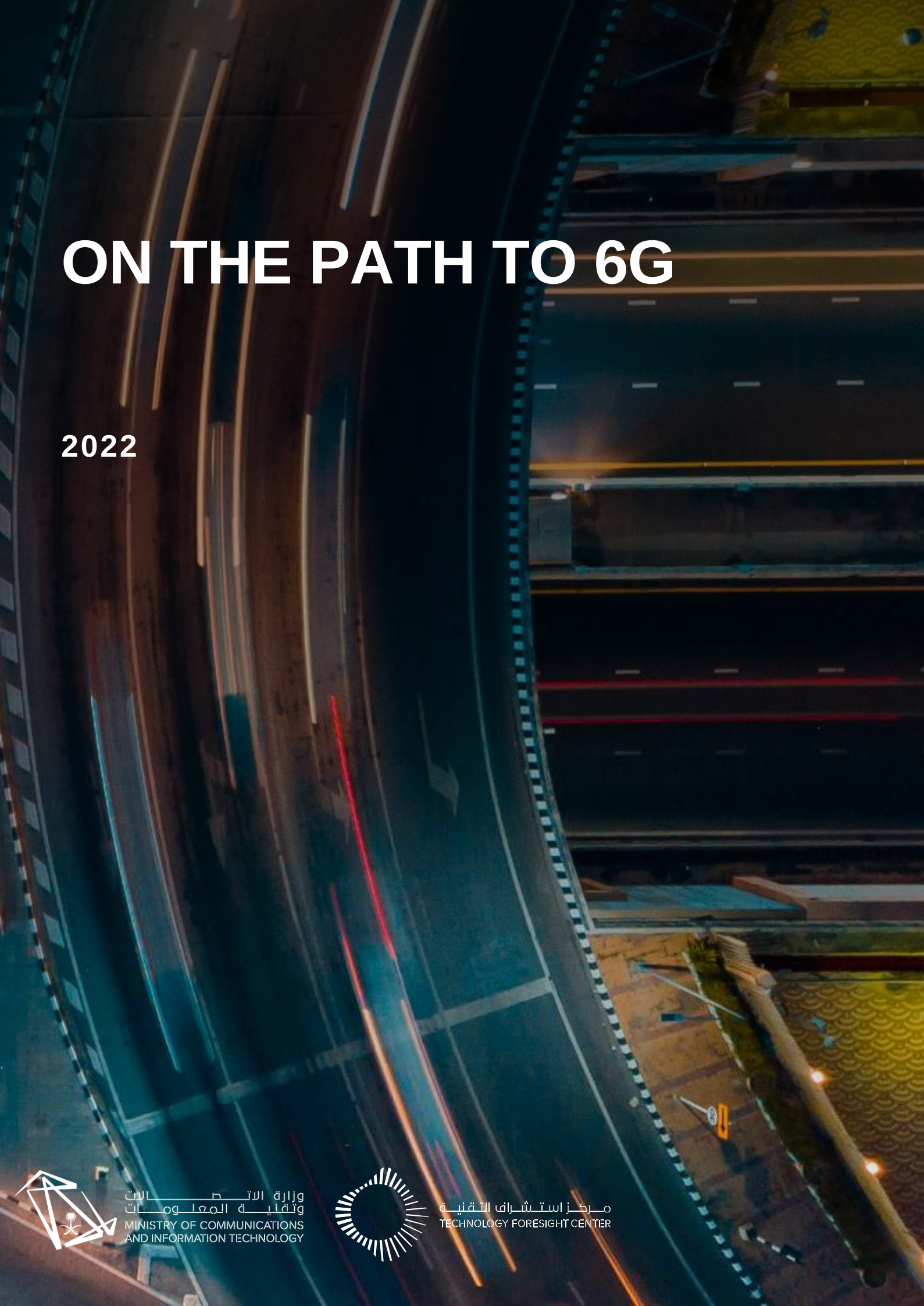
ON THE PATH TO 6G

2022



وزارة الاتصالات وتقنية المعلومات
MINISTRY OF COMMUNICATIONS AND INFORMATION TECHNOLOGY

مركز استشراف التقنية
TECHNOLOGY FORESIGHT CENTER

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6G will be the communications medium for tomorrow's world. 6G promises to help blur the line between the digital and the physical worlds, extending the end-user experience beyond the boundaries of physical reality. Users will be able to visualize, monitor, operate, or even simulate physical objects in the digital world without encountering the usual physical constraints. This will produce a fully interconnected world, where the physical world is represented in fine details in the digital domain and can be analyzed and acted upon digitally.

6G connectivity is expected to provide complete network reliability based on an AI native core. It will interconnect devices across different networks through a multilayered, three-dimensional architecture. Its inherent security enhancements will provide improved system security and trustworthiness.

While the technical requirements of 6G are yet to be fully defined, R&D is already underway in the various parts of the new ecosystem. This research is being led by vendors, national organizations, and ICT standards authorities.

Insight What will the 6G technology enable and how will it do so?

The interconnection of the physical and digital worlds will be enabled through four main areas of innovation:

Firstly, 6G will enable the twinning of physical and digital systems. Sensors and actuators will enable complete digital replication of the physical reality, producing twins of cities, factories, and even our bodies in the form of digital avatars. This will permit significant data mining and highly efficient control of digital domains.

Secondly, the connected intelligence of the 6G AI systems will enable virtual representations of people and physical entities to seamlessly exchange information in the digital domain.

Thirdly, 6G will provide immersive communication that will enable people to extend the range of their senses through the digital domain. This will create an immersive experience utilizing all the senses, one that appears fully "real."

Fourthly, AI-assisted cognitive technologies will produce highly convincing machine-human interactions by enabling machines to interpret and replicate human intentions, desires, and moods.

All these innovations will become possible due to capabilities of 6G networks, which is expected to overpass 5G almost in all dimensions: 5-x times higher throughput; twice higher mobility, 10x times lower latency, 1000 more connected devices per tower and etc.

Innovation What are countries doing to address the 6G opportunity?

Countries are approaching the development and rollout of 6G technology in a number of different ways, depending on their national objectives. These can be classified into three broad groups:

Designers: promote the requirements of their national technology agenda through active participation in the technology standardization working groups.

Developers: seek to increase their country's share in the connectivity value chain by being involved in the early stages of 6G technology development.

Adopters: aim is to accelerate the adoption of 6G technology once it is ready.

Executive Summary (Cont'd)

Interaction Who is involved in addressing the 6G opportunity?

Depending on the role Saudi Arabia chooses to play in the roll out of 6G, and based on the prevailing timeframe of international programs, there are a number of different initiatives that the country could launch.

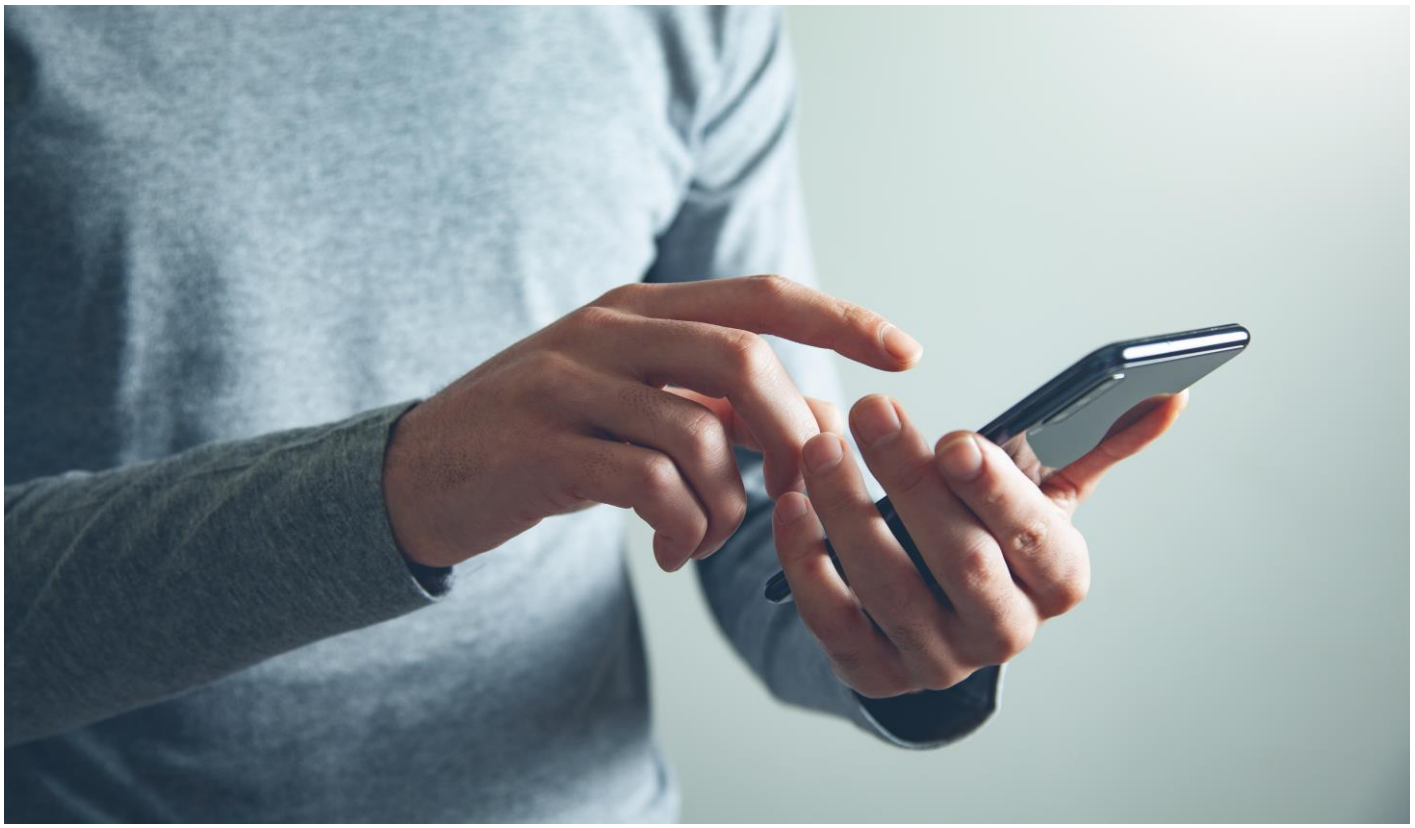
The report outlines the 14 potential initiatives for Saudi Arabia with examples of similar initiatives launched by other countries.

Impact What value can be expected from 6G?

A designer role would enable Saudi Arabia to set in place the policies and requirements for the new infrastructure based on its own needs, which will accelerate future adoption and uptake of 6G.

A developer role would enable Saudi Arabia to push the localization of 6G technology development in Saudi Arabia, thereby creating job opportunities and fostering local talent development. It would also allow it to fast-track the launch of 6G in 2030 and to tap into a larger market share than otherwise possible. The potential value creation for Saudi Arabia in this scenario would be USD 45.5 BN by 2035.

As an early adopter, Saudi Arabia would minimize rollout risks. It would be able to optimize its investment through rigorous testing of its rollout strategy and by allocating the required resources and capabilities in a timely manner. In this scenario, Saudi Arabia could be expected to capture value of USD 30 BN by 2035.



Introduction

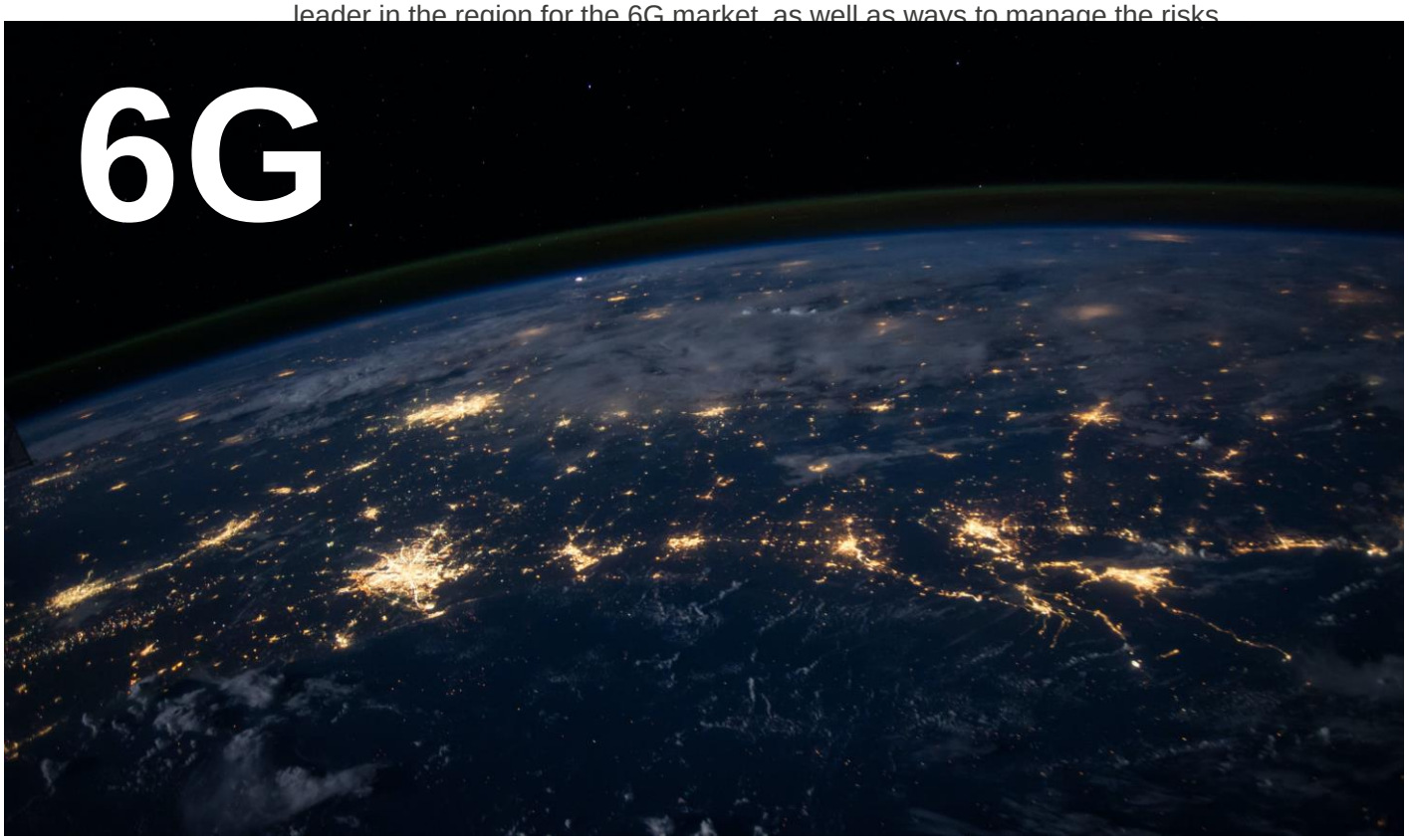
Sixth-generation wireless (6G) technology will be the successor to 5G cellular technology. 6G is expected to launch commercially in 2030. The technology makes greater use of the distributed radio access network (RAN) and the terahertz (THz) spectrum to increase capacity, lower latency and improve spectrum sharing. Early discussions have started to define 6G while research and development (R&D) began in 2020.

The 6G technology market is expected to facilitate large improvements in imaging, presence technology and location awareness. Making use of artificial intelligence (AI), the computational infrastructure of 6G will determine autonomously the best location for computing to occur. This will include decisions about data storage, processing and sharing.

6G will make use of heterogeneous, sometimes competing, networks. 6G wireless systems will drive increasing integration of terrestrial and satellite wireless networks leading to an integrated space and terrestrial network (ISTN). This will give a big role to unmanned aerial vehicles (UAVs) and low earth orbit (LEO) satellites, which will be used to fill gaps in coverage and to provide backup for the network in situations of heavy load demand.

The technology creates multiple opportunities but also brings with it new challenges and risks. 6G will enable the convergence of the digital, physical, and human worlds, which will create numerous use cases in various key sectors. This will have direct and indirect impacts on the economy and society. The technology also raises several concerns about data safety and value leakage.

An assessment of the implications of the future rollout of 6G can identify both opportunities for Saudi Arabia to capitalize on the opportunities and position itself as a leader in the region for the 6G market, as well as ways to manage the risks.



1 Intelligence: What do we know about 6G technology and characteristics?

6G is expected to only be commercially available by 2030. However, there is already consensus about what role 6G should play in the connectivity ecosystem

This section provides an overview of what is expected of 6G technology, its characteristics and current development status

6G will be the communications medium for tomorrow's world. It will integrate all the networks into one single network and meld the physical and digital worlds into a single reality.

Research into the different parts of the 6G ecosystem is already underway. This research is being led by three main classes of players: vendors, national organizations, and ICT standards authorities. The role of the latter is important in defining the roadmap for the development and roll out of 6G:

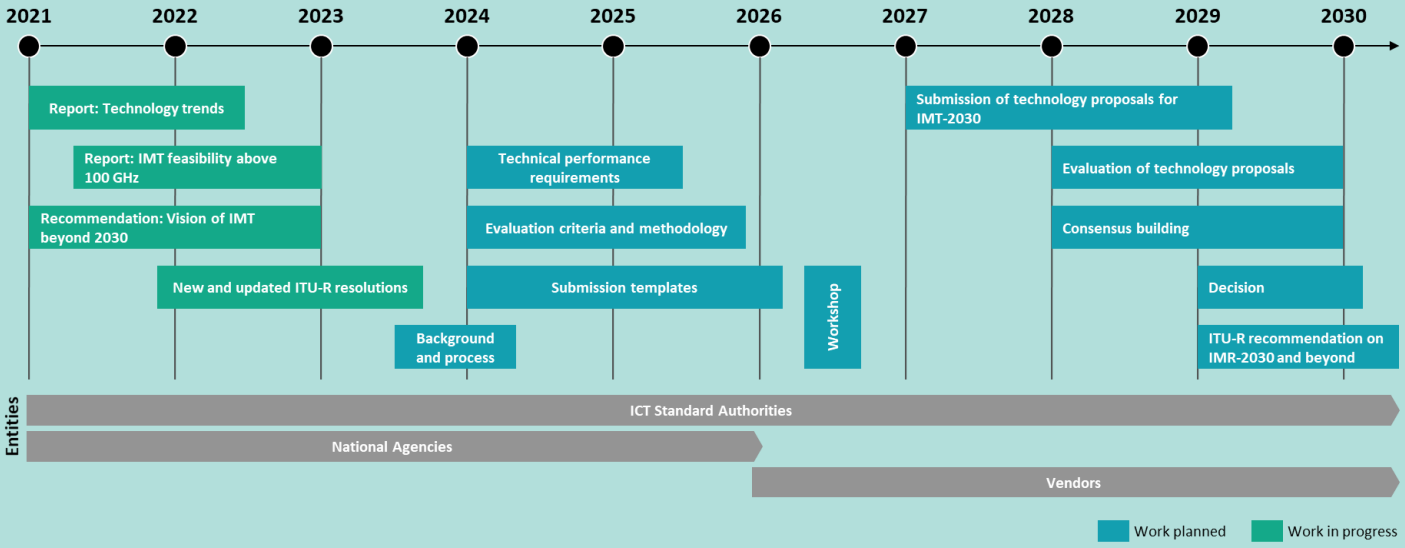
– *ICT Standard Authorities* to define and regulate the standards for the rollout of 6G (e.g., ITU[1], Next G Alliance[2], ITU-R working party 5D)

– *Vendors* to develop the products to commercialize 6G technology (e.g., Ericsson, Nokia, Huawei, Samsung)[3]

– *National agencies* to define the requirements for the development of the 6G technology (e.g., Hexa X project by EU, "6G R&D Implementation plan" by South Korea, and "IMT-2030 (6G)" by China) [4]

International Telecommunication Union (ITU) has defined the roadmap including the key initiatives for the technology development. The current roadmap for 6G development as planned by the ITU-R 6G Vision Group from 2021-2030 is shown in Figure 1[1].

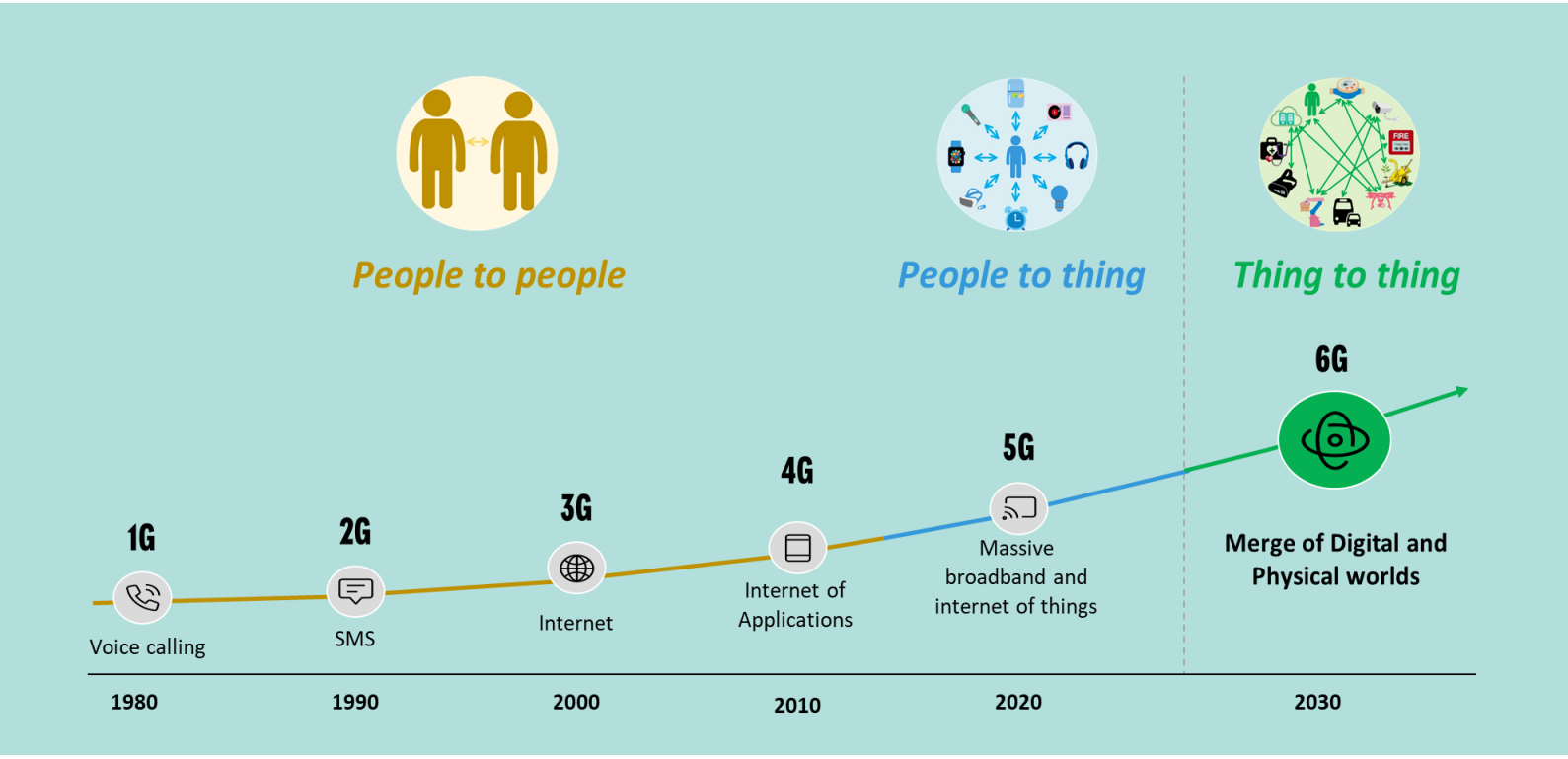
FIGURE 1 **Timeline for 6G development from the ITU-R Working Party 5D**



1. Vision for IMT systems in the year 2030 and beyond. ITU, 2021
2. Next G Alliance Report: Roadmap to 6G. 2022
3. Communication in the 6G era. Nokia Bell Labs
4. The Road Towards 6G: A Comprehensive Survey. IEEE Journal, 2021

The common vision for 6G is for it to enable the merger of the digital and physical worlds

FIGURE 2 **Evolution of cellular technologies and applications**



The shared vision for 6G is that 6G will both merge the physical and digital worlds and will also integrate all other types of networks, producing a single, fully integrated network[5,6].

6G promises to blur the line between the digital and the physical worlds, extending the end-user experience beyond the boundaries of physical reality. Users will be able to visualize, monitor, operate, or even simulate physical objects in the digital world without encountering the usual physical constraints. This will produce a fully connected world, where the physical is represented in high detail in the digital domain and can be analyzed and acted upon digitally.

For example, it is expected that 6G will enable Internet of Sense (IoS), that will bring mind, smell, sight, taste, touch, and sound to the digital world. By combining these senses, 6G can enable various use cases, such as connected sustainability (be anywhere) and sensational services (ability to touch, smell, and see any digital object).

The connection between the physical and digital worlds will be enabled through embedded devices that will place humans in the middle of a cyber-physical continuum, connecting the digital world with both our physical bodies and our human intelligence.

5. 6G – Connecting a cyber-physical world. Ericsson, 2022
6. Communications Network 2030 Report. Huawei

Four pillars enable the merger of the physical and the digital worlds

6G's high level of connectivity will be enabled by four new technologies:

Twinning physical and digital systems[7]

Sensors and actuators will synchronize the physical and digital worlds. These devices will enable complete digital replication of the physical reality, producing twins of cities, factories, and even our bodies in the form of digital avatars. The digital replication of the physical world will enable significant data mining and highly efficient control of digital domains. Data integrity and security will clearly be of the utmost priority.

Connected intelligence[7]

The network's infrastructure is key to 6G. It needs to offer high-capacity links with low latency and secured functionality throughout the network. This will enable AI and allow the virtual representations of people and physical entities to seamlessly exchange information in the digital domain. As a result, it will help to spread autonomous systems.

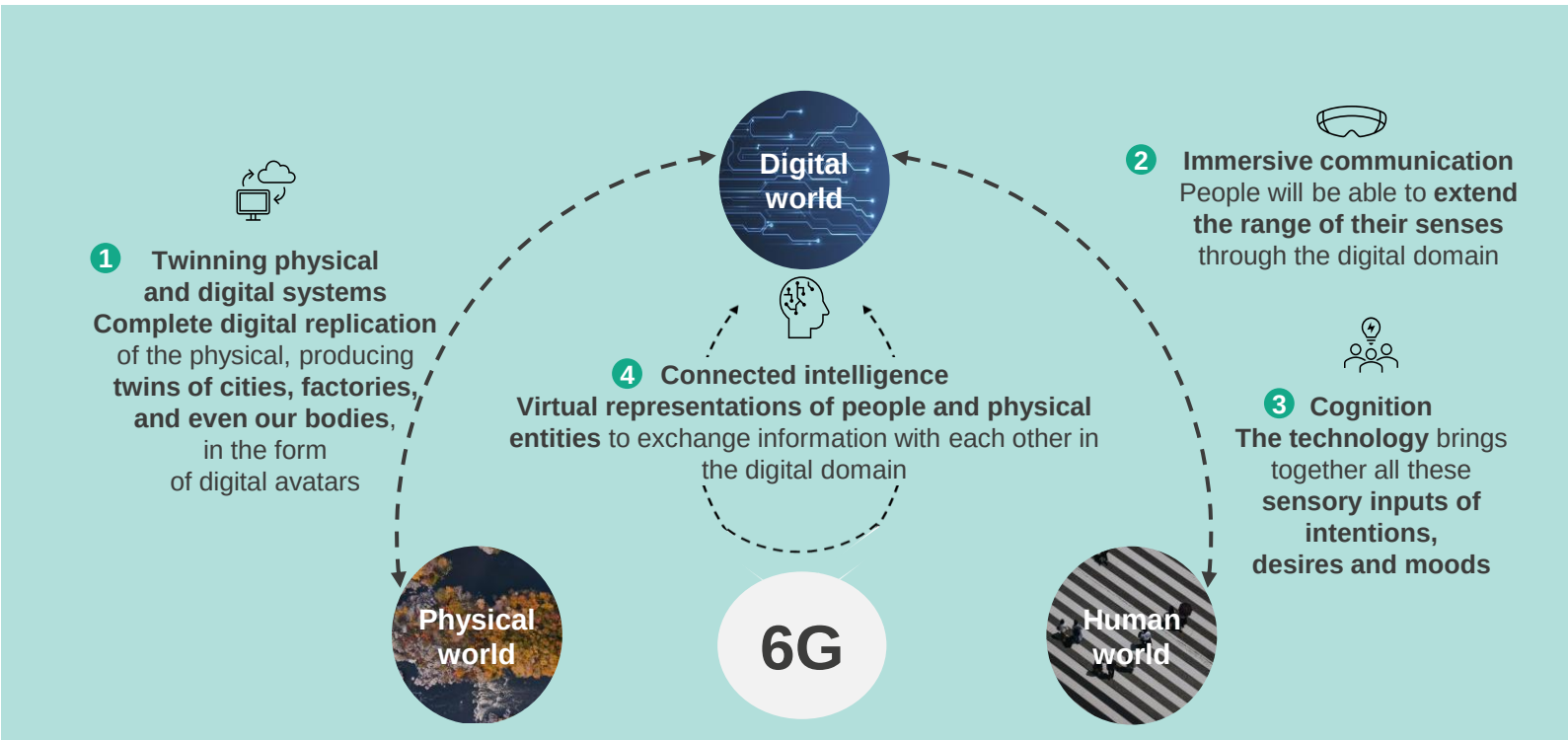
Immersive communication[7]

People will be able to extend the range of their senses through the digital domain. The high throughput and low latency of the 6G network will enable high-resolution (visual/spatial, tactile/haptic, and other sensory) data to be exchanged. This will create an immersive experience in which the digitally created space will appear fully "real."

Cognition

AI-assisted voice recognition tools are already being used to find out what users want when interacting with technology. To produce convincing machine-human interaction, it will be important for AI systems to be able to interpret and replicate human intentions, desires, and moods in order to represent a person more fully in the digital domain. Cognition technology brings together all these sensory inputs. The technology will draw on digital information about preferences and earlier choices.

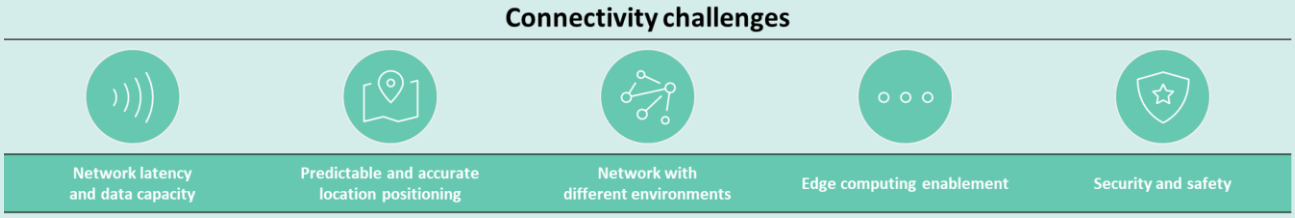
FIGURE 3 **Pillars for the merge of physical and digital worlds**



7. European Vision for the 6G Network Ecosystem. 5GIA, 2021

Existing network technologies are insufficient for merging the physical and digital worlds

FIGURE 4 **Connectivity challenges from previous technologies**



Each new mobile generation is driven by the shortcomings of the previous one. In the case of 6G, the new generation of technology is being driven by the following challenges[8,9].

Network latency and data capacity are insufficient for new applications

The current latency and data capacity offered by 4G and 5G are insufficient for upcoming applications. For example, remote diagnosis and holographic remote surgery will require bandwidth of 1-10Gbit/s. 5G is limited to 1Gbit/s whereas 6G will have the ability to provide up to 100Gbit/s. Other applications, such as autonomous vehicles, the internet of drones, and holographic communication will also require very low latency, below 1ms, which cannot be supplied by 5G (which has a latency of 5ms)[11]. Enhanced mobile broadband, lower latency and increased reliability are also needed for the deployment of the next-generation video sensors. These devices will improve the user experience of real-time video communications and holographic applications and will enable real-time, digital twin models (as used in VR/XR/MR, IoT, holograms, 3D displays, Industry 4.0, etc.).

Positioning and locating systems accuracy is insufficient

The current accuracy of 5G technology is insufficient to twin physical objects with those of the virtual world. The merger of the digital space with the physical world requires high location accuracy of less than 1 cm to enable precise operation in real-time[12].

It is not easy to customize the network to different environments

Traditionally, connectivity networks operate on a “best effort” basis. Deep Packet Inspection (DPI)[10] was the only option to prioritize traffic in LTE networks. 5G was the first network to introduce slicing functionality that splits the available network capacity between the various types of devices. However, the operator still needs to predefine the slices for each device. This can prove to be very complicated in practice. For instance, in smart manufacturing, the operator can be faced with over 50 thousand connected devices. This task becomes even more complicated to manage when devices need to be reconnected from one network to another.

Full-fledged edge computing is difficult to be fully enabled by 5G networks

5G networks prioritize throughput from the cloud to edge (downlink). However, with the continuing development of edge computing, evermore data will need to move in the other direction (uplink). Currently, the speed limitations in the uplink are causing a bottleneck for Edge-computing development[6].

There are several security and safety concerns with today’s networks

Networks are increasingly becoming the target of cyber-attacks. Today’s networks lack a number of safety and security features to protect them against such attacks. The risk of evermore sophisticated botnets, privacy violations, and faster data extraction is likely to escalate with the faster data transfer speeds of 5G. The dynamic nature of these threats

8. 6G explained. Nokia, 2021
9. Five edge computing challenges enterprises face and how to overcome them. ITProPortal, 2021
10. Harnessing intelligence at the core with DPI for vEPC. Rohde & Schwarz, 2021
11. 5G latency: Why speeding up networks matters. CNET, 2021
12. Forget 5G. What’s in Store for 6G? Engineering.com, 2020

To address the current challenges, leading vendors have defined the R&D that will be foundational to 6G

To resolve the challenges presented by the current network technology will require a significant shift in the overall network paradigm. This will change the emphasis of the networks in the following ways:

From predefined services to flexible user-centricity: Today, services and interfaces are predefined by network settings. What is required is a flexible network with the ability to adapt in real-time to the needs of users or connected devices.

From manually controlled to learning networks: Using AI throughout the network will shift the focus from instructing the system on methods of how to achieve specific goals to providing the system with goals that the network seeks to achieve.

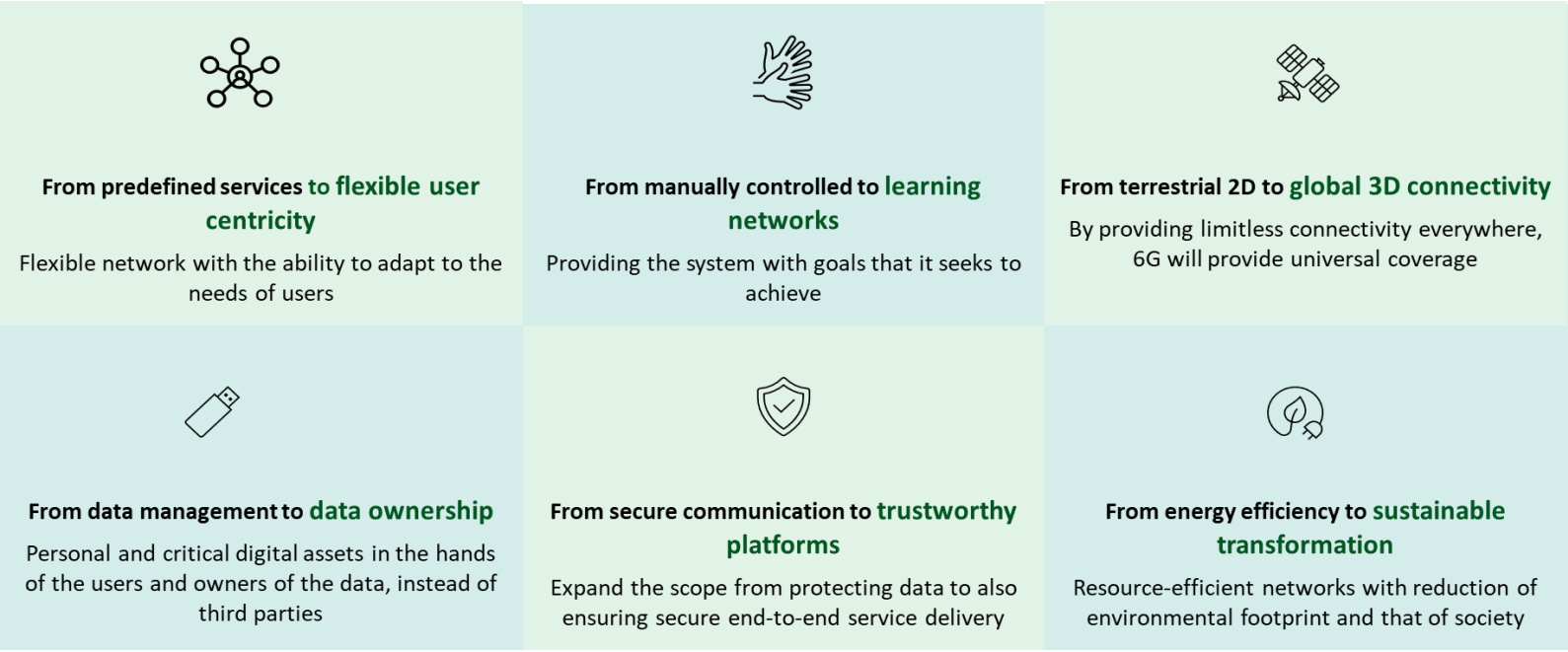
From terrestrial 2D to global 3D connectivity: By providing limitless connectivity everywhere, including remote areas on land, sea, and air, 6G will provide universal coverage. It will, in parallel, also contribute greatly to full digital inclusion.

From data management to data ownership: By placing personal and critical digital assets in the hands of the users and owners of the data, instead of third parties, 6G will ensure personal control of data.

From secure communication to trustworthy platforms: 6G will expand the scope from protecting data to also ensuring secure end-to-end service delivery.

From energy efficiency to sustainable transformation: Networks digitalization is expected to optimize usage of resources, reducing their environmental footprint

FIGURE 5 **Connectivity networks technology trends**



6G's capabilities are expected to greatly surpass previous technologies

6G networks will connect trillions of things and billions of people. The network technologies will have six defining features[13]:

6G connectivity is expected to provide complete network reliability

Current network technologies split the available data capacity between all devices connected to the network. 5G has taken this a step forward by defining network "slices," which are expected to guarantee a predetermined level of service for connected devices. However, this does not provide guaranteed user satisfaction. 6G networks, in contrast, will guarantee the user experience as a core concept. They will do so by ensuring ultra-low latency for connected devices (below 1ms), with availability of as high as 99.999% for industry production control systems. 6G networks are also expected to provide network slicing at the device level.

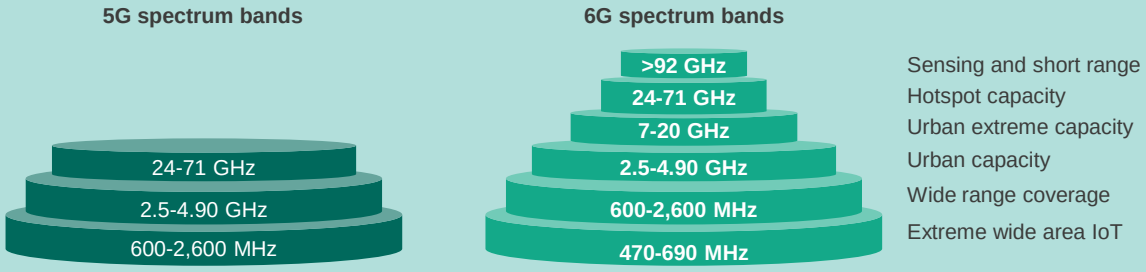
The 6G network is expected to have an AI native core

6G will make use of artificial intelligence (AI) technologies to realize virtualized personal mobile communication. The network's basic architecture will move from one centered on serving functions (such as platforms) to distribute data across the network to where it is made use of by such platforms, to one that is centered on the user, and so it centralizes data and content with the user in one place. AI will be embedded at the core of the 6G network and will be trained to operate in different environments (e.g., manufacturing, airports, offices, homes). 6G networks will thus act as autonomous networks with automatic self-optimizing and self-resolving capabilities.

6G will interconnect devices across different networks

Today, devices are connected to a number of different networks (1G to 5G, low-power wide-area network, satellite, etc.). This diversity creates challenges in terms of the inefficient use of resources and increases latency. 6G networks are expected to extend spectrum bands to cover all types of connectivity services. As a result, 6G network is expected to integrate all the devices currently operating under different networks. This will ensure faster interconnection rates and data transfer.

Multi layered spectrum



6G networks will be multilayered (three-dimensional architecture)

In order for the 6G network to integrate devices from all networks (including cellular and satellite), the architecture will need to be multilayered. It will have nodes not only on the ground but potentially also in the air on drones, balloons, and even satellites. This cubic architecture will ensure full three-dimensional (3D) coverage.

6G security enhancements will provide trustworthy systems

The current expectation is that security and trustworthiness should be an inherent (that is, endogenous) feature of the 6G network and an integrated part of its architecture. This requires that trustworthiness should be built into all the layers across the network, including into platforms, operating systems, and chips. To fulfil this, 6G will have the capability to be self-aware and to conduct real-time dynamic analysis. This ability, combined with adaptive risk mitigation and confidence evaluation, will help realize greatly enhanced cyber space security.

13. Vision, Requirements, and Technology Trend of 6G: How to Tackle the Challenges of System Coverage, Capacity, User Data-Rate and Movement Speed. IEEE, 2020.

The Non-Terrestrial Network will be fully integrated into 6G's architecture

The following architectural developments will be critical in the integration of non-terrestrial networks (NTN) into 6G networks [14]:

Architecture design as a single-access network: The 6G architecture will be designed with no distinction being made between the terrestrial and non-terrestrial network elements. This will provide cost-efficient network configuration.

Constellation with hierarchical design: The hierarchical constellations will consist of nodes flying at different altitudes, with communications between them being conducted through horizontal inter-nodal links. This will make communications possible between nodes flying at different altitudes, as well as with terrestrial nodes.

Smart NTN with computing and storage in the sky: The flying nodes (NTNs) will become the smart edge of the 6G network. 6G NTN will leverage LEO, MEO, GEO satellites, and high-altitude platform systems (HAPS) They will enable the processing and storage of data and communication in the sky. This development is necessary to realize non-terrestrial clouds and space information networks.

Resource optimization with infrastructure as a resource: Resource optimization will address the infrastructure as a resource in itself, reconfiguring it according to service requirements.

Dynamic spectrum management, coexistence and sharing: Dynamic spectrum management, coexistence and sharing will be needed between the terrestrial and NTN segments, as well as among the different layers of the 3D cubic architecture.

New spectrum beyond THz: The use of new spectral bands, including those of optical communications, will need to be investigated. This investigation will include the characterization of propagation conditions and the development of the channel models that will be encountered by the NTN elements, both in inter-node communications and in non-terrestrial to terrestrial communications.

FIGURE 6 **Comparison of performance metrics across cellular technologies[15]**

Performance metrics	1G	2G	3G	4G	5G	6G
Peak Data Rate		50 kbps	21 Mbps	100 Mbps	20 Gbps	≥1 Tbps
Mobility				350 km/h	500 km/h	≥1000 km/h
Latency		300 ms	100 ms	10 ms	1 ms	10–100 µs
Connection Density			10^4	10^5	10^6	10^7
Mbps/m^2			0.001	0.1	10	1000
Spectral Efficiency			0.6x	1 x	3 x	≥15 x
Network Energy Efficiency		0.01 x	0.1 x	1 x	≥10 x	≥100 x

14. Pervasive Intelligent Endogenous 6G Wireless Systems: Prospects, Theories and Key Technologies. Digital Communications and Networks, 2020
15. 5G vs 6G: What is it and when will it be here. Electronics 360, 2021

2 Insight: What will the 6G technology enable and how will it do so?

6G is expected to enable the digitalization of the physical world, the Internet of Senses, and the connection of intelligent machines

This section provides an overview of the expected use cases enabled by 6G, the challenges, and opportunities arising from it

Three main use cases are likely to drive the development of the 6G network[16]:

The digitalized and programmable physical world

In the future, physical objects, humans and the environment in which they live and function will all have digital representation. The physical world will be fully integrated into the digital sphere in that it will also be fully programmable and automated. Digital representations of real things will be used to manage and process data both individually and collectively. This will enable improved predictive assessment and planning in the physical world. A central concept in this integration is the widespread adoption of the "digital twin," a virtual digital entity that mirrors exactly the physical reality in real time. This concept will be applied both in manufacturing and in other fields of society.

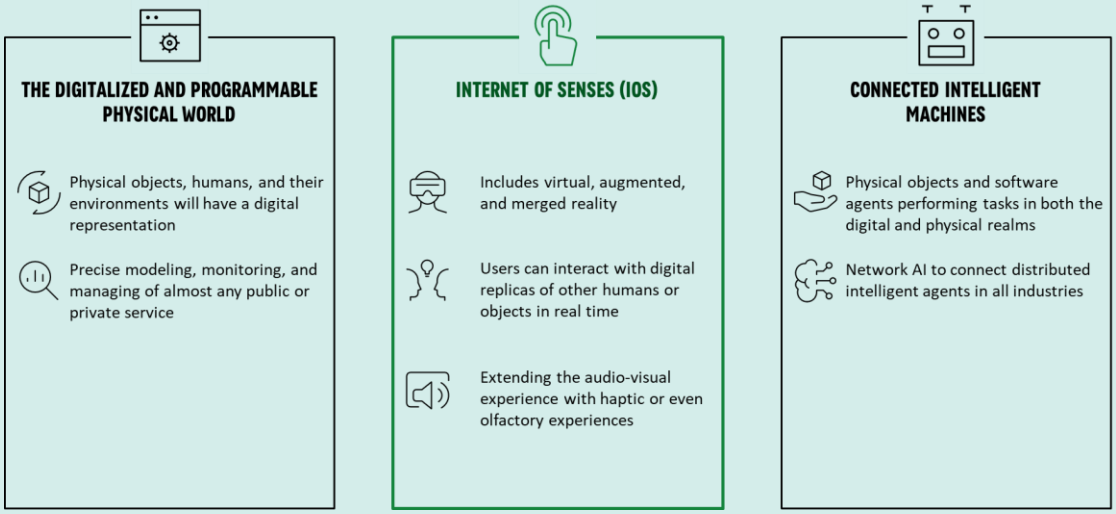
Internet of Senses (IoS)

The IoS enables multisensory digital experiences to be integrated into their surroundings. IoS includes virtual, augmented, and merged reality, where users can interact with digital replicas of other humans or objects in real time using multi-sensory interactions. This includes extended audio-visual experience, with haptic or even olfactory experiences, thereby enabling the merger of the cyber-physical world. The IoS also facilitates remote interaction with people, devices, and robots, creating a digital representation of their presence, as if they were actually present or nearby.

Connected intelligent machines

As the collaborative capabilities of the 6G network advances, the need for improved communication capacities and functional capabilities will increase exponentially. Connected intelligent machines, which are physical objects and software agents that can perform tasks in both the digital and physical realms, will enable advances in such functional communication. Connected intelligent machines will be highly dependent on the precise and timely location of their physical and digital context.

FIGURE 7 **Use cases enabled by 6G**



16. Five network trends towards the 6G era. Ericsson

FIGURE 8 **Selective zoom in on Internet of Senses (IoS)[17]**

Expectations from the senses

The brain to act as the user interface

Mind

Taste buds to become digitalized

Taste

Smell to be conveyed digitally

Smell

Digital touch to affect the whole body not just the hands

Touch

Virtual sight to become merged with reality

Sight

Consumers to control what they hear and what others hear from them

Soun d

Examples of applications

Merged reality

- By 2030, it is expected that the **difference between physical and digital reality will be almost completely gone**
- **Holographic 3D displays** for everything from handheld devices to billboards will be available by 2030

Connected sustainability

- The ability **to digitally "be" anywhere** might save more than just our time – it could help save our planet, too
- The continued transition to a higher consumption of digital experiences over physical products is **expected to reduce global emissions**

Sensational services

- Digital senses will transform current screen-based experiences into **multi-sensory ones, practically inseparable from physical reality**
- Remote working experience to include colleagues appearing and sound totally real. Interactions with every object in the room, including **tasting a colleague's birthday cake and being handed a report**

17. The internet of senses, 10 Hot Consumer Trends 2030. Ericsson Consumer Lab

Certain aspects of 6G architecture will create challenges for countries and service providers

Integrated cellular and satellite networks risk national value leakage and revenue loss for cellular providers[18]

The 6G network is expected to become a 3D network, integrating cellular and satellite connectivity technologies. The deep integration and globalization of networks will mean that a larger number of devices will be connected to the satellite element of the network than is true today. This promises a growing market for players in the satellite technology market, but cannibalization of the future revenue for national telecom operators.

Leading countries support their national satellite players. For example, The Canadian Government announced $1.44 billion of investment in Telesat. China has also recently entered this market with the launch of the world's first 6G satellite in 2020.

Similar to leading countries, Saudi Arabia signed a $200 million joint venture with OneWeb, with exclusive rights to distribute the network's capacity in targeted Middle East regions.

Globalization of network providers will create data sovereignty risks

Once in place, the 6G network will become one vast interconnected digital world encompassing many different types of network and linking billions of individual entities. The more complicated a network becomes, the greater it is at risk. The most pressing danger is that the all-encompassing nature of the 6G network will increase exposure to traditional security risks (such as viruses, malware, cyber attacks, deep-fake and learning-empowered attacks). This would mean that data breaches could both be large-scale and have potentially enormous impact.

The increased exposure of data to global satellite providers produces a second source of risk. Their use means giving them access to sensitive national data, a matter of serious consideration.

The higher bands of 6G will require increased network densification, creating challenges for terrestrial network providers

The 5G network moved from the earlier 900-1800Mhz (GSM) spectrum to 2.5GHz (4G) and then even to the 24-52Ghz spectrum[20]. To ensure similar coverage for higher bands as that achieved for 4G spectrum, telecom operators needed to increase the density of their 5G towers. Small cell towers were introduced as the main tool for 5G network densification where telecom operators needs to deploy five to ten times the number of small cell towers than the number of macro towers they used in the 4G era[19]. This led to a 5G CAPEX increase of four to six times compared to the 4G network.

The 6G network will potentially operate in the terahertz spectrum and will therefore require even greater densification than 5G. This is likely to be a financial challenge for the telecom operators, as the expected revenue growth might not compensate the expected CAPEX growth.

Satellites will play a role in the densification of the network, even more than the case with 4G and 5G . With 6G, however, because there will be no dedicated country coverage allocated to satellites in the network, the network will still require high bandwidth and high signal strength from the terrestrial network. This challenge is likely to be acerbated by the penetration losses suffered in satellite transmission.

The integrated nature of 6G will impact local connectivity value

The enhanced programmability of the 6G network will enable new use cases that are focused increasingly on the specific business requirements of industry, infrastructure, transport, and other specific areas of use. These business-specific applications will create new markets and services for cheaper, scalable, easy-to-use and readily deployable tailored solutions that address specific business needs.

Today's big players in the telecommunications network market, such as Ericsson, Huawei, and Nokia, will not have the capacity necessary to create and provide solutions for all the potential tailored applications that are made possible by 6G networks. This creates new opportunities for local players to increase their value through localization. However, availing these opportunities will require creating strong, local, 6G software

18. Global Satellite Communication market report. Modur Intelligence, 2021
19. 5G knocking on doors but where is the infrastructure? ETTelecom, 2022.
20. What frequency spectrum will 5G technology use and how does this compare to 4G? Arrow, 2019

FIGURE 9 **Selective zoom in on non-terrestrial network**

Integrated space and terrestrial network (ISTN)[21,22,23]

6G wireless systems will drive increasing integration of terrestrial and satellite wireless networks leading to an integrated space and terrestrial network (ISTN). This will give a big role to unmanned aerial vehicles (UAVs) and low earth orbit (LEO) microsatellites, which will be used to fill gaps in coverage and to provide backup for the network in situations of heavy load demand.

Spaceborne network

The spaceborne layer consists of LEO, medium Earth orbit (MEO), and geosynchronous orbit (GEO) satellites.

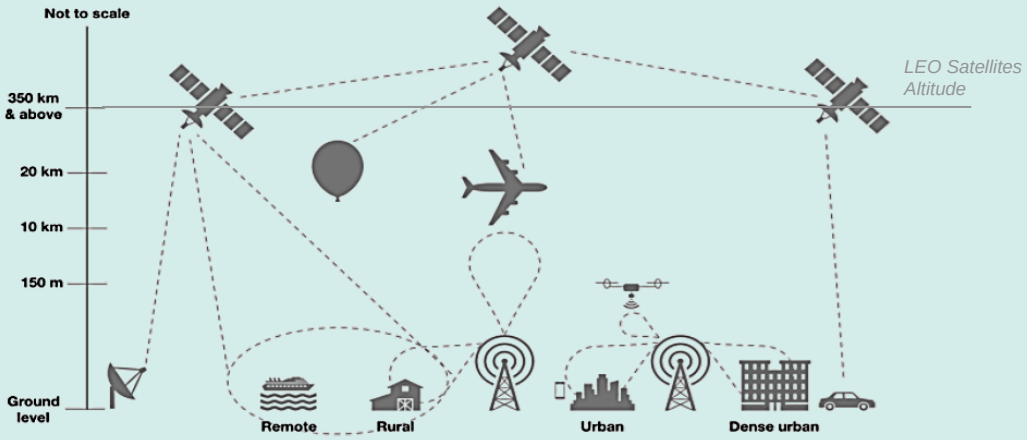
Compared to MEO and GEO satellites, LEO satellite's closer proximity to the Earth results in lower latency and less demand power for signal transmission to and from the satellites. The satellites also require less energy for launch into space.

Challenges of ISTN

While ground based and airborne networks can be managed physically by engineers, who can install software updates or replace faulty components when needed, this is not the case for satellite networks. Due to their high cost of installation and the lack of physical access to the satellites after launch, only well-proven hardware and software is used in their operation in order to guarantee their longevity.

In addition, the development and deployment time for GEO and LEO satellite constellations can take longer than comparable terrestrial solutions. It is likely that the full challenges resulting from the use of such networks will become visible only after their full operational rollout within the 6G network.

FIGURE 9: 6G coverage provided by integrating terrestrial networks with LEO satellite access



LEO satellites

Over the last several years, the world has witnessed a resurgent interest in space-based Internet services, particularly with mega-constellations of LEO satellites, such as SpaceX Starlink, Amazon Kuiper and OneWeb.

Constellation	# of satellites [launched/planned] (as of April 2022)	Altitude [km]	Frequency allocation
OneWeb	428/650	1200	DL: 12 GHz; UL 14 GHz
Starlink	2150/2362	550	DL: 12 GHz; UL 14 GHz
Amazon Kuiper	0/3200	600	DL: 20 GHz; UL 29 GHz

21. White paper on broadband connectivity in 6G. 6G Flagship University of Oulu
22. On the path to 6G: Embracing the Next Wave of Low Earth Orbit Satellite Access. IEEE, 2021
23. Bertin, Emmanuel, et al. Shaping Future 6G Networks: Needs, Impacts, and Technologies. John Wiley & Sons, Incorporated, 2021

3 Innovation: What are countries doing to address the 6G opportunity?

Several countries have launched national 6G programs to address challenges and maximize opportunities

This section provides an overview of the government roles in addressing the 6G opportunity

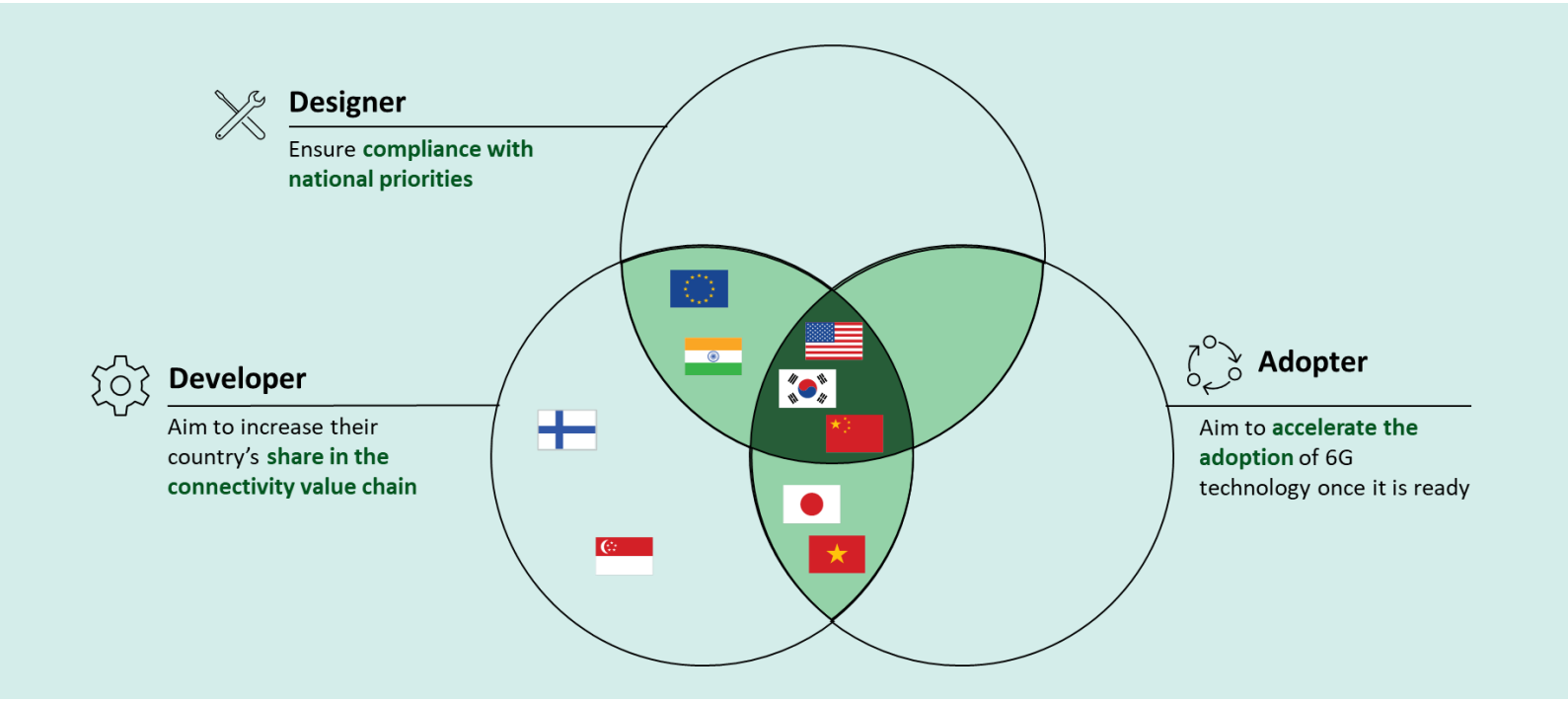
Countries are approaching the development and rollout of 6G technology in a number of different ways, depending on their national objectives. Based on the nature of these objectives, countries' 6G strategies were classified into three broad classes, as either designers, developers, or adopters:

Designers: These countries are dedicated to ensuring the compliance of 6G characteristics with national priorities. They promote the requirements of their national technology agenda through active participation in the technology standardization working groups.

Developers: These countries aim to increase their share in the connectivity value chain by being involved in the early stages of development of 6G technology. They are participating in R&D projects, developing the necessary 6G talent, and creating the requisite regulatory environment for technology testing.

Adopters: These countries aim to accelerate the adoption of 6G technology once it is ready. Their focus is on national incentive programs, for instance, by launching pilot studies, allocating subsidies, planning the allocation of 6G spectrum, and by resolving potential blockages to the 6G rollout.

FIGURE 10 **Benchmark of government roles in 6G development**[24,25]

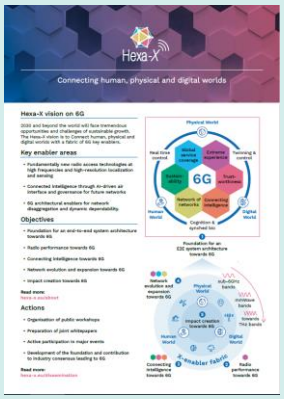


24. 6G Global Publications, Nikkei Asia, Telecom TV, Reuters articles, South China Morning Post articles
25. How China's 5G launch will drive the global 5G industry. Huawei

FIGURE 11 **Selective examples on government roles**

Hexa-X project[26]

Partners: Nokia, Ericsson



Designer
- Organization of public workshop
- Preparation of joint whitepapers
- Active participation in major events

Developer
- Development of the foundation and contribution to industry consensus leading to 6G

Adopter
- Not yet defined

6G R&D implementation plan[27]

Partners: LG, Samsung, SK Telecom

Designer
- Aim to be the first one to roll out 6G in 2028
- Targeting leadership in international standards and patents, with an emphasis on active public-private cooperation in the early stages of 6G

Developer
- Investment of USD 194 MN by 2025 in six focus areas (performance, Terahertz bands, space communications, ultra-precision; artificial intelligence; and reliability)
- Identifying technical requirements for key areas of the 6G network

Adopter
- To roll out additional pilot projects that include some of the use cases expected for 6G, like smart factories, smart cities, autonomous vehicles, and satellites

IMT-2030 (6G) Promotion Group[28]

Partners: Huawei, ZTE

Designer
- Focus on 6G vision and requirements
- Research topic including 6G spectrum requirements and propagation characteristics

Developer
- Promoting the research of 6G and building an international view exchange platform

Adopter
- To decide the vision for 6G by 2023, set technological standards by 2026, roll out relevant technology by 2028, and start preliminary commercial use of the network by 2030

26. Hexa X website
27. Korea lays out plan to become the first country to launch 6G. 6G World
28. 6G Mobile Wireless Communications - Vision, Roadmap, Technologies & Use Cases: 6G Groups. 3G4G, 2021.

4 Interaction: Who is involved in addressing the 6G opportunity?

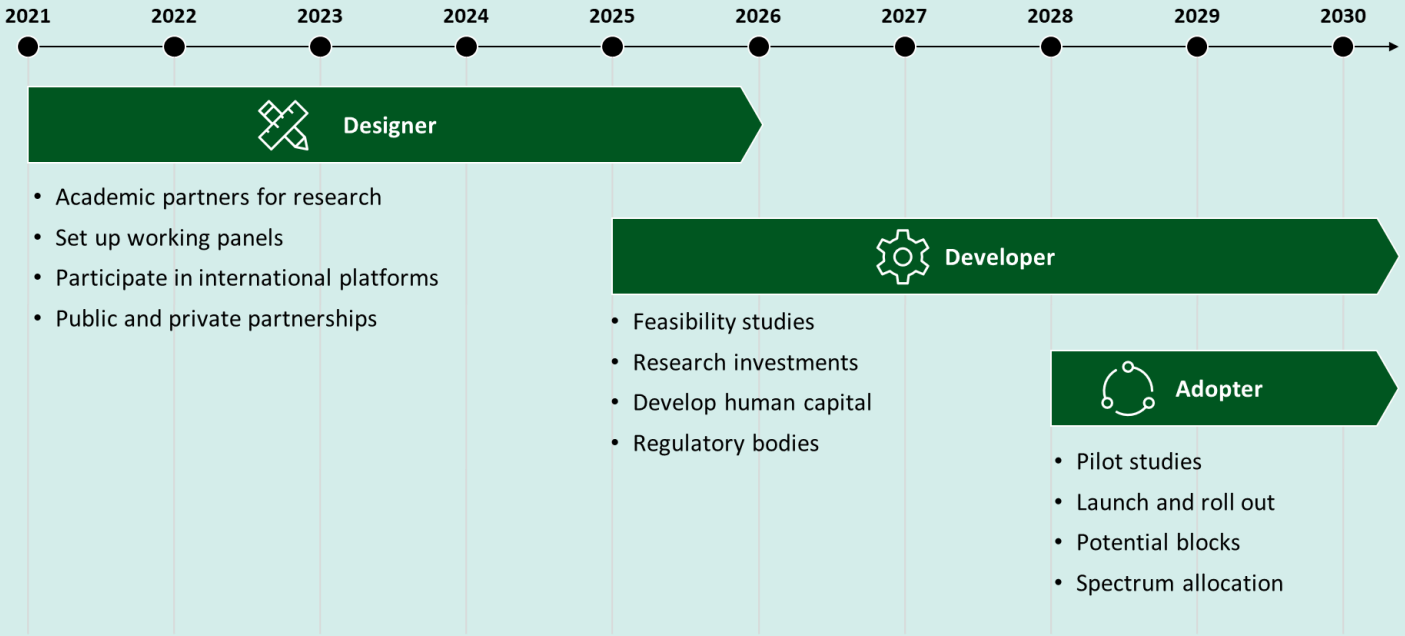
This section provides an overview of the role the government of Saudi Arabia could take in 6G development

Depending on the ambition and objectives, Saudi Arabia could choose what role to play in 6G development, defining when to enter the race

Depending on the role Saudi Arabia chooses to play in the roll out of 6G, and based on the prevailing timeframe of international programs, there are a number of different initiatives that the country could launch.

While the exact timing of Saudi Arabia's involvement will depend on the role it chooses to adopt, the earlier it joins the rollout plans the more likely it is to be to be able to position itself as a regional leader.

FIGURE 12 **Suggested roadmap for KSA for 6G development based on role chosen**



There are 14 initiatives that could be launched by KSA as part of the 6G development program

Designer role: Setting the vision for 6G

If Saudi Arabia decides to take on a designer role, it can focus its efforts on immediately joining the global conversation in setting the vision for 6G. This could include creating public and private partnerships. Most importantly, these partnerships can include both academia and the research partners necessary to 6G development.

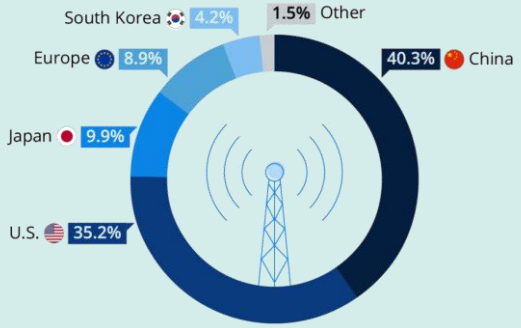
#	Initiatives	Example
1	Encourage academic partners to carry out research on the requirements and technologies for 6G	Jointly authored white papers; participation in major events related to 6G discussions[26]
2	Set up working panels to discuss findings, assess potential use cases and align with national vision and standards	Set up a panel to discuss and analyze technology development, including potential use cases and policies[30]
3	Participate in international platforms to contribute to the vision of 6G	Active public and private cooperation to participate in the early stages of 6G, including international standards and patents[27]

Developer role: Focus on R&D

If Saudi Arabia decides to join the 6G rollout as a technology developer, then its main focus would be on research and development. This requires very significant investment, coupled with training of the appropriate human capital and the setting up of the right regulatory bodies.

#	Initiatives
4	Develop feasibility studies of proposed R&D programs[24]
5	Allocate an investment budget for research of 6G related technologies and patents[27]
6	Incentivize and boost public and private partnerships through joint programs[26]
7	Collaborate with national and international players working on R&D and patents[27]
8	Train and develop the needed human capital through dedicated trainings and workshops[26]

Distribution of 6G patent applications in 2021, by country/region[29]



Adopter role: Early roll out of 6G

If Saudi Arabia decides it would rather join the rollout of 6G as an early adopter, then it can identify ways to realize this ambition. For example, it could leverage its current partnership with OneWeb to prepare pilot studies to test emerging 6G technologies. Likewise, national telecommunication operators could start planning solutions for 6G.

#	Initiatives
9	Launch pilot studies to test the technologies developed[27]
10	Establish programs to allow tech entrepreneurs develop pilot projects[27]
11	Set the launch timeline for 6G and build a roadmap for 6G rollout that includes the key milestones and respective owners[28]
12	Identify the required investment and potential roadblocks[28]
13	Define the national 6G rollout program in collaboration with private and public entities[28]
14	Assess and allocate spectrum bands as per 6G requirements[31]

29. Statista, Cyber Creative Institute via Kikkei Asia, August 2021
30. Japan sets its sights on 6G. SmartCitiesWorld, 2020
31. Vietnam to begin 6G technology research and development. VNExpress, 2022.

5 Impact: What value can be expected from 6G?

6G can play a critical social and economic role in Saudi Arabia's digital transformation

This section provides an overview of the value for Saudi Arabia expected from 6G, depending on the role it chooses to play

In the 6G era, innovative mobile network operators will reap benefits from several new business models. Besides selling connectivity services to end-users, telecommunication operators will provide the required connectivity resources to businesses (including companies, cities, and public authorities) that enable the customers to fulfill their own missions.

The enterprise market will benefit the most from new 6G use cases. The impact on this market will contribute directly and indirectly to the economy across different industries and sectors, as shown in the table below. These benefits will concentrate in increased cost efficiency, labor productivity and the creation of new revenue streams.

Saudi Arabia has a tremendous opportunity in applying the new use cases resulting from 6G which will support Saudi Arabia's Vision 2030 by taking its ongoing digital transformation to the next level. This could support directly the creation of the vibrant society and thriving economy outlined in its Vision 2030.

FIGURE 13 **6G use cases impact**[23]

	Use case	Description	Impact on the market
	Industry and manufacturing	Digital transformation of manufacturing through cyber physical systems and IoT services	– Efficient mining activities – Wide area monitoring of pipelines – Better precision and coordination for cooperative maneuvers
	Teleportation	Holographic delivery of life-sized 3D stereoscopic experiences in real-time	– Stimulate telework – Decrease travel time and expenses – Improve labor productivity
	Digital twin	Digital replica of an object inheriting the same behavior and characteristics of the real object	– Improve the design, engineering, inspection, and maintenance of complex machines and devices – Allow advanced simulations of the product behavior
	Smart transportation	Evolution of automotive industry to support infotainment, automated driving, and intelligent transportation	– Preemptive logistics – Fleet management and telematics – Reduction of goods transportation costs and environmental impact
	Public safety	Collection of services that support fast delivery of information between emergency teams in incident areas and the remote command centers	– Real-time 3D rendering of the incident area to/from the command station – Remote control operations
	Health and well-being	Evolution of healthcare to support telemedicine, healthcare workflow optimizations, and remote patient access to health assistance	– Individualized assistance via virtual patient consultation and monitoring involving all senses and health indicators – Efficient use of healthcare resources through preventive care, digitalization, and access to massive data
	Smart-X IoT	IoT and smart city paradigms targeting life quality improvements, environmental monitoring, traffic control, and city management automation	– Efficient agriculture and farming – Fleet management – Smart warehouse management – Support of zero-energy sensors for home appliances, industrial machines, and robots
	Financial world	Evolution of financial sector through high-frequency trading and blockchain technology	– More accessible trading – Elevated security and reduced fees for banking transactions – Robust/secure fraud prevention – Transition toward digital banking

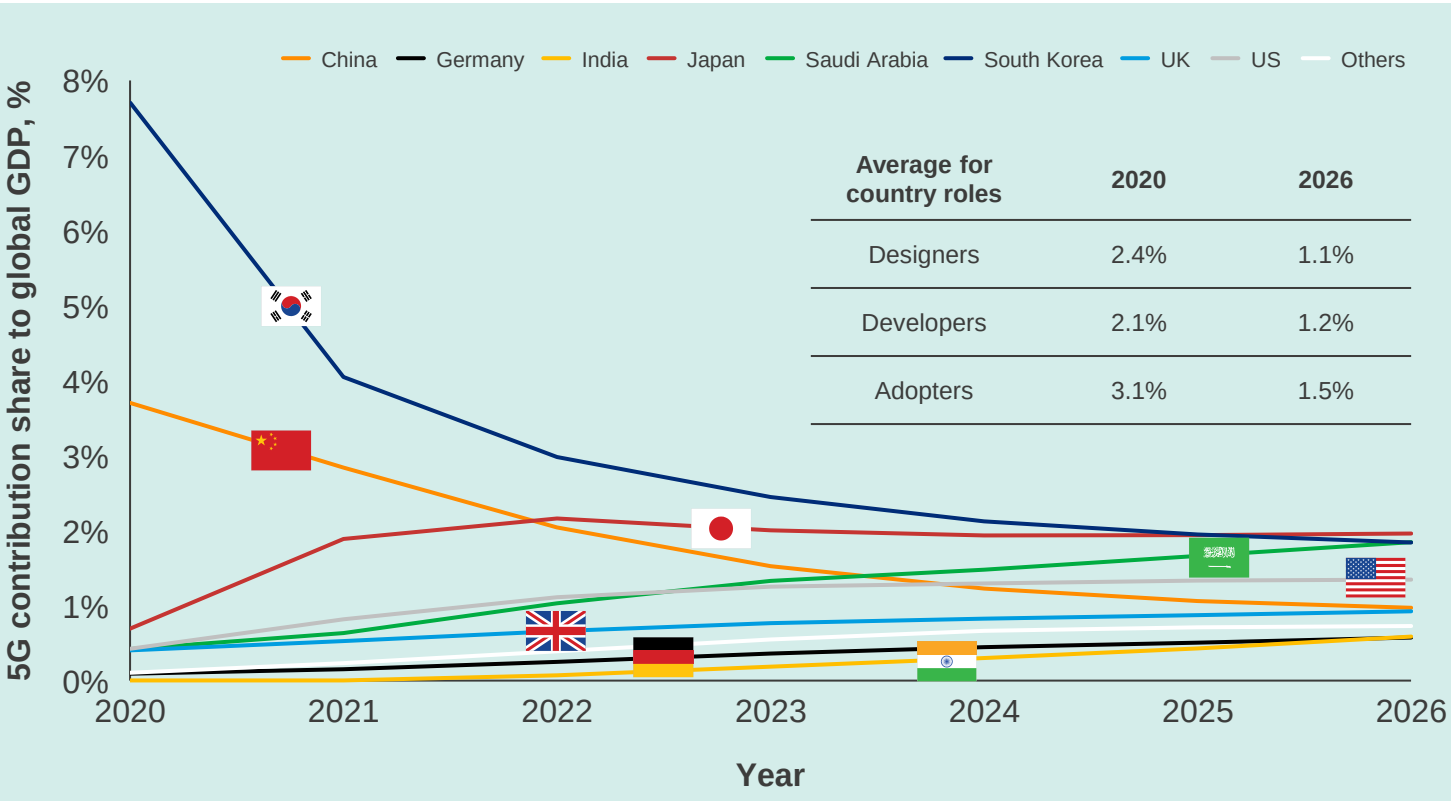
23. Bertin, Emmanuel, et al. Shaping Future 6G Networks: Needs, Impacts, and Technologies. John Wiley & Sons, Incorporated, 2021

6G's expected value can be estimated through study of the 5G market

To predict the 6G value unlocked by three potential roles, we reviewed the historical impact generated by 5G which became commercially available in early 2020. The different initiatives launched by various countries at different times determined their position in the early market. As shown in Figure 6, each of these countries had varying degrees of success in sustaining their leadership later on in terms of their 5G's contribution to global GDP.

- **Designer:** Taking a lead role as a designer may not have a direct monetary impact on the potential value created by the 5G market for a country. However, it does help accelerate the digitalization of industry, as was the case in Germany, and supports the creation of sustainable smart cities.
- **Developer:** The early development and testing of 5G technologies enabled China and South Korea, as developers, to capture a large initial market share. However, over the longer term, as more players enter the market with newer technologies and initiatives, the ratio of these country's shares in the 5G contribution to global GDP is expected to decline, coming to match their fair share by 2026.
- **Adopter:** Saudi Arabia, the US, the UK, and Japan were early adopters of 5G. Although they all started with a negligible share of the 5G market, this share is predicted to ramp up over time and they are expected to be among the countries holding the largest shares of global 5G market by 2026.

FIGURE 14 **Share of country's 5G contribution to global GDP[32]**



Average for country roles	2020	2026
Designers	2.4%	1.1%
Developers	2.1%	1.2%
Adopters	3.1%	1.5%

32. Omdia 5G revenue report; Statista GDP predictions and figures

Saudi Arabia's chosen role and time of entry will define the size and growth of its 6G market after 2030

There is more than one approach to ensure value from 6G. Saudi Arabia is in a position to choose between any of the three roles – those of designer, developer, or early adopter of the technology.

However, the monetary value created by 6G for Saudi Arabia will depend on the role it selects

Saudi Arabia in a designer role: As discussed previously, being a designer does not reflect directly into added market value but, instead, helps to address national incentives. Given the challenges and potential risks posed by 6G, such as value and data leakage, Saudi Arabia might benefit from taking the lead in setting the standards based on research and collaboration. Furthermore, as a designer, Saudi Arabia could also be a position to design the standards and use cases for 6G to support Vision 2030 goals.

– A designer role could help Saudi Arabia to set in place the policies and requirements for the new infrastructure based on its own needs, which will accelerate future adoption and uptake of 6G

Saudi Arabia in a developer role: If Saudi Arabia wishes to acquire a larger initial share of the 6G market, it would need to make considerable investments in research and development. The aim should be to launch pilot projects as soon as possible. This would allow Saudi Arabia to fast-track the launch of 6G in 2030 and could enable it to tap into a larger share of the market than would otherwise be possible. The potential market value that could be captured by Saudi Arabia by 2035 in this scenario is USD 45.5 BN.

– A developer role could help push the localization of technology development in Saudi Arabia, thereby creating job opportunities and fostering local talent development

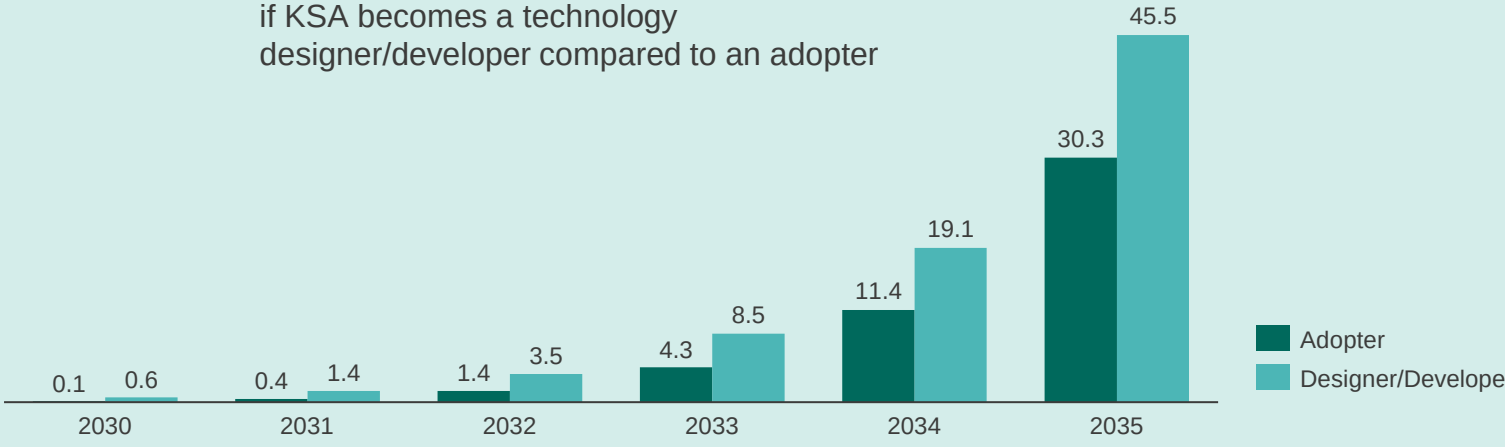
Saudi Arabia in an adopter role: Should Saudi Arabia choose to maintain an early adopter role, as was the case for 5G, the country will have more time to plan the strategy and build up capacity, talent, and technologies once 6G has been rolled out. Saudi Arabia would then be expected to capture its fair share of the global 6G market, estimated to be USD 30 BN by 2035.

– An early adopter role could help Saudi Arabia minimize rollout risks; it would be able to optimize its investment through rigorous testing of its rollout strategy and by allocating the required resources and capabilities in a timely manner

FIGURE 15 **Saudi Arabia's 6G market ($ billion)[33]**

1.5x higher value

if KSA becomes a technology designer/developer compared to an adopter

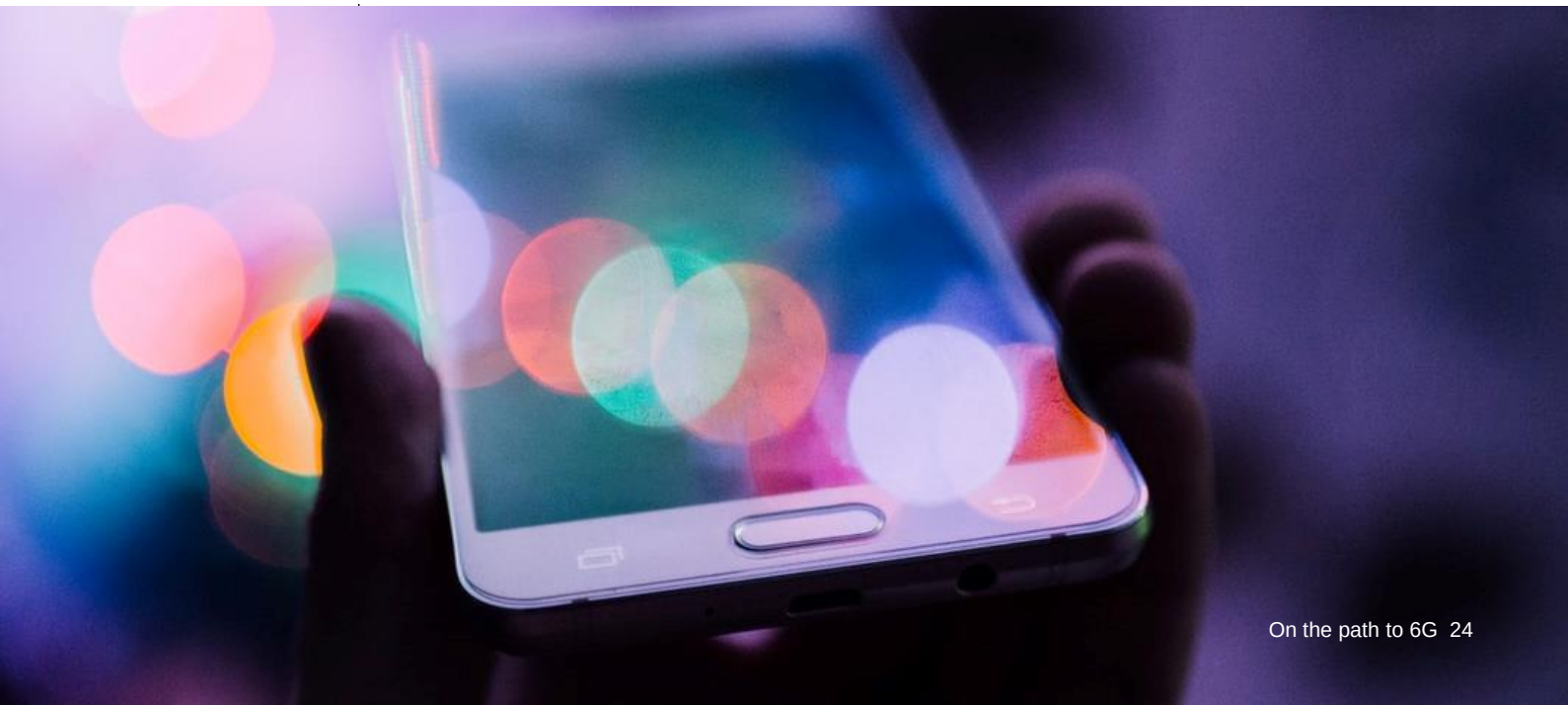


33. Estimated, directional figures only; BIS Research, Brandessence Market Research

Conclusion

6G will not only enhance greatly the connectivity of the world but change the world as we know it. It will converge the digital and physical worlds in a human-centric approach to data and digitalization. The entire world will be interconnected through universal network coverage. This will change the way numerous sectors operate, including those of education, healthcare, industry and entertainment.

Saudi Arabia has the choice of all three options regarding how to be involved in the rollout of 6G. It could act as a designer, developer, or adopter. The timing and nature of its initiatives will differ based on its chosen role, as will the entities that will need to be involved. Saudi Arabia's choices will help to ensure its position as a leader in the region in 6G, as was the case in 5G. Its role in 6G will enable it to capitalize on the opportunities the new technology offers, including those for realizing the goals of Vision 2030 in improving the standard and quality of life in Saudi Arabia.



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