.
5	Gender Equality	Access to internet-connected mobile phones with women and persons from the third gender can help in promoting equality by providing life-enhancing opportunities like access to work
6	Clean Water and Sanitation	ICTs can enable smart water management, thus preventing clean water supply from getting polluted, among other things. ICT systems can also help in effectively managing sewage treatment systems etc, thus providing better sanitation facilitates
7	Affordable and Clean Energy	ICT are energy sector are connected in two ways – (i) greening of ICTs and (ii) greening through ICTs
8	Decent Work and Economic Growth	ICTs help by digitising businesses and thus, help create new employment opportunities. New-age solutions like fintech are providing newer opportunities to entrepreneurs for accessing credit, etc.

S. No.	SDG	Contribution by ICT
9	Industry, Innovation, and Infrastructure	In the industrial sector, IoT systems are finding newer applications every day. Further, industries also require a high-speed internet connection for managing their day-to-day operational work, among other things.
10	Reduced Inequality	Mobile communication will promote access to information which will facilitate social and political inclusion, thereby reducing inequality
11	Sustainable Cities and Communities	Technologies like IoT can help make cities smart. Further, remote working becomes possible which can help reduce the burden on bigger cities.
12	Responsible Consumption and Production	Smart systems like smart grids, smart metering etc can reduce consumption. Further, ICTs can be used to optimise production lines and increase efficiency in industries.
13	Climate Action	Connecting through ICTs can help reduce carbon emissions as the need to travel would be reduced. Further, smart solutions can reduce energy consumption, thus helping in climate action.
14	Life below Water	ICTs can help provide real-time monitoring of data below water and help in the conservation of biodiversity. Further, applications like autonomous underwater vehicles can be enabled using ICTs.
15	Life on Land	ICT can facilitate the conservation of biodiversity and the environmental ecosystem through real-time monitoring of pollution, weather patterns, and ecosystem evolution and plan corresponding mitigation plans.
16	Peace, Justice, and Strong Institutions	ICTs can help prevent violence by enabling lawful surveillance. However, a strict data protection regime needs to be in place to prevent misuse and unlawful surveillance.
17	Partnership for the Goals	ICT can be a sector for creating public and private sector partnerships.

Source: White Paper on 6G Drivers and the UN SDGs[177]

[177] 'White Paper on 6G Drivers and the UN SDGs' available at: http://jultika.oulu.fi/files/isbn9789526226699.pdf

Annexure 2: Key Telecom-related Initiatives in India

India

Programs by the Government of India, such as Digital India, Smart Cities, Digital Saksharta Abhiyan (DISHA), National Broadband Mission, Industry 4.0, and others, are expected to increase demand in the telecom market.[178] The government of India has enacted several policies to encourage R&D and manufacturing grit in India's telecom sector. Following are some of the significant schemes and policies recently adopted by the government.[179]

- The National Digital Communications Policy, 2018, aims to eliminate regulatory barriers, create appealing investment opportunities in new technology segments, and stimulate the deployment of new technologies in India.

- The National Policy on Software Products, 2019, was issued to develop a sustainable Indian software product industry, entrepreneurship and innovation, domestic market access, and cross-border trade promotion, etc.

- The Ministry of Electronics and Information Technology (MeitY) has a special scheme for promoting Electronics System Design and Manufacturing (ESDM) covering Auto Electronics, Industrial Electronics, Medical Electronics, Strategic Electronics, etc.

- The preferential Market Access scheme envisions preference for domestic products and services with domestically owned IPR in government procurements.

- The government has different Promotion Linked Incentive (PLI) schemes for the telecom sector: i) in domestic manufacturing of telecom and networking products, ii) for the development of India's semiconductor and display ecosystem and iii) for large-scale electronic manufacturing with a target segment of specific electronic components.

- The Electronic Development Fund (EDF) was established as a "Fund of Funds" for providing risk capital to ESDM and IT start-ups.

- The government runs the Technology Incubation and Development of Entrepreneurs (TIDE) scheme to build national capacities in electronic and ICT fields.

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178 'Consultation Paper on Promoting Networking and Telecom Equipment Manufacturing in India' available at: https://www.trai.gov.in/sites/default/files/CP_11022022.pdf

179 *Ibid*

Another such program is the Next Generation Incubation Scheme (NGIS) designed to foster growth in the ICT sector.

- The government also runs the Future Skills PRIME initiative, which, in collaboration with industry, aims to reskill or upskill a total of about 0.4 million employees over five-years, as well as the Champion Service Sector Scheme (CSSS).

Annexure 3: Security Threats Envisioned in 6G across Different Communication Layers

Layer	Technology	Threats	Solutions
Application	Distributed scalable AI/ML	1. DoS Attacks 2. Poisoning Attacks 3. Lack of end-to-end Encryption 4. Encryption and 5. malicious behaviour	1. Big Data Analytics 2. ML: a. Random Forest b. Bayesian Network c. kNN clustering
Presentation	Blockchain/DLT	1. Majority Vulnerability 2. Double Spending 3. Transaction Privacy Leakage	1. Ring Signatures 2. Zero Knowledge arguments and proofs 3. Coin Mixers
Session	Quantum Crypto [180]	*	*
Transport	Orbital Angular Momentum [181]	*	*
Network	New IP architecture	*	*
Data Link	Spectrum Sharing	1. Attack surface expansion 2. Primary user emulation attack 3. Eavesdrop 4. DoS a. Jamming	1. ML-based solutions Extracting required features and performing clustering techniques to identify anomalies. 2. Blockchain a. Using smart contracts
Physical	Molecular communication	1. Jamming 2. Collision 3. Eavesdrop 4. Packet loss	1. Artificial immune system 2. Molecular cryptography

** Literature and research support not yet available*

[180] "When Machine Learning Meets Spectrum Sharing Security: Methodologies and Challenges' available at IEEE Open Journal of the Communications Society.

[181] 'Performance Analysis of Orbital Angular Momentum (OAM): A 6G Waveform Design' available at IEEE Communications Letters, vol. 25, no. 12, pp

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