Bharat 6G VISION

Taskforce Report
6G Devices

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Government of India
Ministry of Communications
Department of Telecommunications
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6G Taskforce Report:
6G Devices

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1. Executive Summary

6G technology will have significant advancements in communication, sensing, imaging, presence technologies and location awareness. The computational infrastructure of 6G will automatically select the ideal place for computing, including artificial intelligence (AI) driven decisions regarding data storage, processing, and sharing. Future networks will be pervasive component of life, society, and industries, fulfilling the communication needs of humans as well as intelligent machines. 6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication.

1. Four main drivers will emerge for the 2030 era

- Trustworthiness of the systems that will be at the heart of society,
- Sustainability through the efficiency of mobile technology,
- Accelerated automatization and digitalization to simplify and improve our lives, and
- Limitless connectivity meeting the demands for intensifying communication anywhere, anytime, and for anything.

It is expected that 6G will provide the ultimate experience for all through hyper-connectivity involving humans and everything. New themes are likely to emerge that will shape 6G system requirements and technologies, such as:

- New man–machine interfaces created by a set of multiple local devices acting in unison; We will have more intuitive interfaces, with access through gesturing rather than typing.
- Ubiquitous universal computing distributed among multiple local devices and the cloud;
- Multi-sensory data fusion to create multi-verse maps and new mixed-reality experiences;
- Precision sensing and actuation to control the physical world.
- A certain class of device is one that will be extremely low-power and potentially battery-less, relying on the network to power the device.
- The end device will evolve in many scenarios to be a network of devices or a sub network. As examples, we can imagine a machine-area network or a robot-area network involving connecting multiple parts of a machine such as a controller and its drives
- With 6G targeting to enable ubiquitous mmWave coverage and going further to exploit even higher spectrum (~THz), there comes an inherent need for compact network densification to build coverage, and with this, a vital need to contain deployment costs. In such a context, 6G devices will not only be communication end-points; 6G devices will be able to act as active network nodes in a data path and, ultimately, form standalone networks.

- Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviours, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.

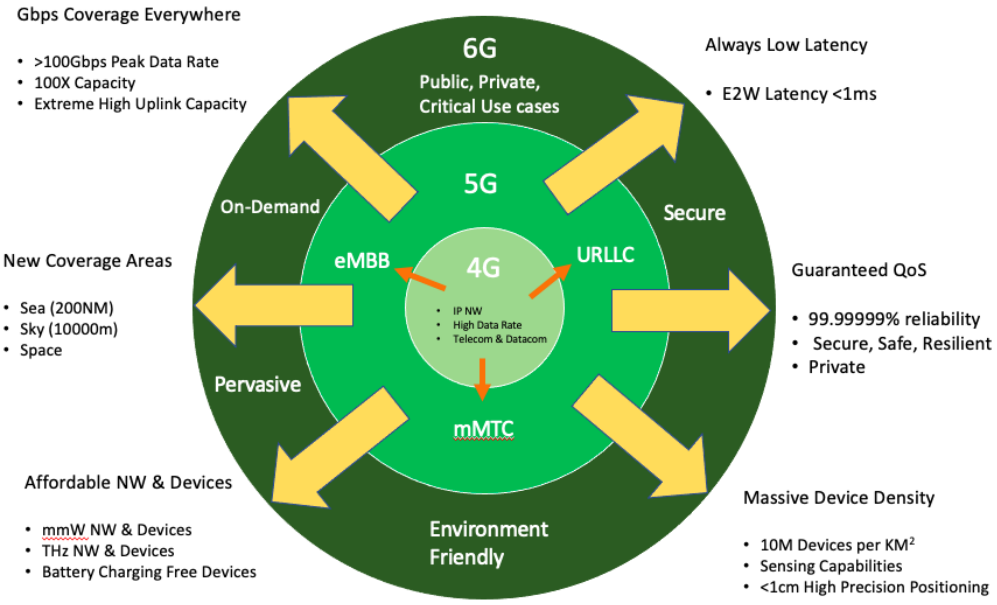
- Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices, provide trustworthy connections that are available all the time.

- 6G connectivity can help India to leapfrog to become highly industrialized society. While the technology adoption improves productivity, quality of life, for rural and urban citizen, achieving a leadership in the development of technology will create immense job opportunities in the country

- 6G Connectivity can help India address many social issues like law and order, healthcare, knowledge led job creation, improvements in living standards of the citizens in the urban and rural areas, improvements in government and citizen interaction through smart cities, internet of things, digitalization and G2C services, better governance of urban, rural, border areas, islands, forests and animal kingdoms, vast ocean geography, sovereignty and security, cyber and physical integration among many others.

- New industry verticals will emerge driven by 6G technologies, these may include Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communication across road transport, trains, airlines, in personal, community and public transport sectors, Holographic communications, tactile and haptic internet applications, tele health including diagnosis, surgery and rehabilitation activities. Extremely

high-rate information access, connectivity for everything, convergence of networking and compute among others.



Our Vision for developing 6G devices will be based on 6G standards, network and performance expectations, use cases the devices are expected to deliver. We would start with Inside out approach developing needed silicon level IPs, interfaces, chips and enable the leading applications using the existing semiconductor and devices ecosystem. We may also own and steer couple of strategic and mission critical components, chips, devices and applications to show case end to end capabilities as part of the 6G test bed program.

Regarding R&D funding, there is limited R&D push towards indigenization of 5G-adv/6G device modem chipset. Considering the current domestic scenario, significant R&D investments are essential to achieve Atmanirbhar in the 5G-adv/6G device space with following key considerations.

- 6G R&D funding to have a 10-year horizon with the outcomes aligned with the IMT-2030 6G standards. However, the intermediate deliverables should target compliance with 5G-advanced specifications, viz. 3GPP Rel-17/18 and beyond.
- The funding should cover development of modem chipsets, end-to-end systems including software/firmware, security elements and applications. Adequate funding should also be given to emerging technologies such as AR/VR, next generation sensors, human-machine interfaces etc.
- The funding should be prioritized towards the development of
    - SOCs: Modem, RF ICs (Sub 6, mmWave and higher frequencies)
    - Multiple classes of SOCs to address low end and high end IoT applications
    - AI processors
    - End-to-End Devices including the applications

2. Societal View

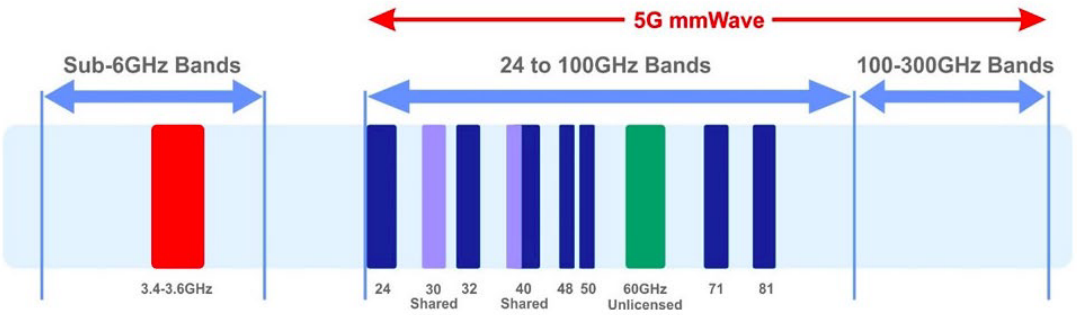
- Let us imagine India in 2040. With Global population at 9.2 Billion people, India would be the most populous country with 1.5 Billion people living in the subcontinent. Young India is aspiring to grow it's per capita income from current 1900$ to 5000$ in 2030 and 12000$ in 2040. India will be the third largest economy in the world by GDP ranking having overtaken Japan.
- India would be the world's largest democracy with 100% of its citizens having home, food, water, sanitation, education, job and income sources, electricity, connectivity, television, mobile, and most of the Govt to citizen services through digital platforms.

- India is expected to increase its literacy rate from current 77.7%, closer to triple digits, add few more years to current average life expectancy of 69.8 years, see leapfrogging increase in human capital ranking, innovation ranking, standards of living and happiness index.
- India is expected to continue its position at the top, in terms of mobile subscriber base, increase it's internet penetration and broadband penetration closer to 100% by 5G Broadband and Fibre to Home connectivity. 2G/3G would have been switched off, main connectivity is 5G and some 4G connectivity to support the needs of the society. There would be telecom services, private networks, community networks everywhere based on 5G/4G. All critical networks would be secure, protected and indigenous.
- India would have achieved its smart cities mission with 100+ cities offering smart city services to its citizens through digital platforms. All 600000 villages in India would have got internet connectivity and people access to information, entertainment and services through mobile and fixed broadband.
- 1.5B people interacting with Government and among each other through Digital platforms, availing Government to Citizen (G2C) services, Tele-Health Services. 500M+ students using Tele-Education platforms across India including primary, secondary, higher and advanced studies. All Hospitals would be interconnected, all doctors and health professionals would be available on National Health Network for consultation, diagnostics, and patient dialogue. Entertainment would be available at the home, in vehicles, in public areas and on the move.
- Smart Agriculture will be everywhere, with use cases like drone usage for pesticide dispensing, smart monitoring, smart storage systems, smart transportation systems and farm to plate traceability.
- Security, Surveillance, Public Safety, Policing, litigation and justice systems, courts all moved to digital platforms with real time access to previous case studies, evidence, real time tele-hearings. Body cameras for policing, surveillance, evidence collection, traffic management will be prevalent in urban areas. Road tolling will be satellite based, with V2V and V2I technologies deployed across the personal and public transport systems. There will be instantaneous identification and verification at Police stations, passport offices, courts, government offices, G2C service centres, Hospitals, Airports, Bus/train stations to avoid procedural delays and physical paper-based systems.
- Future technologies should help contribute further to the success of a number of UN SDG goals including environmental sustainability, trust and inclusion, efficient delivery of health care, reduction in poverty and inequality, improvements in public safety and privacy, support for ageing populations, and managing expanding urbanization.
- 6G connectivity can help India to leapfrog to become highly industrialized society. While the technology adoption improves productivity, quality of life, for rural and urban citizen, achieving a leadership in the development of technology will create immense job opportunities in the country
- 6G Connectivity can help India address many social issues like law and order, healthcare, knowledge led job creation, improvements in living standards of the citizens in the urban and rural areas, improvements in government and citizen interaction through smart cities, internet of things, digitalization and G2C services, better governance of urban, rural, border areas, islands, forests and animal kingdoms, vast ocean geography, sovereignty and security, cyber and physical integration among many others.
- New industry verticals will emerge driven by 6G technologies, these may include Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) Communication across road transport, trains, airlines, in personal, community and public transport sectors, Holographic communications, tactile and haptic internet applications, tele health including diagnosis, surgery and rehabilitation activities. Extremely high-rate information access, connectivity for everything, convergence of networking and compute among others.

3. Radio centric view

In the last few decades every new generation of cellular technology until 5G brought significant improvements in data speeds (that spurred many new applications) but the operational frequency range was limited to sub 6-Ghz frequencies where the radio propagation conditions are conducive to cellular network deployments. 5G is the first radio access technology that extended the frequency of operation beyond 6GHz (expanded the operation to milli-meter wave or mmWave). While defining 6G vision and use cases, it is therefore important to clearly differentiate and outline the vision, network

evolutions and the operational scenarios for sub 6Hz, mmWave and beyond mmWave frequency ranges.



3.1 Sub 6GHz

For frequencies below 6GHz, where the signal propagation characteristics are conducive to small and large cell deployments, 6G radio access technology is likely to evolve as an enhanced radio access technology that leverages the key components and features of 5G while ensuring backward compatibility.

3.2 Beyond mmWave

However, for extremely high frequency operation, especially T-Hz range where the data rates and latencies are beyond the conventional cellular range (use cases are more like fiber replacement) 6G requires a completely new radio definition that requires grounds up development. While commercial use cases and deployment feasibility is not clear in this operational frequency range, the landscape will be clear only after a few years. India should make the necessary R&D investments in order to be able to compete with the rest of the world.

3.3 mmWave

For frequencies above 6GHz and below 52.6 GHz (the mmwave range), the ongoing network deployments around the world indicate that achieving contiguous network coverage in this frequency range remains significant challenge, and therefore, further R&D aimed at enhancements to mmwave operation are being envisioned as part of the 5G -advanced standards. Therefore, development of reliable mmwave networks will be an important consideration for 6G standards.

3.4 5G-Advanced vis-à-vis 6G

While 6G is an IMT-2030 technology (specifications to be available by 2030), 5G advanced (5G-A) that includes rel-18 and beyond may play a significant role in fulfilling many 6G use cases and applications. Therefore, 5G-A may be viewed as a pre-6G standard. In such a scenario, most 6G applications would ride on 5G and 5G-adv radio technology with innovations mainly introduced in the development of new types of devices, applications, network architectures rather than relying solely on improvements made in physical and MAC layers (exception will be for the T-Hz use cases)

3.5 New Services

5G Supports eMBB (very high data rate, moderate latency), mMTC (low-to-medium data rate, moderate to high latency, ultra-high connection density), URLLC (medium data rate, very low latency, very high reliability), as three distinct services. 6G will provide many more new services that will include various combination of the aforementioned three services that will cater to the new use cases envisaged for 6G.

3.6 Beyond cellular uses cases

5G and 5G-advanced specifications cater to new uses and verticals that go well beyond the capabilities offered in the previous generations: examples include Non-Terrestrial-Networks including Satellite (GEO/LEO), HAPS (High Altitude Platforms). Combined with terrestrial services, 6G would offer

universal connectivity anytime, anywhere on the earth including land, sea and air. Therefore, 6G will eliminate/minimize the rural-urban digital divide. This is feasible when the available spectrum in both sub 6 and mmwave frequency range is leveraged to the full extent.

4 6G Global view

	2G	3G	4G	5G	5G Advanced	6G
Introduction Year	1992	2000	2010	2020	2025	2030
Key Features	Voice, SMS	Broadband Data	MTC, Video	Industrial IOT Interactive Video	mMTC+ URLLC+ eMBB+	Connecting Worlds Massive Scale AI & Sensing Holographic Video
Broadband Data Rate Device MIMO		1-10Mbps 1Tx/1Rx	10Mbps-1Gbps 1Tx/2+Rx	100Mbps-20Gbps 2Tx / 4+Rx		1GBps -1Tbps+ 4Tx/8+Rx
Spectrum		FDD+ 2.3Ghz TDD ~100MHz+	+2.5GHz TDD+ Unlicensed 5GHz ~600MHz+	+3.5 – 7 GHz +mmW ~3+GHz		+7 – 24GHz +Sub THz ~50 GHz+
Network Densification		Nominal	+	+device		++device
User Plane Latency			50ms	4 ms (eMBB) 1ms (uRLLC)		25 us – 1ms
Mobility			350 KMPH	500 KMPH		1000 KMPH (Multiple moving platforms)
Killer Use cases	Voice, SMS, VAS	Mobile Web	Mobile Video/TV Social Media Video Call	V2X Smart City/Factory/Home Cloud Gaming, XR UHD Video	Telemedicine Wearables	N-D Holographic Comm AI efficient System NTN Systems Tactile/Haptic/Digital Sensing Automated Driving Internet of bio-nano things

The market for 6G technology is predicted to enable significant advancements in imaging, presence technologies, and location awareness. The computational infrastructure of 6G will automatically select the ideal place for computing, including decisions regarding data storage, processing, and sharing, using artificial intelligence (AI).

Future networks will be a fundamental component for virtually all parts of life, society, and industries, fulfilling the communication needs of humans as well as intelligent machines. To make the best out of it, we – the industry and research community — should contribute together towards a common vision. 6G should contribute to an efficient, human-friendly, sustainable society through ever-present intelligent communication.

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5 Enhanced end-to-end connectivity

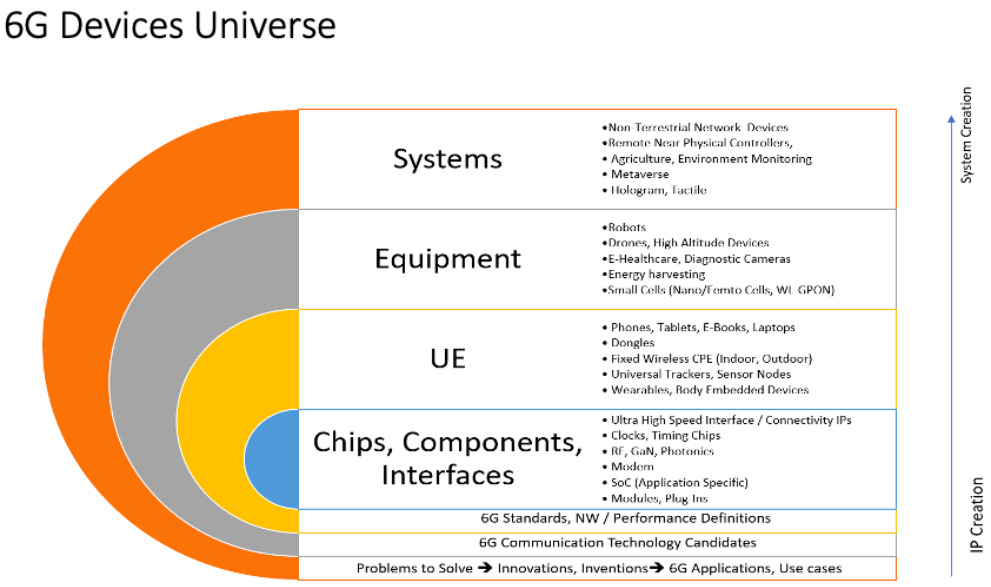
Future applications need to leverage high-performance connectivity, fulfilling required bandwidth, dynamic behaviours, resilience, and further demands. Network capabilities need to be available end-to-end and match the evolution of applications and internet technology. This affects, for instance, application–network collaboration, resilience mechanisms, evolution of the end-to-end transport protocols, and ways to deal with latency.

6 Embedded devices everywhere

Future services will require connectivity everywhere and in everything. 6G networks can support trillions of embeddable devices, provide trustworthy connections that are available all the time.

7 Global 6G activities in area of Device

6G Device universe is expected to be built on the user problems to be solved, fulfill user needs and wants, bring in new inventions and innovations in experiences, applications and use cases. There are several possible communication technology candidates which will be further evaluated, developed and matured. The best candidate would eventually evolve into 6G Standards including network requirements and key performance Indicators.



In terms of devices evolution, the ecosystem is expected to take two approaches

7.1 Inside out approach

IP Creation, Interfaces, Components, SOCs, Modules, UE devices, Equipment Subsystems, Systems. This approach will be taken by mainly semiconductor players and component suppliers.

7.2 Outside in approach

Which basically focuses innovations at the software and system level and integration of various subsystems to bring in efficiencies, lower cost and provide better user experiences. This approach is expected to be taken by high-tech / consumer tech / Software / AI developers and system suppliers.

Both approaches are expected to meet and harmonize over the next few years of evolution towards 6G.

8 Modem and Application Processor Evolution

It is expected that Modem and Application Processors will continue to remain separate in the 6G device architecture. Individually Modem will continue to evolve from being a 5G Modem to a 5G Advanced Modem and will work with the available frequency bands with 5G Advanced use cases. Application processors will evolve based on the application and likely to include parallel processing, increased performance of Neural processing units able to support Machine Learning and Artificial Intelligence based software architectures, operating systems that will work across different device classes and applications.

We expect to have discrete modems being preferred over those integrated along with main SOC.

In terms of device universe, the following devices are expected to be available in 6G era as well.

8.1 Communication Interfaces

This includes module or dongle for laptop, gaming devices or other devices needing ultra high speed 6G connectivity

8.2 Timing, Clock Chips

Very high-performance timing and clock chips are essential to ensure proper working of very low latency, ultra-high speed communication systems, devices, applications.

8.3 RF Front end chips and modules

These include RF Transceivers, power amplifiers, GaN devices, antenna arrays, front end modules needed for 6G devices.

8.4 IoT/Industrial IoT/Trackers

Location Tracking: Future 6G communications will be dependent on satellite technology to attain global coverage. 6G will connect telecommunications, earth imaging, and navigation satellites in the future to provide cellular users with location services, broadcast and Internet connection, and weather forecasting data. The provision of high-speed Internet connectivity onboard fast trains and planes is one example. Precision ranging techniques like UWB are likely to find even more relevance.

8.5 Universal IoT Chip

- The one which works both indoor as well outdoor, uniquely identifiable, includes all wireless connectivity standards and interfaces, on software defined radio architecture.

8.6 Sensor Nodes & Energy Harvesting

- Combination of different sensors in on a silicon or in a module
- Energy harvesting devices which can power ultra low power sensor nodes.

8.7 Smartphone

- 6G will hopefully fulfill and surpass a variety of standards, including delivering high-energy performance, particularly in the context of extensive IoT use and an eco-system of innumerable minute sensors. Additionally, it is required to lengthen the battery life of smartphones, based on the notion that their skills and capacities to cope with sophisticated multimedia signal processing grow exponentially as their power consumption increases. Low energy consumption and a longer battery charge life are two research topics in 6G that attempt to

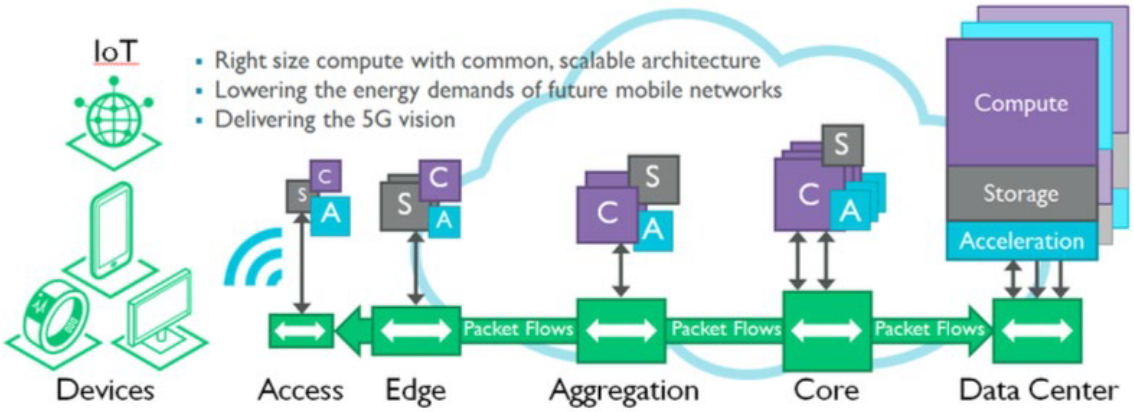
overcome the majority of communication equipment's daily recharging issues while still meeting communication goals.

8.8 Cellular Cameras, Body Cameras, Dash Cameras

There are two possible evolution paths viz.

- Cellular connectivity driven device architecture, which assumes that a broadband connectivity of 1Gbps+ would be available, which reduces need for processing power and storage in the device and
- Application Centric where the storage & processing power at the edge, decision with analytics at the edge will decide how to communicate the video clips or streams back to the storage in the cloud or at the base station or in the device.

Scalable processor cores will support different device classes based on compute, storage and acceleration needed by the application/use case.



Source: ARM

8.9 Wearable and Body embedded Devices

Wearables are expected to evolve from current smart watches, smart glasses and ear buds to include the personal global navigation devices, help humans to interact with different types of experiences, utilities and services like smart home, workplace, factory, retail, healthcare, travel, business among others.

Another category of products would be body embedded devices, for animals, plants, patients with specific ailments and need critical monitoring etc. these devices need body safe materials, power sources, fail safe mechanisms.

8.10 Connectivity devices

- Indoor CPE
- Outdoor CPE
- Mobility CPE-Train, metro

8.11 NTN devices- Aircraft, ships, drones

6G research is currently focusing on the development of non-terrestrial networks (NTNs) to promote ubiquitous and high-capacity global connectivity. The potential of NTNs has been acknowledged in the standard activities. A work item for 3GPP Rel- 17 has indeed been approved in December 2019 to define and evaluate solutions in the field of NTNs for NR. Study items have also been identified for Rel-18 and Rel-19, thus acknowledging long-term research within the timeframe of 6G.

Existing handheld satellite communication terminals are generally bulky, unattractive and costly when compared to terrestrial cellular devices. The combination of a common TN/NTN air interface and TN

frequency band re-use can virtually suppress any device incremental complexity at any level (RF front end, RF transceiver, baseband, form factor, etc.). NTN/TN technology alignment can then be combined with a single subscription covering both TN/NTN, and turn NTN into a mass-market mainstream feature of the existing vast, dynamic and highly innovative smartphone ecosystem. Crucially, 6G TN/NTN device capability can become one additional feature widely available by default to all consumers, with the same form factor and cost structure as before this feature is introduced. 6G TN/NTN capable devices can also be delivered through already well-established OEM manufacturing and existing retail channels. Further to this, the combination of NTN technology with 6G device mesh/relay capability can be used to provide deeper indoor coverage in remote areas.

8.12 Sensors- Diagnostics, Robots, cameras, actuators, Digital/bio sensing and e-health

With the rising frequency of COVID-19 infections, biosensors that are precise, accurate, sensitive, easy-to-use, and specific to detect and monitor infectious illnesses are in high demand. These biosensors can be incorporated into cell phones with the introduction of 6G to provide early warning and control of pandemics .6G networks might be capable of a lot more with the integration of quality control, machine learning, and biotechnology. Detecting viral illnesses effectively by examining the body temperature of affected individuals. Optical biosensors may also be used to monitor the pathological function of bio recognition molecules including antibodies, enzymes, entire cells, and DNA zymes in order to better identify a variety of disorders. 6G can also be useful in other fields of electronic health (e-health), such as controlling ambient conditions (temperature, proportion of gases, and light condition). Autonomous robots can be employed in a variety of health activities, including emergency treatment, medical exams, cleaning polluted floors, and drug delivery in remote locations.

9 Agriculture

According to estimates, present agricultural productivity would need to grow by 60–70% by 2050 to meet the demands of the entire population; to do this, widespread deployment of high-precision wireless technologies will be critical. Autonomous cars, augmented reality for training, sensors for detecting factors on the farm, and data are some examples of application cases. An automated irrigation control is another use of precision agriculture. Precision agriculture, also known as smart farming, will make this possible by using wireless sensor networks to track agricultural factors and make intelligent decisions. (I) data collection, (ii) diagnosis, (iii) data analysis, and (iv) precision field operation and assessment are the steps of precision agriculture identified in. This opens up the possibility of carrying out agriculture activities. It has been proposed that AI be infused into precision energy in 6G to increase agricultural efficiency.

10 Metaverse Devices- AR/VR/XR

THz communication in submillimeter bands can be supported by 6G networks with exceptionally low latency. 6G supports virtualized service sets, which ease holographic communications across physical boundaries and improve management. This enables autonomous, real-time experienced reality (XR) for 3D pictures. 6G communication will be designed to offer dense network connectivity, large coverage, low-power nodes, and effective AI capabilities for mIoT. 6G can accommodate up to 106 parallel sensor connections per square kilometre of range. 6G will enable computational intelligence to improve AR/VR perception models with extraordinary reliability and range. 6G is expected to support smart city verticals such as vehicular-to-anything networks, internet-of-bio-sensory-things, supermassive edge computing, AR/VR use-cases (for example, remote surgery, holographic mind-mapping, immersive gaming experience, haptic communication via sub-millisecond (1 ms TI service), optical radio access cores with photonic communication for super-dense visible light communication.

Example: Metaverse experience at MWC 2022

11 Hologram

Hologram is a next-generation media technology that can present gestures and facial expressions by means of a holographic display. In order to provide hologram display as a part of real-time services, extremely high data rate transmission, hundreds of times greater than current 5G system, will be essential.

Japan recently introduced 7-eleven stores with touch free holographic self-checkouts. The holographic interface, called the Digi POS (Point of Sale), projects an image of a touch screen floating in air when a shopper directly faces the self-checkout register and scans the items they want to purchase.

The Digi POS was developed by six different companies, including 7-Eleven Japan, Toshiba Tec, Asukanet, Kanda Kogyo Development, Mitsui Chemicals Development and Mitsui Bussan Plastic.

12 Energy Efficiency or Zero Energy Devices

Although the battery life of NB-IoT/LTE-M devices can be up to ten years in some cases, battery replacement or charging limits the applicability of these devices.

Fast forward ten years into the future and imagine similar use cases but without the hassle of replacing or charging the battery. Enter the era of zero-energy devices, devices that from the end-user perspective operate without a battery. Instead, the energy necessary for communication is harvested from the surroundings – from vibrations, from light, from temperature gradients, or even from the radio-frequency waves themselves.

Packages in a warehouse can be tracked by using low-cost, zero-energy devices, potentially printed directly on the boxes –this could work even if the box is behind other boxes, avoiding the use of optical bar codes. The box may even provide information on, for example, temperature or humidity in the box, something which is not possible with a passive bar code. Monitoring the environment is another scenario where miniaturized, low-cost, zero-energy devices can play a role.

Source: Ericsson: Example of Zero Energy Device for environment monitoring

In the future, ubiquitous zero-energy devices will help us monitor pollution, weather or even disease prevalence. Zero-energy devices could also transform the retail industry. Imagine you're in a department store shopping for a shirt. As soon as you pick one up from a shelf, the zero-energy device embedded in the shirt's tag tells the store network that you're interested in that particular shirt style or model. With that information, the TV screens in your vicinity could offer you additional options for similar shirts and accessories. All this without the user having to bother charging or replacing batteries in the thousands or even millions of zero-energy devices around!

As a result, 6G will need to develop a comprehensive strategy for energy-efficient wireless communication. A fundamental aim of 6G communication is to run without the need of batteries whenever and wherever feasible, with a target efficiency of 1 pico-joule per bit. Aside from the advantages of high-power THz waves, 6G communication also allows for directed beam communication through MIMO antenna arrays, which allows devices to transmit power beams in a specified direction. This technology has the capability of providing adequate energy to networked devices. One example is:- Packages in a warehouse can be tracked by using low-cost, zero-energy devices, potentially printed directly on the boxes –this could work even if the box is behind other boxes, avoiding the use of optical bar codes.

13 New 6G Man-Machine Interfaces

While the smartphone and the tablet will still be around in 2030, we are likely to see new man-machine interfaces that will make it substantially more convenient for us to consume and control information. We expect that:

- We will have multiple wearables that we carry with us, and they will work seamlessly with each other, providing natural, intuitive interfaces. Not only, wearable devices, such as earbuds and devices embedded in our clothing, will become common, but also skin patches and bio-implants will become prevalent. We might even become reliant on new brain sensors to operate machines. The figure below shows the potential evolution of devices.

- Touchscreen typing will likely become outdated. Gesturing and talking to whatever devices we use to get things done will become the norm.
- The devices we use will be fully context-aware, and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new human-machine interfaces will make our interaction with the physical and digital world much more intuitive and efficient.

The computing needed for these devices will likely not all reside in the devices themselves because of form factor and battery power considerations. Rather, they may have to rely on locally available computing resources to complete tasks, beyond the edge cloud. Networks will thus play a significant role in the man-machine interface of tomorrow.

14 Other Advanced 6G Devices

- Integrated spectroscopy- health, agriculture, forensics, meteorology
- Observability, Learning, edge & fog compute
- Remote sensing, Local sensing through terrestrial network
- Split computing-multiparty computing
- Security- Device and applications
- Human-Machine Interface

15 Terahertz and Si-Photonics

Conventionally, terahertz circuits, including those in the 300 GHz band, have been realized using compound semiconductors and BiCMOS circuits. However, it is not only the transistors that determine the performance of communication. Terahertz communication is expected to blossom in the very near future. The development of optoelectronic terahertz devices will greatly influence the pace to bridge the technology and application gap of terahertz communications. The transmitting power, energy consumption, and chip size are among the key aspects to attract effort in development for the near future.

Photonics integration technology is progressing rapidly, which could push optoelectronic terahertz communication toward the terabit-on-chip target. Photonics integration is a feasible approach to improve transmitting power and reduce energy consumption. The progress of Si photonics integration technology paves a new way for development of optoelectronic terahertz communications. The Si photonics integration technology also makes its integration with Si electronics and low-loss waveguides easier, which is expected to further improve the system efficiency.

16 Security

5G has following security enhancements compared to previous generation technology

17 Zero Trust

3G employed mutual authentication between devices and base station, same level of distrust continued in 4G. 5G has implemented the Security Edge Protection Proxy (SEPP), a gatekeeper that prevents any traffic that isn't authorized and verified from entering the network carrier's network. For implementing the separation of duties, components from previous cellular standards have been broken up with gateways in between them to ensure that the data received is valid. To help facilitate this is an updated cryptographic key hierarchy. Effectively, these sub-components now have specific encryption keys between them. In the event that one sub-key is compromised, the rest of the 5G environment remains protected.

18 Data Transmission Security

The encryption and integrity controls have slowly been increasing over the generations of technologies. The second-generation (2G) added encryption between a user device and base station but left the rest of the network lacking. The 3rd and 4th generations effectively added another hop of encryption to their standards.

The situation was made worse by the fact that critical vulnerabilities due to lack of cryptographic and integrity controls were found in the signalling protocols leveraged by those cellular generations. Signalling protocols are what's leveraged to manage telephone calls, route text messages, and perform roaming. The abuse of these protocols allow adversaries to intercept and listen in to phone calls, perform fraudulent cellular activity, track users, and more.

With 5G, the standard has finally reached a point where all signalling traffic is encrypted and integrity protected. And user traffic is encrypted with optional integrity protection. The SEPP ensures that traffic sent from one network operator to another is encrypted.

19 Privacy

The previously discussed enhanced authentication, encryption, and integrity controls help to address privacy concerns. But 5G also directly addresses privacy concerns discovered with the 4G/LTE standard.

In order for a device to leverage the cellular network, it has to perform an attaching procedure. In 4G/LTE, the device will continuously beacon out an identifier that the cellular network uses to identify and authorize the user. This value is called the International Mobile Subscriber Identity (IMSI). During the attachment procedure, the device and base station authenticate each other and agree on security controls they will use to communicate.

Because the IMSI is beaconed out before security controls are agreed upon, the attribute is transmitted in plaintext, allowing users to be tracked and, in some cases, even for adversaries to perform fraudulent cellular activity on a victim's behalf. Vulnerabilities related to the IMSI have been discussed in many security conferences around the world

5G addresses the weaknesses of the plaintext IMSI by taking the 5G equivalent, now called the Subscription Permanent Identifier (SUPI), and encrypting it with that device's home carrier's public key. The encrypted SUPI is called a Subscription Concealed Identifier (SUCI). The SUCI is then leveraged to initiate the attachment procedure.

20 Virtualization and Software-Defined Networking — 5G Deployment Dangers

Because 5G is implemented in the cloud, all components are virtualized. As such, 5G networks can be constructed like Lego pieces, hot-swapping components as needed. Instead of having a flat network where all internal components can talk to each other, 5G can ensure that the only areas of a network

that should be able to communicate can. Also, in the case where vulnerabilities are found, machines can be updated or mitigations can be put in place instantly to address the concerns. The cloud also enables resiliency not found in previous generations of cellular technologies. Cellular components can scale to address communication surges.

On top of the overall virtualization that's achieved by being in the cloud, internal networks are similarly virtualized with network slicing. Network slicing enables mobile network operators to ensure that each type of data flowing through the mobile network is treated in the way that best suits it. For example, payment card data flowing over the cellular network can be configured with more secure encryption and integrity algorithms. In cases where availability is more important than security, network slicing can ensure that fast response times are enforced.

21 5G Security Risks and Concerns

As 5G becomes more ubiquitous across the globe, the security community is taking the opportunity to review and understand the potential security risks associated with implementing the standard. These security risks fall into the following categories viz. Inherited flaws and Out-of-specification issues

22 Inherited Flaws

22.1 Legacy Protocols

The legacy protocols that possess the most vulnerabilities are the aforementioned signaling protocols. A brief summary of what each protocol does and its vulnerabilities are summarized below:

SS7: Used in 2G/3G to exchange information needed to transmit voice and text messages between parties. This protocol lacks authentication and integrity controls resulting in any party being able to establish man-in-the-middle connections, allowing communications to be intercepted. Abusing this protocol also allows an attacker to perform telephone spam, spoof numbers, and track a user's location.

Diameter: With the transition from 3G to 4G/LTE, the Diameter protocol was brought in to replace SS7. Diameter provides authentication, authorization, and even encryption. Weaknesses were discovered in this protocol that allow adversaries to send spoofed messages that can leak information about a cellular user such as their location.

GTP: Recently, Positive Technologies released research into another vulnerable protocol leveraged in 4G/LTE and 5G: GTP. GTP is used to transmit user traffic on all generations of mobile technologies from 2G to 5G. Abusing this protocol can result in a bad actor being able to impersonate a user, perform fraudulent cellular activity, and achieve denial of service. Unlike the other two protocols, GTP is defined for use in 5G standalone architectures.

22.2 Downgrade Attacks

Because of how fast technology moves forward, it can be difficult even for tech enthusiasts to keep up-to-date, let alone non-technical people. To ensure that everyone has sufficient time to upgrade, new standards are typically made to support older ones as well. However, in allowing support for older generations, there's the potential that downgrade attacks can be performed.

Downgrade attacks trick users into leveraging the insecure and out-of-date versions of a protocol. These types of attacks can be found everywhere. For instance, the Transport Layer Security (TLS) protocol that a browser leverages to securely surf the internet. Even the latest TLS version published in 2018 has been found to be vulnerable to downgrade attacks [15]. But, there's an easy fix. A web browser can be configured to limit access to websites that leverage the latest, most secure protocols, disabling anything deemed insecure. With those protocols disabled, if someone attempts a downgrade attack against it, the browser will simply refuse.

Cellular devices don't have the same flexibility that web browsers do. When a mobile device connects to a cellular network, the user has no control over the process. There's no setting in an iPhone or a Pixel that can be configured to prevent a phone from connecting to out of date and insecure cellular networks

(like 2G). The Electronic Frontier Foundation (EFF) is actively lobbying tech giants, namely Apple, Samsung, and Google, to allow users the ability to disable insecure cellular standards within their devices [16]. Until these changes are implemented, adversaries have the potential to side-step all the security controls implemented by 5G by performing downgrade attacks.

22.3 Out-of-specification Issues

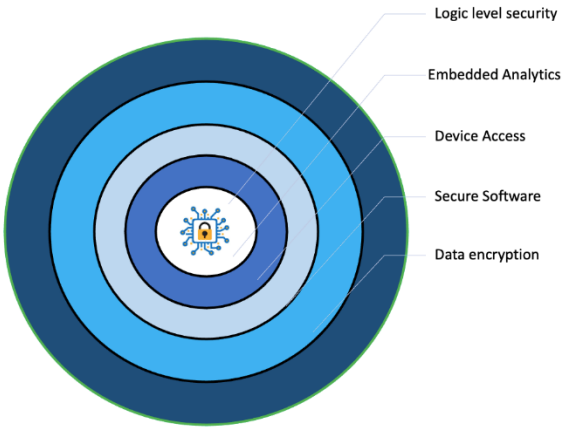
3GPP has defined very explicit details on the 5G standard in their releases, but there's a number of areas of 5G that they deem out-of-scope. It's these areas that companies and network operators have to figure out on their own and therefore where there is the highest probability of something going wrong. This includes security problems with the cloud, web application vulnerabilities, and privacy concerns.

22.4 Complications Managing User Privacy

Mobile network operators will need to work with cloud providers and third-party developers to define who has what responsibilities in terms of user privacy, and how each player will be held responsible. One might suspect that current privacy regulations help provide assurance here. But 5G networks do not stop at a country's border since radio waves have no comprehension of political jurisdictions. So it is entirely possible for overlapping laws to conflict. The situation becomes even more convoluted when an incident occurs because it's not possible to predict which law(s) will take precedence when a victim, an attacker, and the service provider are from different locations.

And all of this is assuming that a nation-state has implemented 5G with industry best practices. To ensure confidentiality and integrity of over-the-air communication, 5G leverages the New Radio Encryption Algorithm (NEA) and New Radio Integrity Algorithm (NIA), respectively. Both algorithms support the highly secure Advanced Encryption Standard (AES). However, in both cases, these algorithms also support weaker algorithms (like SNOW 3G [18]) and can be disabled entirely so no protections are in place.

As 5G becomes ubiquitous, Indian lawmakers will need to devise adequate policies to address security concerns to ensure there are no gaps in protecting end-user data. When one looks at a secure, embedded system built using a chip , includes layers of protection starting with the logic level.



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At a device level we should focus on logic level security that monitors specific operations at the logic transition level. The logic level is integral to the silicon so that it cannot be hacked or removed. In older generation systems, the NW element is considered to be trusted and device could be / can go rouge. In the next generation systems eve device should have an ability to authenticate and then only initiate data sharing process. As devices become powerful and capable to collect, process and stream large amount of data, this ability to ensure that the recipient is a trusted one is a much needed ability in the device silicon. A dedicated analytics engine for on-chip analysis uses real-time data from the hardware monitors. This engine has to be separate and cannot be impacted by the functional software stack. As data need to move off the chip, access to the chip has to be secure. This requires silicon based root of trust including a level of authentication before another system can connect. Once the device/chip is accessed, as data is sensitive, secure software and data encryption is necessary.

23 Domestic Capabilities

Indigenous development of 5G UE chipset is a nascent stage. Capabilities listed by MEITY as part of the semicon India deliberations have been listed here:

- India Semiconductor Mission has announced an MoU between Cyient, WiSig Networks and IIT Hyderabad to enable mass production of "5G Narrowband-IoT- the Koala Chip, Architected and Designed in India".
- MoU between Signal chip Innovations, MeitY and Centre for Development of Advanced Computing (C-DAC) for not only design and manufacture but also deployment and maintenance of 10 Lakh Integrated NavIC (Navigation with Indian Constellation) and GPS Receivers. Signalchip, an Indian Fabless semiconductor company has developed “Agumbe” series of baseband, modem and radio frequency (RF) chipsets for 5G/4G networks with integrated support for global navigation satellite systems including NavIC.
- Partnership was announced with Synopsys, Cadence Design Systems, Siemens EDA and Silvaco for making available their Electronic Design Automation (EDA) tools & design solutions for Chips to Startup (C2S) Programme being implemented by CDAC, a scientific society under Ministry of Electronics and IT, Govt. of India at 100+ Institutions for 5 years.
- An MoU was announced between Semiconductor Research Corporation (SRC) USA and IIT Bombay to focus on bringing together SRC's industry experts and India's R&D talent to create a compelling industry driven world-class R&D program.
- MoU between Global Institute of Electrical and Electronics Engineers (IEEE India) and Centre for Development of Advanced Computing (C-DAC) was announced for skill and technical standards development in semiconductor electronics focusing on VLSI design and Electromagnetic interference (EMI)/ Electromagnetic compatibility (EMC).
- MeitY announced an MoU between Atal Community Innovation Center Kalasalingam Innovation Foundation (ACIC-KIF) and Centre for Development of Advanced Computing (C-DAC) for collaborative R&D, Product development and Trainings in the areas of semiconductor technologies, Power electronics, Energy harvesting, Electric vehicles etc.
- DIR-V has announced Five MoUs for the use of indigenously developed RISC-V Processors - SHAKTI and VEGA.
- MoU between SONY India and DIR-V SHAKTI Processor (IIT Madras) for the Systems/Products developed by SONY.
- MoU between ISRO Inertial Systems Unit (IISU), Thiruvananthapuram and DIR-V SHAKTI Processor (IIT Madras) for development of high performance SoCs (System on Chip) and for Fault Tolerant Computer Systems.
- MoU between Indira Gandhi Centre for Atomic Research (IGCAR), Department of Atomic Energy and DIR-V SHAKTI Processor (IIT Madras) for the Systems/Products developed by IGCAR.
- MoU between Bharat Electronics Limited (BEL) and DIR-V VEGA Processor (C-DAC) for Rudra Server board, Cyber security, and Language Solutions.
- MoU between Centre for Development of Telematics (C-DOT) and DIR-V VEGA Processor (C-DAC) for the 4G/5G, Broadband, IOT/ M2M solutions
- Additionally, an intent of MoU was announced between IISc Bangalore and SEMI, USA for building core competence of quantum technologies - multi-qubit superconducting quantum processors, photonic processors, diamond-based magnetometers, lab-level quantum-secured communication network etc.
- SEMI, USA and IESA also announced an MoU for exploring the potential for growth of Electronics and Semiconductor industry in India and thereby bring global major players in semiconductor to leverage the opportunities for catalysing the semiconductor ecosystem in India.

24 6G Devices R&D Funding

There is limited R&D push towards indigenization of 5G-adv/6G device modem chipset. Considering the current domestic scenario, significant R&D investments are essential to achieve Atmanirbhar in the 5G-adv/6G device space. The key considerations for the R&D funding agencies are:

- 6G R&D funding should have a 10-year horizon with the outcomes aligned with the IMT-2030 6G standards. However, the intermediate deliverables should target compliance with 5G-advanced specifications, viz. 3GPP Rel-17/18 and beyond.
- The funding should cover development of modem chipsets, end-to-end systems including software/firmware, security elements and applications. Adequate funding should also be given to emerging technologies such as AR/VR, next generation sensors, human-machine interfaces etc.
- The funding should be prioritized towards the development of
    - SOCs: Modem, RF ICs (Sub 6, mmWave and higher frequencies)
    - Multiple classes of SOCs to address low end and high end IoT applications
    - AI processors
    - End-to-End Devices including the applications

25 Academia and Industry Cooperation

- Fundamental R&D and blue sky research should be encouraged.
- Projects are carried out through academia where industry is encouraged to participate in the co-development mode at an early stage. Industry contributions can come in the form of expert resources, access to labs and test instruments, outcome linked financial aid, subsystem components etc.
- Some projects may provide seed funding to the academia, and upon delivery of successful initial prototypes, industry/start-ups may take the outcomes forward with additional investment by the industry/VC.

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