Jio PLATFORMS

6G *and* BEYOND

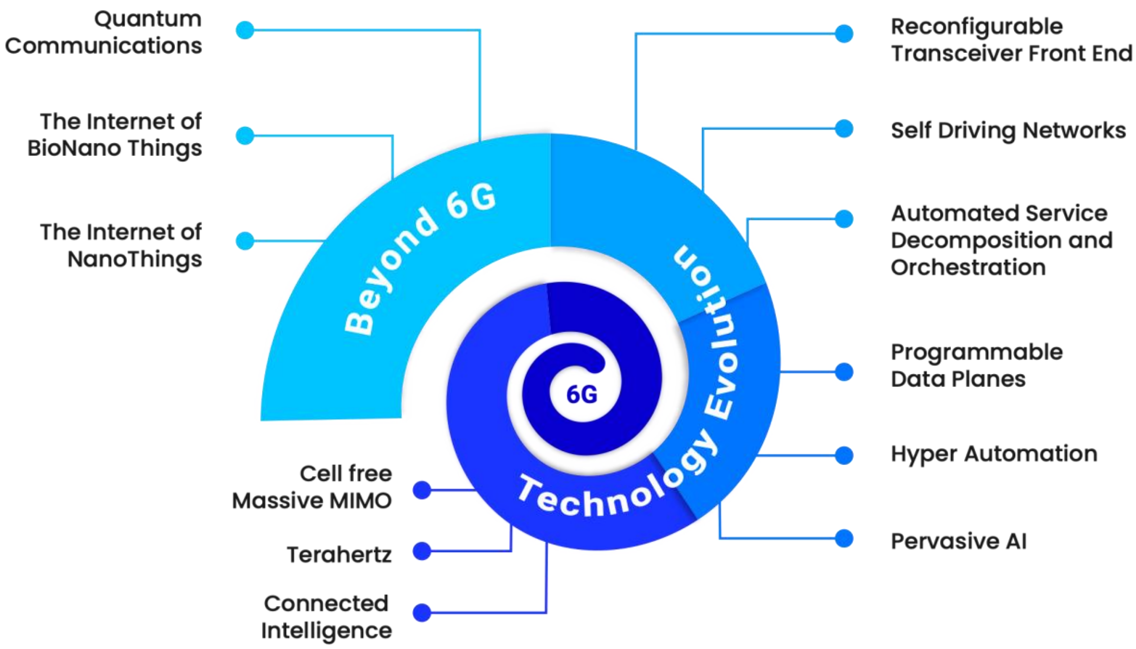
Whitepaper

APR 2021

What's
Inside

Wireless
Technology Landscape

While the phase wise deployment of fifth generation (5G) wireless communication networks has commenced from 2020, more capabilities continue to be standardized in 3GPP Release 17 and beyond. Capabilities like mass connectivity, ultra-reliability, and guaranteed low latency will soon be available in the real world with 5G Standalone deployments. However, 5G networks will need to continuously evolve to further improve upon their capabilities and for meeting new use cases



Future networks of the world in the year 2030 and beyond (Usually called 6G), will require enhanced spectral/energy/cost efficiency and better cognitive capabilities.
To meet these requirements, 6G networks will rely on new enabling technologies for the air interface and a novel architectures such as waveform design, multiple access channel coding schemes, multi-antenna technologies, cell-free architecture, and cloud / fog / edge computing.

While there is an overlap between 5G evolution and 6G wireless technologies, there are some unique aspects of 6G which are described in the present white paper along with use cases. These are **briefly depicted in the figure above**.

6G is expected to be truly an AI-driven communication technology. All smart devices will be converted into intelligent devices in the era of 6G.

6G networks will be able to use higher frequencies (THz bands) than 5G networks and provide substantially higher capacity and much lower latency.

One of the goals of the 6G Internet will be to support one micro-second latency communications, representing 10 times faster -- or 1/10th the latency than conventional wireless technologies known to us today.

This will also require a transformation of internet protocols from what we know today !

> “6G wireless communication networks will be the backbone of the digital transformation of networks by providing ubiquitous, reliable, and near-instant wireless connectivity for humans and machines.”

Along with 6G, this paper discusses the presence of several promising early-stage technologies that are tipped to revolutionize how we perceive data communications in 6G era, namely the Internet of NanoThings, Internet of BioNanoThings, and Quantum communications.

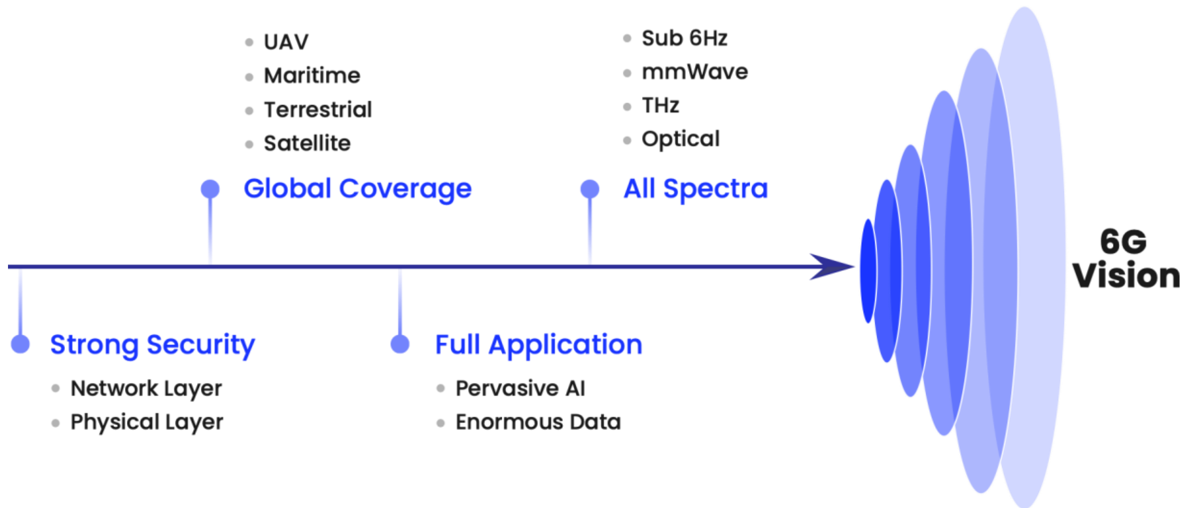
6G Vision

In order to address advanced use cases such as fully autonomous vehicles, flying networks, holographic teleportationn and the tactile internet; 6G wireless communication networks will introduce new paradigm shifts.

Computing technologies such as the cloud computing, fog computing, and edge computing play a vital role in providing network resilience, distributed computing, lower latency and time synchronization.

Hence, their rollout in the context of 5G would lay a solid foundation to the evolution process towards 6G

Some of the attributes of the 6G Network Vision are depicted below:



> With global coverage, strong security, all spectra communication and pervasive AI, 6G networks bring the human world and physical world closer to each other for benefits of the society.

6G wireless communication networks will be space-air-ground-sea integrated networks to provide complete global coverage.

Satellite communication, UAV communication, and maritime communication will largely extend the coverage range of wireless communication networks. To provide a higher data rates, all spectra will be fully explored, including sub-6 GHz, mmWave, THz, and optical frequency bands.

To enable full applications, AI and ML technologies will be efficiently combined with 6G wireless communication networks to have a better network management and automation.

Furthermore, AI technology would further enable the dynamic orchestration of networks, caching, and computing resources to improve the performance of next-generation networks.

Jio envisions that 6G will not only enable a pervasively intelligent, reliable, scalable, and secure terrestrial wireless networks, but will also incorporate space communications to form an omnipresent wireless network.

Key Metrics of 6G Evolution

Compared to 5G, 6G networks are expected to achieve superior network performance. The peak data rate for 5G is 20 Gbps, while for 6G networks it can be 1 Tbps with the aid of THz and optical frequency bands.

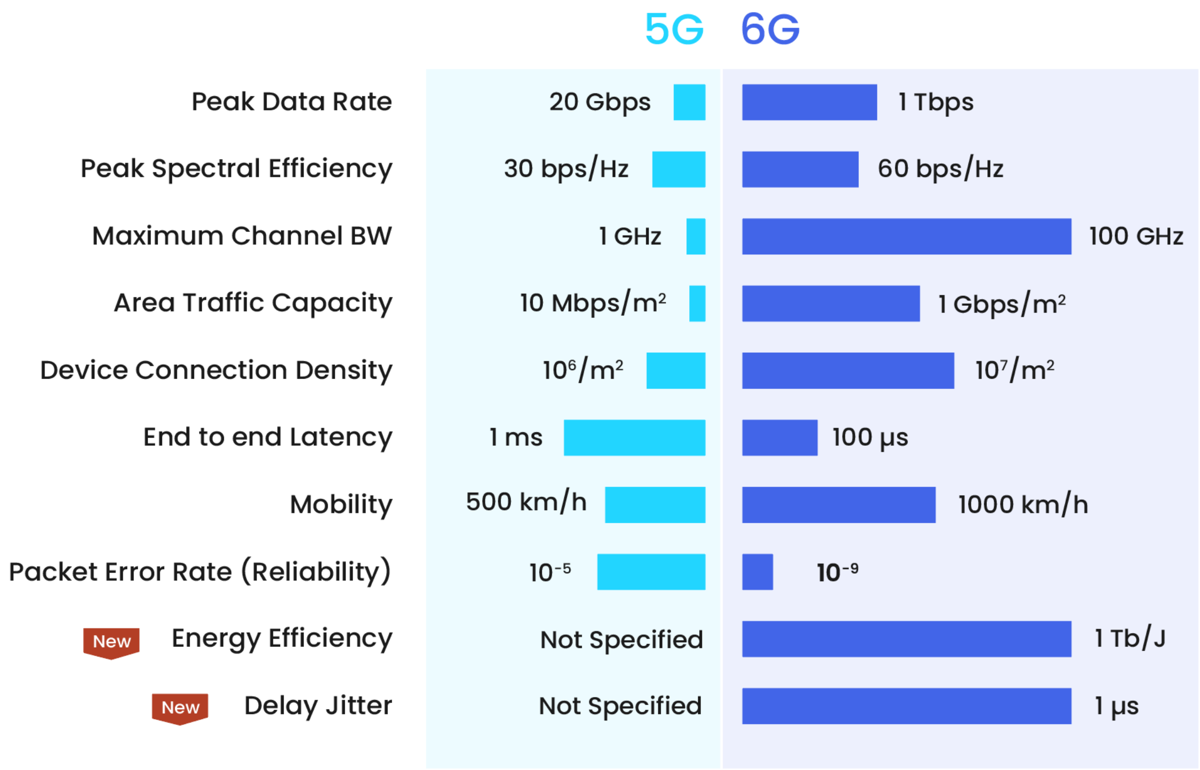
The end-user data rate can achieve Gbps-levels with these high frequency bands. The area traffic capacity can be more than 1 Gbps/m^2.

The spectrum efficiency is expected to increase 2 times, while the network energy efficiency must also increase to make-up for the increase in data rate by 50 times.

The connection density will increase 10 times owing to the use of extremely heterogeneous networks (Small cells), diverse communication scenarios, large numbers of antennas, and wide bandwidths.

There are multiple types of mobility scenarios which will be introduced by satellites, UAVs, and ultra-high-speed trains, which can move with a much higher speed of larger than 500 km/h in comparison to the existing terrestrial terminals.

For a selected set of applications, the latency is expected to be less than 1 ms. Some of the key metrics of 6G technology are covered further in this white paper.



In addition to these differentiators, the Key Performance indicators (KPIs) that are essential to the realization of a 6G network are as follows:

System Capacity: This class of KPIs primarily deals with metrics that are associated with system throughput. These include peak data rate, experienced data rate, peak spectral efficiency, experienced spectral efficiency, maximum channel bandwidth, area traffic capacity, and connection density. Within this context, the experienced data rate and spectral efficiency metrics refer to the values that should be guaranteed to 95% of all user locations.

System Latency: This class of KPIs includes the end-to-end latency metrics, along with delay jitter. We note that jitter is a new KPI for 6G that quantifies the latency variations in the system and is absent from 5G.

System Management: This class of KPIs primarily deals with metrics related to the management and orchestration of networks such as energy efficiency, reliability, and mobility. Here too we note that while 5G does not specify a target KPI for the energy efficiency metric, 6G introduces a target energy efficiency of 1 Tb/J.

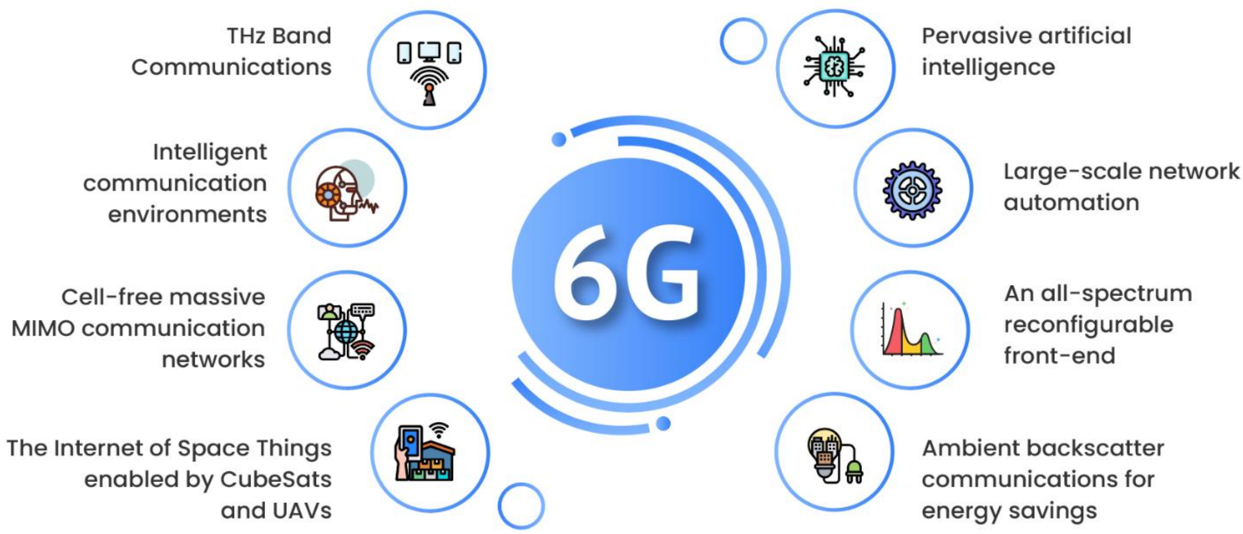
Key Technology Trends and Jio's Areas of 6G Research

Achieving the KPIs highlighted earlier will require revolutionary breakthroughs across all domains of wireless communications.

Jio is actively investing in the research on the following major technology thrusts for the fulfillment of the grand vision of 6G:

- A network operating at the THz band with abundant spectrum resources
- Cell-free massive MIMO communications
- Intelligent communication environments that enable a wireless propagation environment with active signal transmission and reception
- Pervasive Artificial Intelligence
- Large-scale network automations
- An all-spectrum reconfigurable front-end for dynamic spectrum access
- Ambient backscatter communications for energy savings
- The Internet of Space Things enabled by CubeSats and UAVs

These aspects are covered in detail in the subsequent sections of the white paper.



TeraHertz

Enabled Wireless Communications

Terahertz (THz) transmission is a complementary wireless technology for communication networks, which allows high-speed wireless extension of the optical fibers for beyond 5G.

Terahertz transmission as a wireless backhaul extension of optical fiber will be an important building block to face this challenge and guarantee high-speed internet access everywhere beyond 5G.

Moreover, the increasing number of mobile and fixed users in the private sector as well as in the industry will require hundreds of Gbit/s in the communication to or between cell towers (backhaul) or between cell towers and remote radio heads (fronthaul).

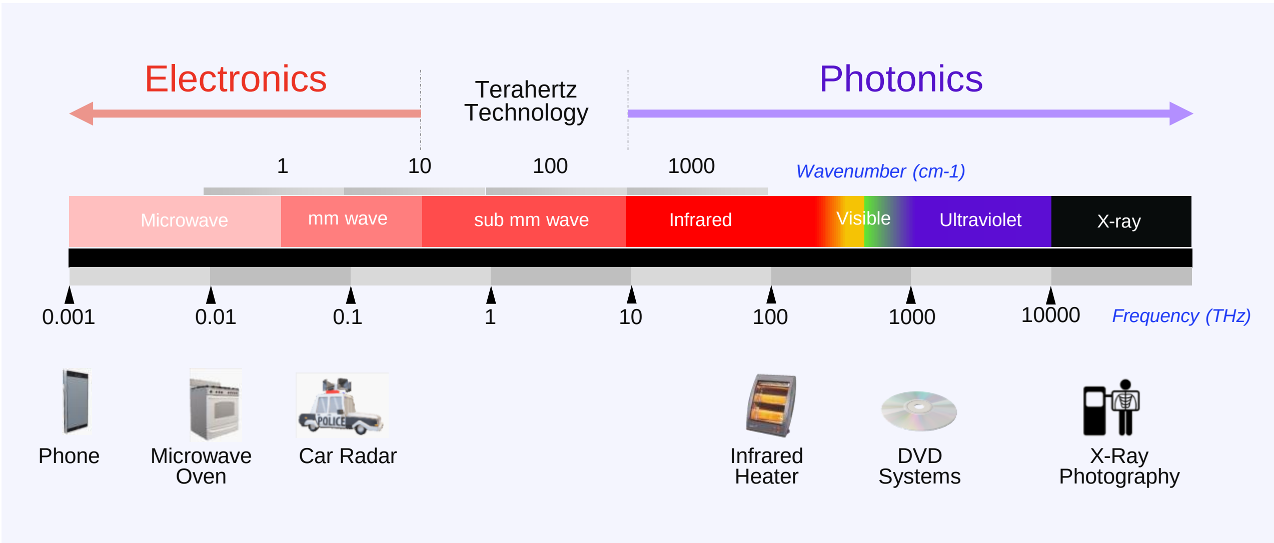
Ever increasing growth in data consumption will be accompanied by the demand for higher data rates. 6G networks being the successor of 5G, will continue to use, mm-wave frequencies along with the future THz frequency bands, where tens of GHz frequency (spectrum) is available.

Supported by the availability of ultra-wide spectrum resources, the THz band can provide terabits per second (Tbps) links for a plethora of applications, ranging from ultra-fast massive data transfer among nearby devices in Terabit Wireless Personal and Local Area Networks to high-definition videoconferencing among mobile devices.

“The advent of THz waves into a mobile network portfolio could provide solutions for 5G applications where technology fails to meet the high data throughput requirement or ultra-reliable low latency regimes”

THz-band wireless communication has several unconventional application scenarios, owing to the distinct electromagnetic and photonics characteristics of this tremendously high frequency band.

This is represented in the figure below.



Terahertz bands can complement mmWave communications in the commercial realization of indoor wireless networks, position localization and gigabyte Wi-Fi support of IoT applications.

In addition to the promised Tbps-level, THz-band spectrum can also be leveraged in local, personal area networks and data center networks - to provide fibre like properties for short distance communications.

Nanometer range wavelengths motivate wireless network on chip and nano-networks which leads to miniaturization and weight reduction of transceiver.

THz band communication will find applications in inter-satellite communications. Since these communications are not constrained by the atmospheric attenuation, high bandwidth, high link performance and stability can be achieved.

Cell free

Massive MIMO

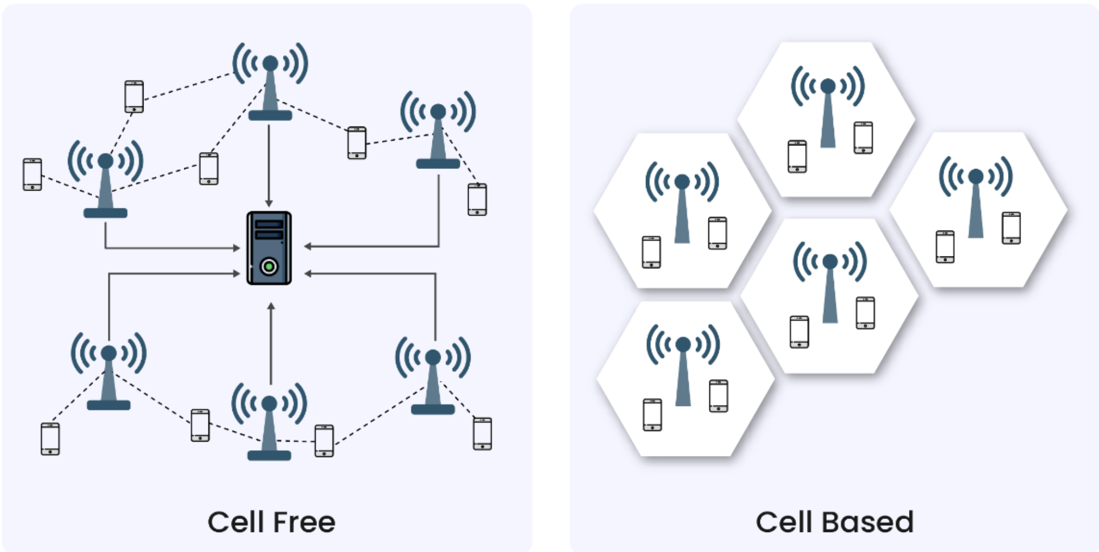
The large variations in performance between cell center and cell edge is a main drawback of the conventional cellular networks.

The concept of cell-free massive MIMO is designed for achieving nearly uniform performance and seamless handover across the user equipment (UEs) regardless of their position.

In Cell Free-MIMO, the original densely-packed antenna array set with a few hundred elements at the BS is distributed in a fairly large area in the form of smaller sets with fewer than 10 antenna elements, while still serving a similar number of users in the same area.

Compared to cellular connections, the cell-free ultra massive MIMO technology can effectively avoid excessive inter-cell handover, reduce the effect of detrimental shading, and depress the control signaling interaction.

A Cell-free massive MIMO system consists of distributed APs that jointly serve the UEs. The cooperation is facilitated by a front haul network and a CPU.



In this design the user is allowed to attach to multiple Base stations which coordinate among themselves to serve a user. Base Stations use their local Channel State Information (CSI) to compute the channel conditions rather than a shared global channel condition.

> “The cell-free massive MIMO architecture is not only meant for increasing the peak rates in broadband applications, but also to vastly outperform traditional small-cell and cellular massive MIMO for majority of the users”

The cell-free massive MIMO deployment can also provide support for the implementation of low latency, mission-critical applications.

The availability of many APs, coupled with the rapidly decreasing cost of storage and computing capabilities, permits using cell-free massive MIMO deployments for the caching of content close to the UEs and for the realization of distributed computing architectures, which can be used to offload network-intensive computational tasks.

Moreover, in low-demand situations, some APs can be partially switched off (control signals may still be transmitted) with a rather limited impact on the network performance, thus contributing to reducing the OPEX of operators.

Intelligent

Communication Environments

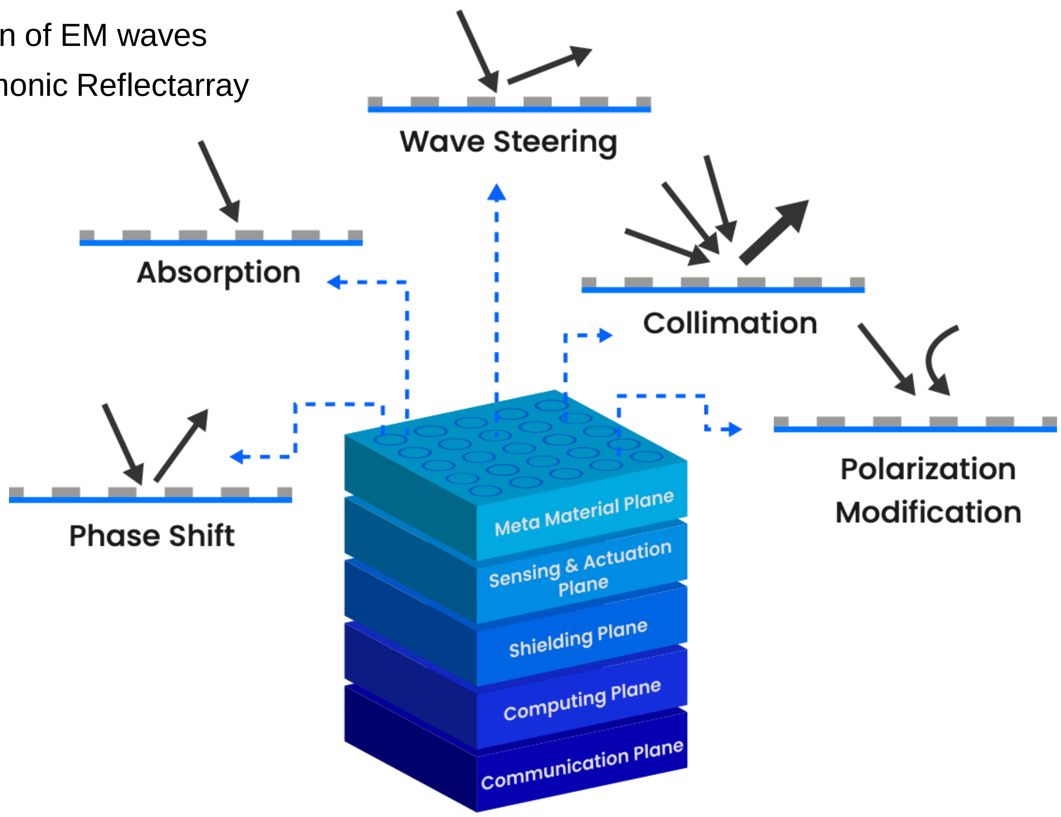
The major challenge at mmWave and THz-band frequencies is the limited communication distance because of the remarkably high path loss inherent to these wavelengths and the limited transmission power of mmWave and THz-band transceivers.

The existing massive MIMO technologies for 5G networks provide spatially, efficient ways of enhancing communication performance.

However, complex signal processing, increased power consumption, hardware design, and THz wave's propagation properties (ex: blockage due to obstacles) pose a real challenge.

Furthermore, at THz frequencies, due to low scattering very few scattering paths exist. Thus, using antenna arrays becomes a challenge due to the shrinking size of the antenna elements. Typically, the controllable behaviors of electromagnetic waves include controlled reflection, absorption, wave collimation, signal waveguiding, and polarization tuning, as illustrated in the figure.

Manipulation of EM waves using Plasmonic Reflectarray



> The notion of “Intelligent Communication Environments" resides in the control algorithms where deep learning and reinforcement learning are to be exploited to dynamically configure the environments.

An intelligent surface will act as a boon to enhance overall communication between transmitter and receiver in a cost effective and energy-efficient manner.

It is a passive reflective surface of electromagnetic signals without requiring a dedicated power source. These are generally made of reflective arrays, liquid crystals, or software defined meta-surfaces. These surfaces will manipulate and reflect the incident RF signal from different sources and direct them toward the receiver to assist in wireless communication. They intelligently reconfigure the modulation or phase of the reflected signal with respect to the channel condition such as fading and path loss.

Further, the intelligent surface can aggrandize beamforming of massive MIMO in the 6G networks due to the software programmable feature. In 6G networks, Intelligent Surfaces will find its applications apart from physical layer communication – in Edge computing, wireless power transfer, device-to-device communication, positioning and localization.

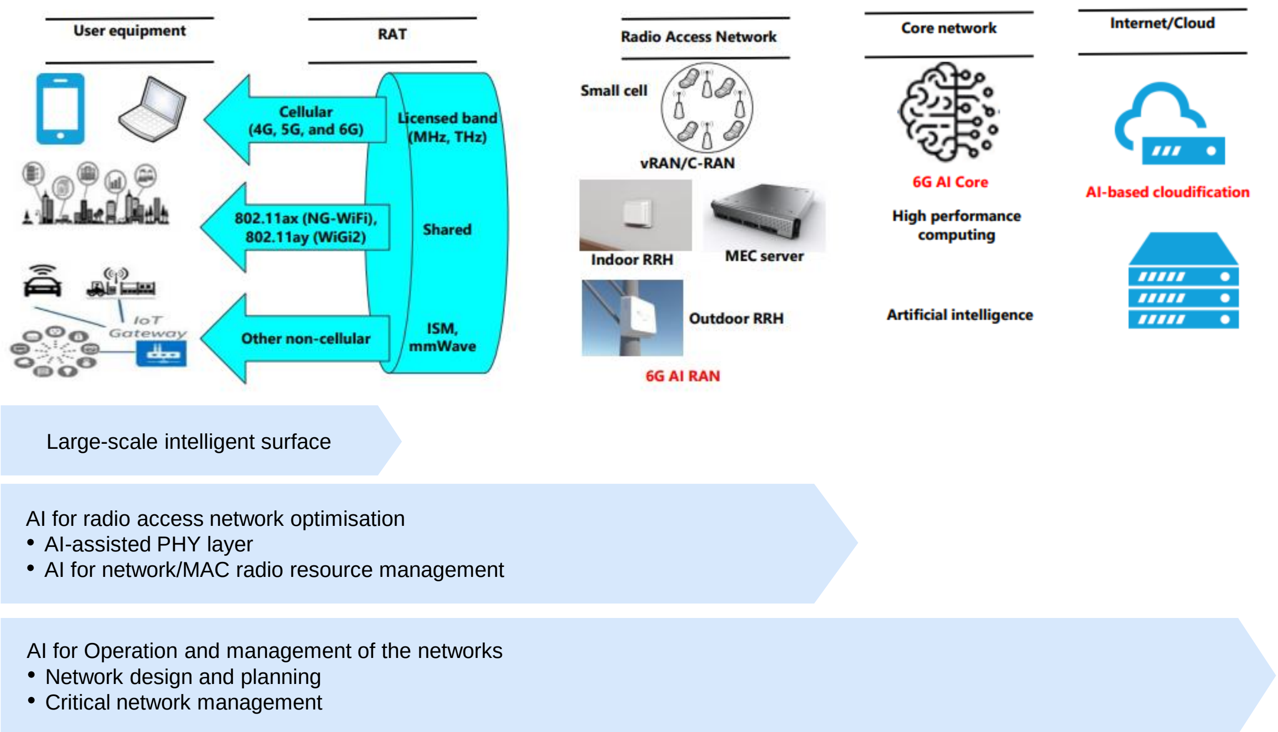
Pervasive
Artificial Intelligence

AI algorithms have powerful distributed and parallel computing capabilities and can be used to improve the performance of individual modules in a wireless transmission system or optimize the entire transceiver structure.

Although 5G introduces AI, its intelligence is limited to network operation, management, and maintenance.

6G will become a true intelligent cognitive wireless system, realizing full intelligence from the application layer to the physical layer. Distributed AI algorithms, running under severe delay constraints, are expected to play a key role in various aspects like self-optimization of network resource allocation, adopting proactive strategies based on network learning, development of semantic inference algorithms and semantic communication strategies to incorporate knowledge representation in communication networks.

The 6G wireless network will be designed to leverage advanced wireless communications and mobile computing technologies to support AI-enabled applications at various edge mobile devices with limited communication, computation, hardware and energy resources. The figure below depicts the potential of AI in 6G networks:



> "AI is an indispensable tool to facilitate intelligent learning, reasoning, and decision making in 6G wireless networks for wide range of applications"

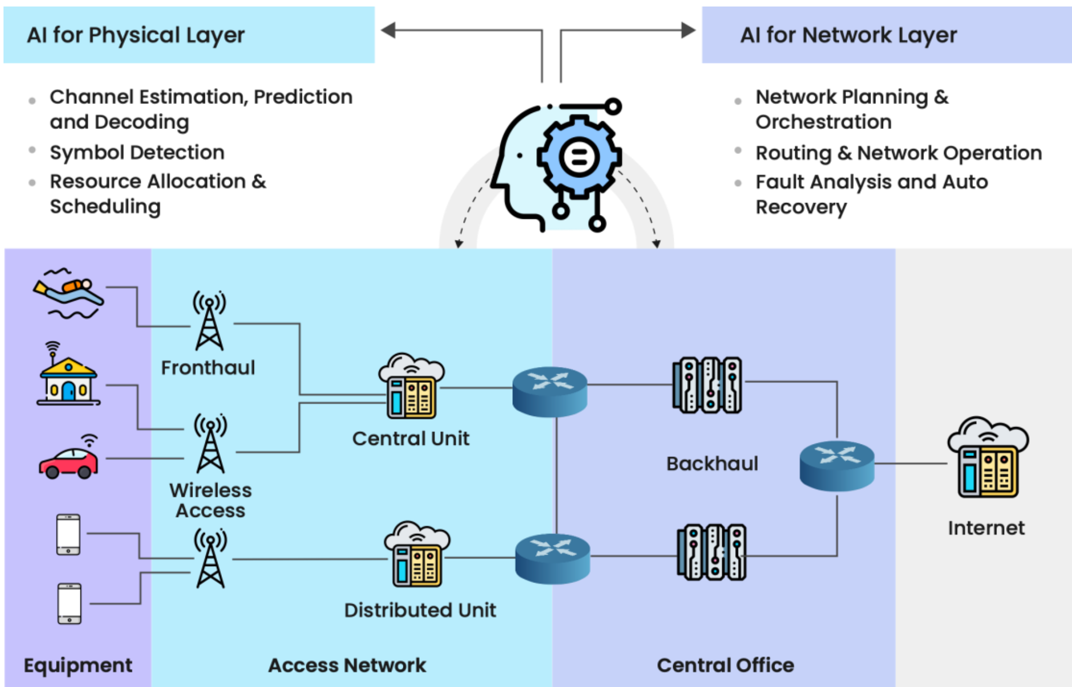
Current wireless communication networks follows a layered structure, in which each layer primarily serves several functions.

Artificial intelligence can be applied to each layer of the wireless network. At the network layer, Machine Learning (ML) algorithms can be used for traffic clustering to further adapt the network resources to various scenarios .

At the physical and MAC layers, deep learning can optimize resource allocation strategies for power distribution, modulation and coding schemes.

Artificial intelligence (AI) with strong learning, powerful reasoning and intelligent recognition ability, allows the architecture of 6G networks to learn and adapt itself to support diverse services accordingly without human intervention.

6G is expected to provide flexible platforms for developing advanced communication and computation technologies.



Following applications can be envisioned with AI in communication systems of 6G:

AI in the Physical Layer : Traditionally, physical layer modelling has been model oriented - a practice in which mathematical models following a certain framework are proposed and optimized under constraints to satisfy a series of pre-determined performance requirements. However, in real-world scenarios, the applicability of such model-based solutions falls short in complicated environments.

Another approach, which is based on statistics, or data sets, builds the model through learning from the data.

For the channel estimation and symbol detection, deep learning-based symbol detection algorithms can provide robust and accurate results with reduced complexity.

Furthermore, it also shows an improved channel estimation accuracy under the effects of non-linearity of power amplifiers, I/Q imbalance, and quantization errors induced by hardware impairments. A lot of these techniques have been introduced in 5G Physical layers as well. However, with 6G these will become essential components.

AI in Network Layer : In other essential layers of a wireless network, the existence of rich datasets lends itself to the applicability of machine learning-based solutions.

In routing protocol design for wireless sensor networks, researchers have successfully utilized reinforcement learning methods to achieve a more energy-efficient routing scheme for underwater sensor networks.

Due to the constant movement of vehicles, a predictive model based on real-time data has superiority over traditional theoretical models in terms of accuracy.

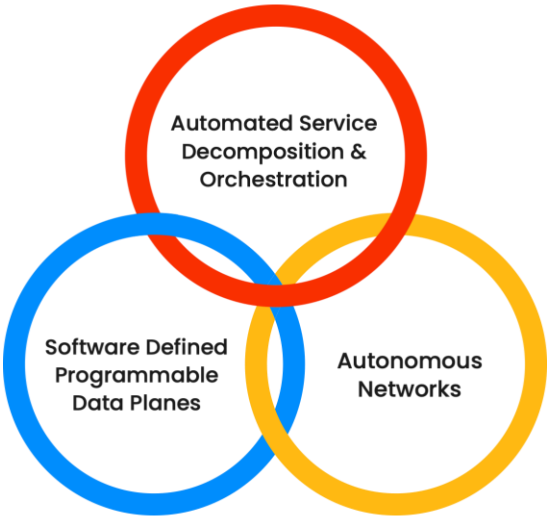
AI in Network Management & Orchestration: AI and ML have an integral role to play in the management of networks. Recently, with software-defined networking (SDN) and network function virtualization (NFV) becoming mainstream, large-scale data acquisition has become easier than ever before, making a strong case for ML-based management and orchestration primitives within 6G, ultimately leading to full network automation.

This consists of supervised learning where network traffic load is pre-emptively determined, reinforcement learning where elastic orchestration of network infrastructure is done and unsupervised learning where end users QoE and security can be ensured.

Large Scale
Distributed Network Automation

Network automation is intended to speed up the delivery of network services while adhering to dynamic and robust service-level Agreements (SLAs), and reducing the potential for errors through minimization of manual intervention.

Three key tenets of network automation with 6G can be envisioned i.e. software-defined programmable data planes, automated service decomposition and orchestration, and self-driving networks.



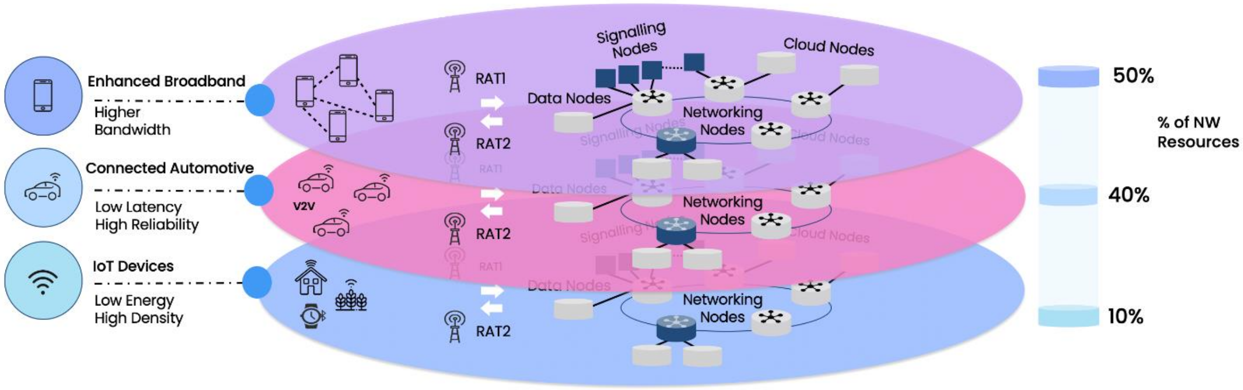
Software Defined Programmable Data Planes

Data plane programmability as a feature allows data plane devices, such as 5G UPFs, to expose their packet-processing logic to the control plane in order for it to be completely reconfigurable.

Further, the operation of many applications depends upon the real-time state of the system. Relying on the controller to update the forwarding state each time, introduces a significant latency burden.

Consequently, there has been growing research in this field that seeks to develop stateful data planes, wherein some of the stateful packet processing and control tasks are offloaded to the data plane switches.
Programmable stateful data planes present a variety of inter-related research challenges. Since packet-level state maintenance can be done by distributed switching devices, there is a need for a state consistency mechanism. A mechanism of this kind could potentially be enforced through the controller, to prevent conflicting forwarding actions. Hence, the SDN Controller would need to re-invent itself.

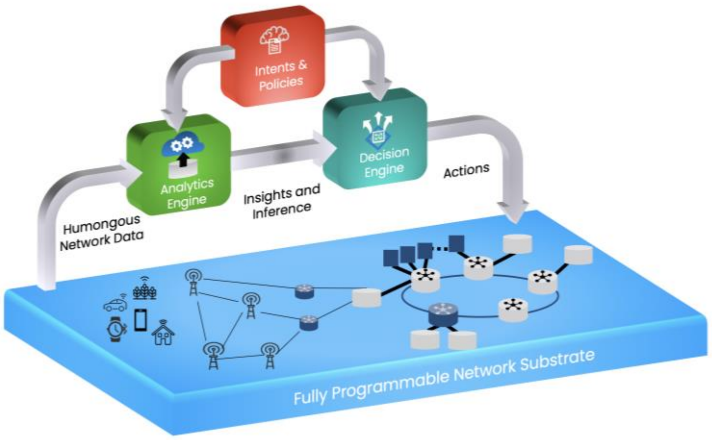
Automated Service Decomposition and Orchestration



The current 3GPP network slicing specification is primarily based on the concept of network slice templates (NSTs). An NST explicitly defines the virtual network functions (VNFs) and associated service function chain that comprise a network service. Consequently, such network slicing primitives allow for the deployment of a limited set of network services, i.e., only those services for which a template has already been defined. Clearly, an approach of this kind is not scalable because: (i) it does not provide a mechanism to deal with new kinds of network services, and (ii) as network services increase in complexity, the effort required to create and maintain templates will become an operational burden.

> “Self-driving networks are expected to allow for elastic utilization of resources, error-free operation, prompt and targeted responses to security incidents, and proactive rather than reactive service handling.”

There are various proposals for automated service decomposition and orchestration, in which based on real time service type and SLA requirements, network slices are created and deployed. Network slicing is a network architecture that enables the multiplexing of virtualized and independent logical networks on the same physical network infrastructure. Each network slice is an isolated end-to-end network tailored to fulfil diverse requirements requested by a particular application. The service to network slice mapping is not based on a template but makes use of deep learning models to extract service requirements and construct the corresponding network slice. Once the service has been deployed, continuous monitoring and real-time telemetry are used to ensure operational optimality.



Autonomous Networks

Seeking complete automation of network management, a self-driving network is defined as a network where: (i) network measurements are task-driven and tightly integrated with the control of the network, and (ii) large-scale data analytics and machine learning models are used for network control. In a nutshell, self-driving networks should be capable of measuring, analyzing, and controlling themselves in an automated manner. This type of networks can assess the current state of network resources, identifies the traffic demand based on real-time, engage business policies that drive an automated network response to re-program infrastructure and allocate more resources to high demand areas.

Collecting performance data from across the network, and analyzing this data using machine learning, provides the ability to more accurately predict potential network problems and anticipate trends by turning mountains of data into actionable insights. However, the realization of self-driving networks brings forth several research challenges.

> “The network utilizes automation, guided by analytics, intent-based policies, to rapidly scale, self-configure and self-optimize by constantly assessing network pressures and demands.”

Accurate intent definitions: There must be clear framework for defining the intent such that it is not too imperative (abstract) and not too declarative (descriptive).

Automated real-time inference: The major challenge is the native integration of inference generated from the machine learning algorithm and the network decision taken to change the network in real time.

In-band telemetry: It makes use of programmable data plane to send additional metadata along with the packets. This may lead to increase in the packet size and accumulating metadata overburden at hops.

Reconfigurable

Transceiver Radio Front-Ends

The primary goal for 6G radio is to establish dynamic all-spectrum sensing and communication from RF to THz bands, therefore, transforming the way in which wireless devices sense, access, and share the EM spectrum. To achieve such a goal, key steps included are described below:

Intelligent all-spectrum sensing solutions:

Development of wireless network-aware state inference for cognition over the swath of frequencies from RF to the THz bands, along with constrained algorithms for the physical and cross-layer control protocols.

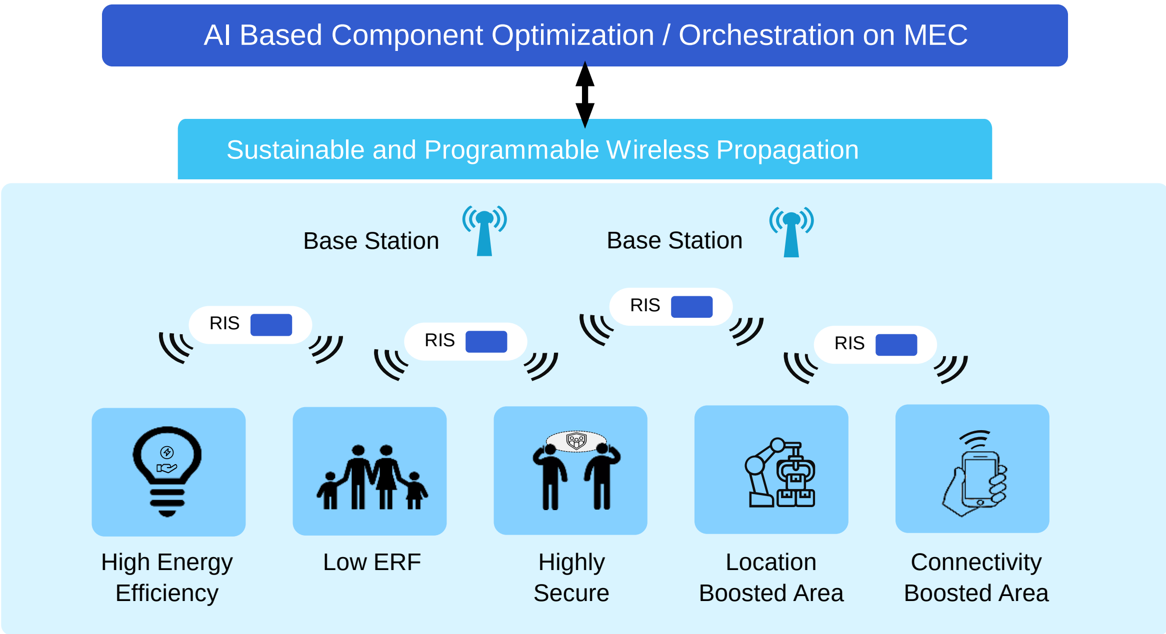
Transceiver hardware design & implementation:

Metaelectromechanical materials (MEMS), MEMS switches, and even nano electromechanical systems (NEMS) switches should be sought to implement hybrid front-ends, which are able to simultaneously sense the EM spectrum, identify the best available band, and communicate over it, at frequencies anywhere from 1 GHz to 10 THz.

Furthermore, fast-evolving deep learning algorithms serve as an efficient solution for identifying available spectrum, tuning channels, and adjusting RF power levels.

Reconfigurable front ends:

Accompanying the dynamic all-spectrum sensing and multi-band operation, agile front-ends should also be equipped with re-configurability. In terms of hardware design, the plasmic reflect arrays can be deployed in the 3D environment, with a size ranging from 1m^2 to 100m^2 depending on the operating frequency (mmWave/THzband).



The biggest hurdle lies in the implementation of an integrated ultra-broadband hybrid front-end that is capable of sensing and communication from the RF to the THz bands, over a target distance of a few hundred meters. Meeting this multidisciplinary challenge requires us to:

- Close the THz gap by developing new device technologies
- Design and integrate re-programmable circuitry, interconnects and antennas that can support all-spectrum operation
- Develop new material integration and packaging techniques to satisfy the electrical, thermal and EMI requirements of disparate bands
- Develop scalable all-spectrum communication using the front-ends.

> “The system is able to simultaneously sense and communicate over the full EM spectrum(1 GHz to 10 THz), and serves as a major contributor towards the infrastructure needed for the next generation of wireless communications”

Ambient

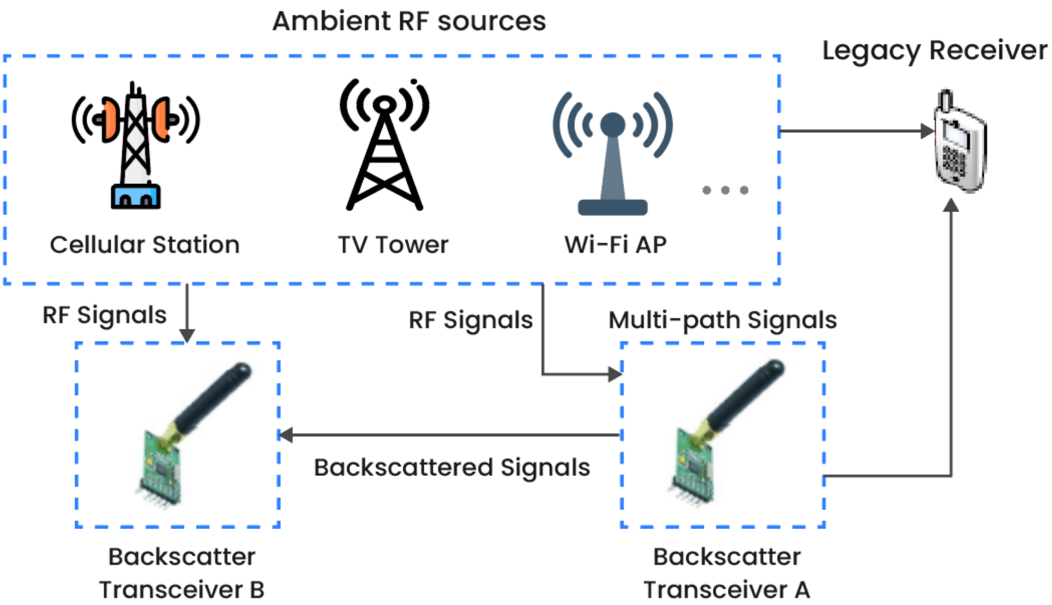
Backscatter Communications

Ambient backscatter communications is a cutting-edge technology which enables smart devices to communicate by utilizing ambient radio frequency (RF) signals without requiring active RF transmission.

This technology is especially effective in addressing communication and energy efficiency problems for low-power communications systems such as sensor networks.

Moreover, it does not require battery as it derives its operational power using simple harvesting circuit from ambient RF energy. An ambient backscatter device communicates by absorption and reflection of RF signals.

The device uses harvesting circuit to convert received ambient RF energy into DC voltage. The charge is being stored in capacitor for its operation. The harvester part also has power management system which takes care of utilization of stored power. In backscatter communication system, device communicates by modulating reflection of incident RF signals rather than having generation of its own RF signals.



Ambient Backscatter Architecture

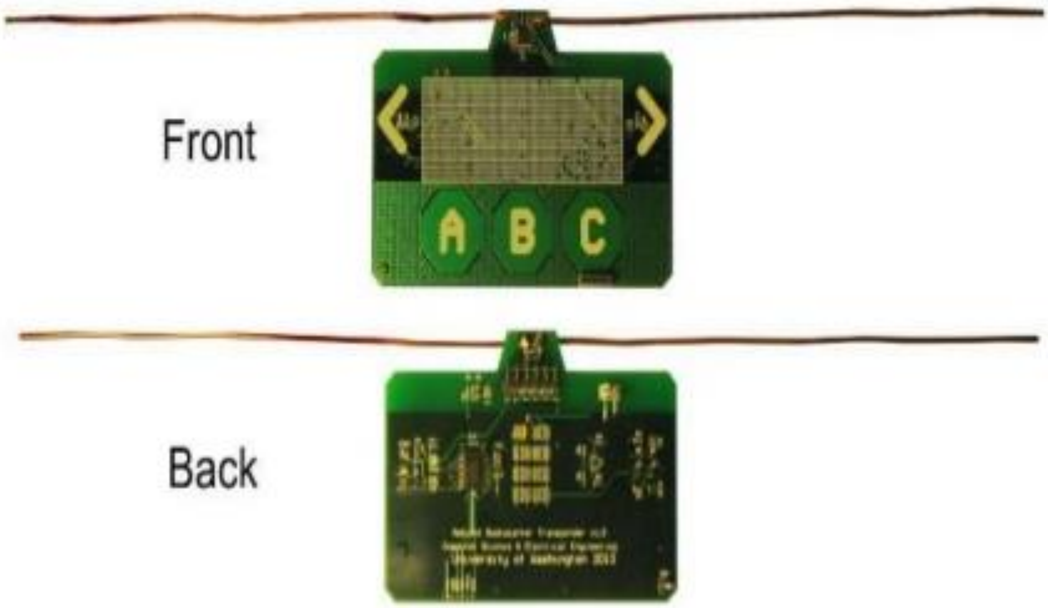
“Ambient backscatter communications are not restricted to a single-band operation as it can operate in wide range of SHF bands, covering Bluetooth, WiFi and other bands”

The figure depicts ambient backscatter architecture. It consists of RF energy harvester, transmitter and receiver.

A device transmits by modulating reflection of incident RF signals rather than generating its own RF signals. This communication method is more energy efficient in comparison to conventional RF communication utilizing its own RF source.

In the ambient backscatter transmitter design, a simple switch consisting of a transistor and connected to the antenna can be used to modulate the impedance of the antenna: a mismatch of impedance indicates a reflection mode of the impinging signals, whereas a matched impedance allows for the signal being absorbed by the antenna.

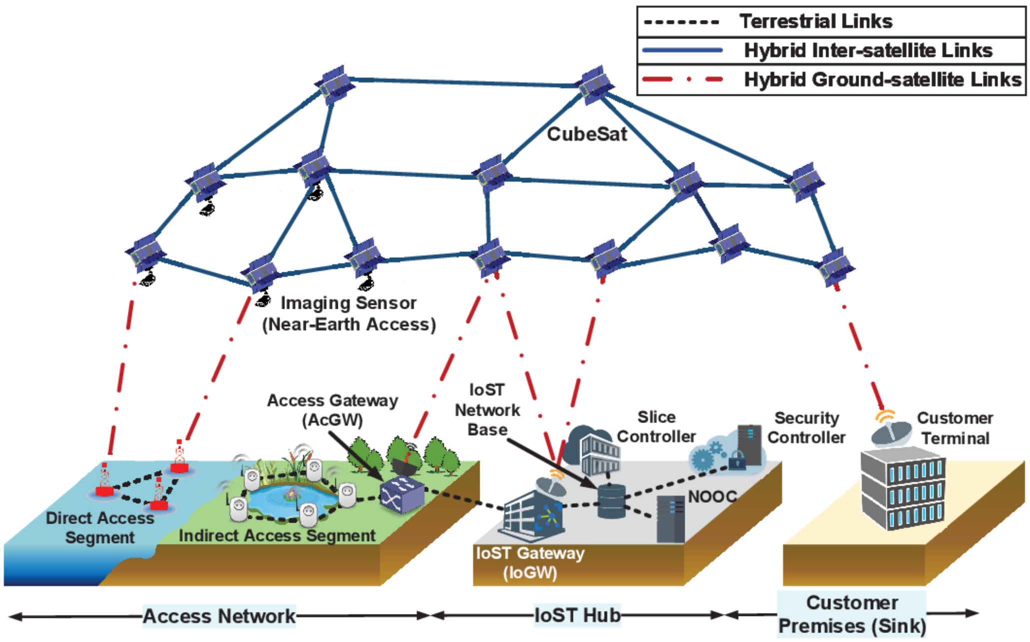
The main advantages of Ambient backscatter communication are that it does not require battery for its operation, the circuit size is very small and no need of allocation of new spectrum as it utilizes RF signals.



Internet
of Space Things

IoST is envisioned as a ubiquitous cyber-physical system for the connected world. IoST is envisioned as a means to achieving global connectivity at low costs, which is further bolstered by the use of Software-Defined Networking and Network Function Virtualization which provide fine-grained control over the system hardware, improve network resource utilization, and simplify network management.

IoST is majorly categorized into two separate segments - ground and space. Ground segment will encompass ground stations and receivers while the space segment will include Cubesats, UAVs.
Cubesats and UAVs have the added advantage of being inexpensive, smaller design and smaller deployment lifecycle in comparison to traditional satellites (LEO and GEO). Existing CubeSats have limited communication capabilities, largely relying on spectrum ranging from L-(1-2 GHz) till Ka- (26.5-40 GHz) band. To overcome the spectrum scarcity and capacity limitation, Multi-band communications can be used for multiple frequency bands from RF to THz frequencies.



The physical architecture of IoST consists of the IoST Hubs, on-Earth and near-Earth sensing devices, and the CubeSat network. The IoST Hubs communicate with the CubeSats and house a large portion of control framework for the entire network, whereas the CubeSats operate in the exosphere (altitudes of 500 km and above) forming the network in space to receive, transmit, and relay data efficiently.

Also as shown in the above image, the customer premises, which in the context of IoST, serves as the termination point or destination for the data. More specifically, as shown, while passive sensing provides monitoring and reconnaissance capabilities, the IoST Hubs and active sensing applications utilize the CubeSat network as a backhaul. The application scenarios of IoST can be divided into three categories based on functionality: (i) monitoring and reconnaissance, (ii) in-space backhaul, and (iii) cyber-physical integration.

> IoST is envisioned as a ubiquitous cyber-physical system spanning ground, air, and space, with applications in monitoring and reconnaissance, in-space backhauling and holistic data integration

In addition to multi-band transrecievers, CubeSats are also equipped with multi-frequency antenna systems for massive MIMO and UM MIMO communication schemes. Design of multi-band antennas can follow two approaches as below:

- Use of MEMS, NEMS and origami structures to create physically reconfigurable antennas which can thereby modify the resonant frequency of the antenna.
- Use of materials such as graphene to create electronically tunable nano-array antennas. In this case resonant frequency can be controlled by changing the Fermi level or chemical potential.

As an added constraint IoST communications at global and regional scale requires constellation of Cubesats and UAVs. This requires novel design of system management and autonomous data routing between nodes to handle disruption in communication due to factors such as orbit, altitude, distance, etc. Solution of the challenges will play a vital role in realization of pervasive cyber-physical systems of this kind.

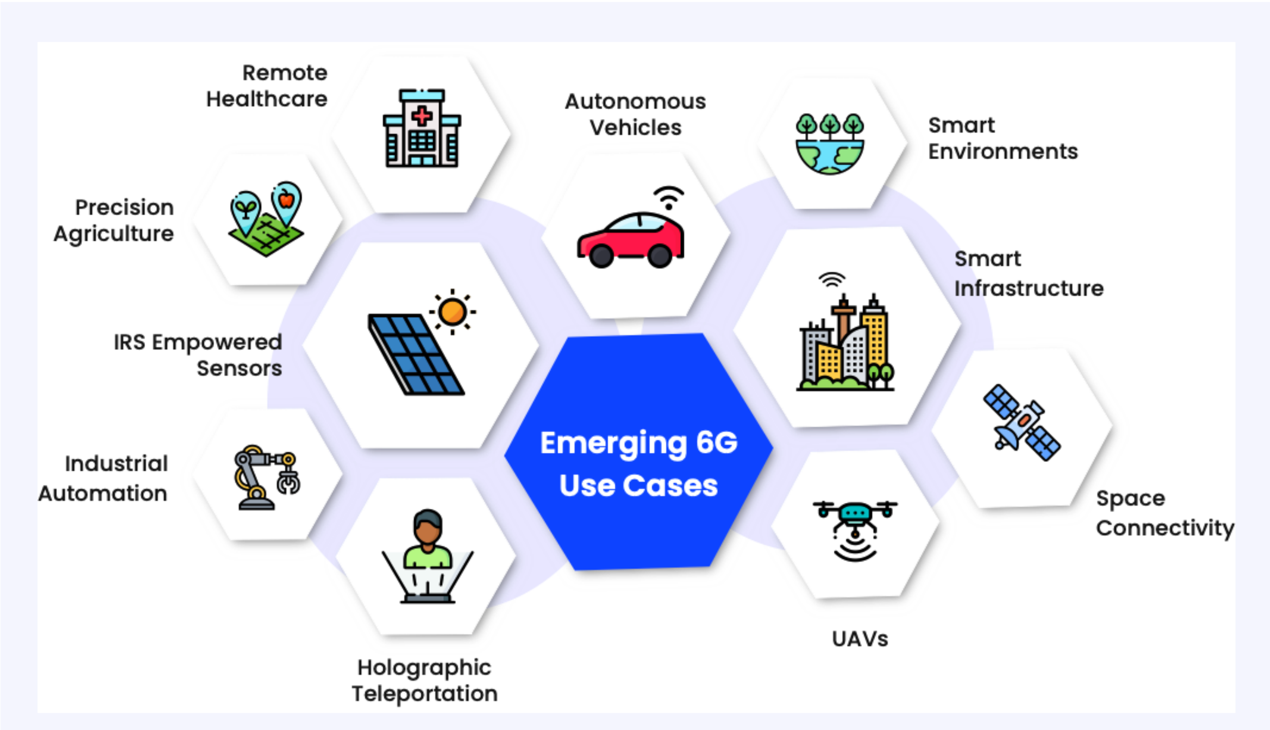
IoST expands the functionalities of the traditional IoT, by not only providing an always-available satellite backhaul network, but also by contributing real-time satellite-captured information, and, more importantly, performing integration on the ground data and satellite information to enable new applications. The fundamental building block for IoST is a new generation of CubeSats, which are augmented with SDN and NFV solutions.

The use of SDN and NFV allows us to introduce novel and innovative concepts such as vCSI, SSR, and satellite diversity that are purpose-built for tackling the long delays and topological variations that characterize the space environment. Additionally, the major open problems which are critical to a full deployment of CubeSat-based IoST are identified. A system performance evaluation covering single-hop, next-hop, and end-to-end metrics further cements the potential of IoST. In this manner, IoST helps realize pervasive end-to-end global connectivity.

Emerging
Use Cases

5G first introduced the targeted use cases of enhanced mobile broadband (eMBB), ultra-reliable low latency communication (URLLC), and massive machine type communications (mMTC), intended to serve a wide variety of applications.

6G builds upon 5G, and it will provide a secure, reliable, intelligent, seamless and holographic network infrastructure.



One of the significant requirements of the 6G networks, as different from the previous generations is to have all round global connectivity such as high altitude, underwater, and terrestrial connectivity to adeptly accommodate a wide range of verticals.

With this vision, 6G networks target to achieve extended and continuous communication between humans and smart things, machine-machine such as underwater vehicles, UAVs, or spacecraft, and robots or even IRS(Intelligent Reflecting Surfaces) Empowered Sensors enabling Blockchain enabled Solar Energy Platform.

01

Multi-Sensory Holographic Teleportation

The human tendency to connect remotely with increasing fidelity will pose severe communication challenges in 6G networks. It can be achieved through a realistic projection of real time mobility in a very short time.

Unlike existing solutions, holographic teleportation operates in a true three-dimensional space and leverages different human senses - to provide a truly immersive experience.

It requires data rates close to 1 Tbps and an end-to-end latency of less than 1 ms. 6G, with its expected Tbps-level throughput and sub-millisecond latency, will play a vital role in this regard.

Multiple sensors can be allocated to gather sensory data. Hence, the Extended Reality (XR) in 6G networks will be formulated from URLLC and eMBB.

> “Holographic teleportation needs computation with sub milli seconds latency, real time rendering and synchronization with the environment. Huge data sets coming from multiple sensors requires high throughput data processing on the edge.”

02 Real-time Remote Healthcare

6G will revolutionize the health-care sector, eliminating time and space barriers through remote surgery and guaranteeing health-care workflow optimizations.

Besides the high cost, the current major limitation is the lack of real-time tactile feedback. The emergence of 6G networks will be a game-changer when telemedicine and remote healthcare will be considered by diminishing the space and time constraints.

Concerning the former, through its use of key enabling technologies such as THz band communications which ensures quality, IoST which provides pervasive connectivity and network automation solutions, 6G will usher in the highest possible wireless communications quality focusing on very-high throughput with extremely low latency.

> “6G Enabled AR helps to view the inside of the body of a patient without any incision and doctors can adjust the depth of the specific location in the body.”

03

Holographic Autonomous Cyber Physical Systems

In 6G networks, connectivity between various devices will be highly interactive in real-time (responsive), including the transfer of data, control, and feedback with a sense of touch.

Autonomous vehicles and Industrial / Military Unmanned Aerial Vehicles (UAVs) are some of the most promising cyber-physical systems in existence today.

The operation of these autonomous systems is characterized by the exchange of large amounts of data between the constituent nodes, i.e., both vehicles and UAVs, relating to high-resolution real-time mapping of the terrain, route optimization, traffic and safety information.

These systems operate at the speeds in excess of 100 km/hr.

Mobility with ultra low latency and extreme data rate required by such cyber-physical systems can only be achieved through 6G networks.

> “6G’s high speed robust operation enables exchange of large amount of data between constituent nodes i.e, both vehicles and UAVs”

04

High Performance Precision Agriculture

A challenge identified with precision agriculture using wireless technology is the topology, making wireless signals susceptible to attenuation. This challenge can be eliminated with the use of IRS (Intelligent Reflective Surfaces) proposed in 6G networks.

This allows deployment in non-line-of-sight environments, and it is more efficient than using relays.

Truly AI-driven communication can offer real-time communication which is very important for modern Agriculture. Going beyond simple automated irrigation solutions, high-performance precision agriculture is largely centered around delivering data-driven insights to address the specific needs of customers, farms, crop, and soil.

6G enabled and fully automated farm systems will contribute in a more efficient process and will improve agricultural productivity.

> “Confluence of digital technologies and physical systems (including cyber-to-biological integration) helps the farmers to monitor the environmental parameters and plant growth to predict pest behaviour”

05

Intelligent Industrial Automation

The automation of the entire Industrial process for higher production rates will be easier with 6G network connectivity with low power communication protocols.

The applications are categorized from sensor tools, smarter mobile devices, machine learning (ML) systems, interfaces used for remote appliances to various types of distributed intelligent automated hardware.

With the higher device connection density of 6G technology, large number of devices can be connected and automated.

> “New technology improves existing processes with better quality control and leverages on connected and intelligent automation.”

06

Space Connectivity and Communication

With miniaturized satellites being developed, satellite communications will play a vital role in actualizing 6G networks.

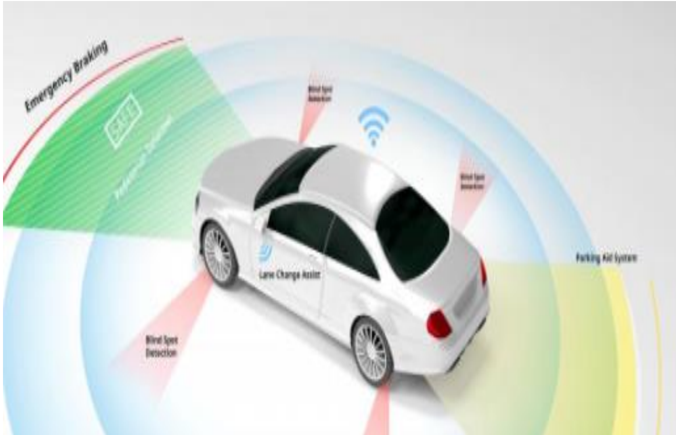
While near-earth and deep-space connectivity are still nascent within 5G, there are a wide variety of use cases ranging from radio astronomy and remote sensing to navigation and backhauling that would stand to benefit from the pervasive connectivity offered by 6G.

Such applications include freight tracking, terrestrial cellular offloading, environmental monitoring, and long-range UAV coordination and many more.

The Internet of Space Things will serve as the key enabling technology for beyond-Earth connectivity, furthering the reach of 6G systems. 6G will consist of a multitude of small radio cells that need to be connected by broadband communication links.

The LEO satellites will offer extended coverage, high-speed data, low latency communication support to terrestrial communication in conjunction with GEO satellites that acts as backbone network.

> “6G will contribute to a disaggregated architecture to guarantee improved flexibility, automation and agility in the delivery of services to the terrestrial terminals”



07

Connected Autonomous Vehicles (CAVs)

Connected autonomous vehicle (CAV) is a critical vertical envisioned for 6G, holding great potentials of improving road safety, road and energy efficiency.

New channel access algorithms and intelligent control schemes for connected vehicles are needed for 6G supported CAV.

The evolution towards fully autonomous transportation systems offers safer traveling, improved traffic management, and support for infotainment, with the market.

Connecting autonomous vehicles demands unprecedented levels of reliability and low latency, even in ultra-high mobility scenarios (up to 1000 km/h), to guarantee passenger safety, a requirement that is hard to satisfy with existing technologies.

> “Seamless processing of extreme volume of data transactions for full automation of vehicles can be achieved through promises of extreme reliability, instant access and high throughput with 6G networks.”

08

Smart Infrastructure and Environments

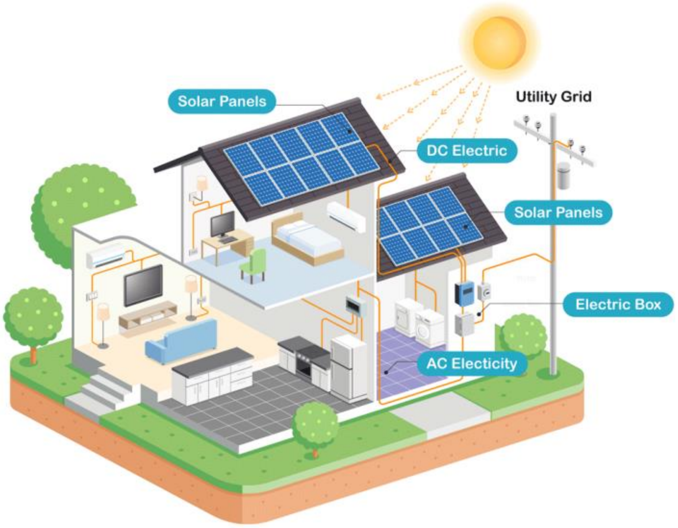
Intelligent communication environments will play a leading role in the ubiquity and pervasiveness of the next generation of wireless systems.

A combination of road sensors and cameras has allowed many cities to optimize the length of any given signal at a traffic light. Sensors embedded in concrete and tunnels reduces the cost as they allow for early detection of potential problems.

The multi-faceted communication capabilities of 6G will contribute immensely to global sustainability and offer massive support for various services at the application layer.

With seamless and fast ubiquitous communication predictive analytics of 6G, the buildings, bridges, areas that needs to be fixed can be identified before failures.

> 6G will enable context-aware environment sensing and indoor localization to aid online monitoring and support the massive uplifting of the SDGs ecosystem.



09

Intelligent Reflecting Surface(IRS) empowered energy-efficient sensors for 6G IoT

With an energy source as abundant as the sun, and a growing need to supply reliable electricity to all, it comes to no surprise that Solar Energy as a service is the technology of the near future. The solar energy as a Service aims to bring solar energy systems and solutions primarily to remote and rural areas and bring about a transformation in the quality of life & the multi-faceted communication capabilities of 6G with the help of IRS (Intelligent Reflecting Surfaces can contribute immensely to this whole environment.

Intelligent Reflecting Surfaces (IRSs) is regarded as one of the most promising and revolutionizing techniques for enhancing the spectrum and/or energy efficiency of wireless systems. These devices are capable of reconfiguring the wireless propagation environment by carefully tuning the phase shifts of a large number of low-cost passive reflecting elements. IRS can be regarded as a physical evolution of massive MIMO, where hundreds (or even thousands) of antenna modules (or meta-atoms) are coated on the walls of buildings, roof of homes, factories, etc thereby providing connectivity to millions of sensors attached to solar panels.

In essence, an IRS intelligently configures the 6G wireless environment to help the transmissions between the sender and receiver by carefully tuning the phase shifts of a large number of low cost passive reflecting elements.

The Blockchain platform will also be involved in the payments and settlements process with the customers & grid providers to accrue revenue based on the power units fed to them.

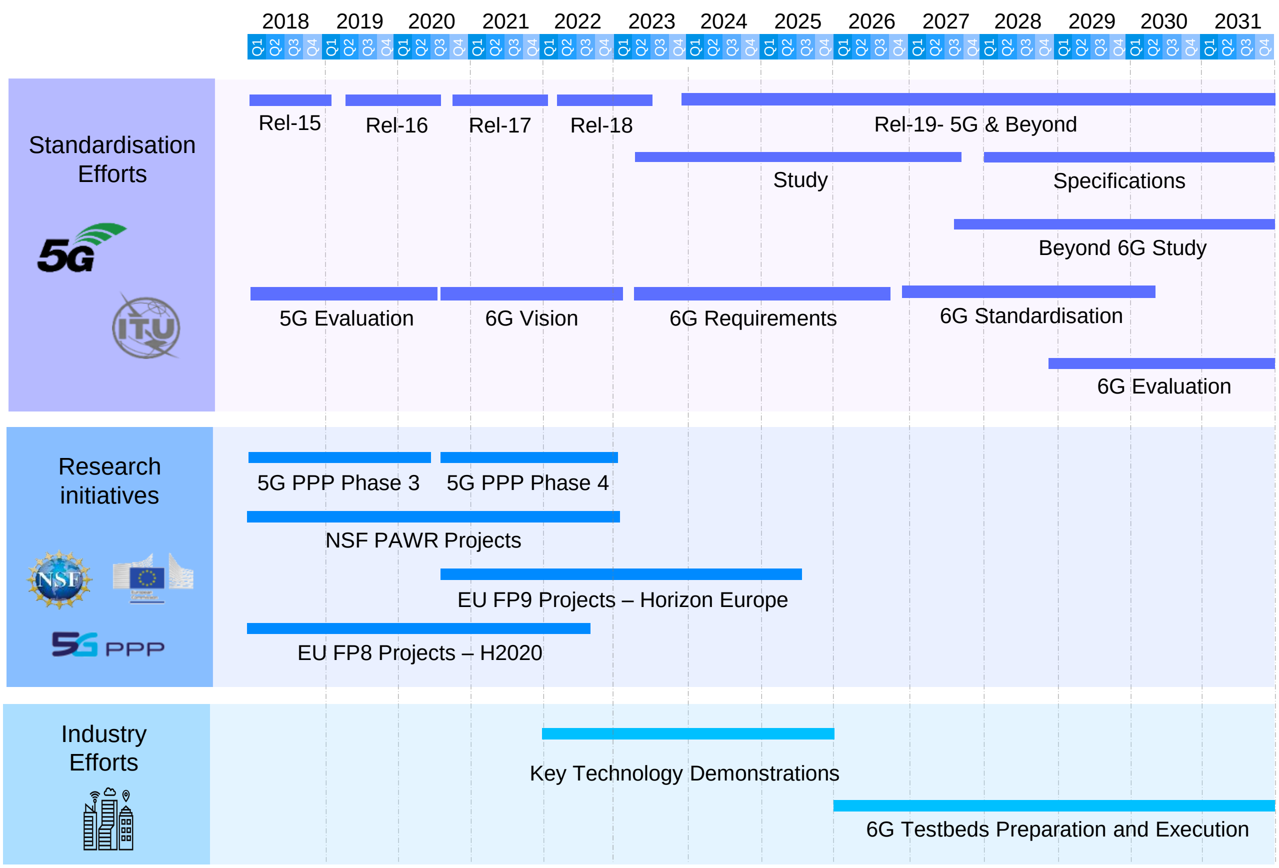
> “Intelligent Reflecting Surface (IRS) is a very promising technology for the development of 6G wireless communications due to its low complexity, intelligence, and green energy-efficient properties.”

Timeline
for 6G

While 3GPP standards over the next few years, up to Release 18 in 2024, are expected to primarily deal with 5G, the ITU has recently convened the Focus Group on Technologies for Network 2030 (FG NET-2030), to study the capabilities of networks for the year 2030 and beyond.

Both the National Science Foundation (NSF) through its Platforms for Advanced Wireless Research (PAWR) initiative and the European Commission are expected to play a major role in the development of 6G.

At the same time, going beyond academia, it is expected a significant rise in industry involvement in the development of these technologies over the next few years, culminating in key hardware and software technology demos by 2025, followed by full-scale 6G testbeds in 2026 and beyond.



Beyond 6G:
Internet of Nano Things

The Internet of NANO Things (IoNT) is the interconnection of nano devices with existing networks. Thus, it creates a state-of-the-art revolution in electromagnetic communication areas among nano scale devices.

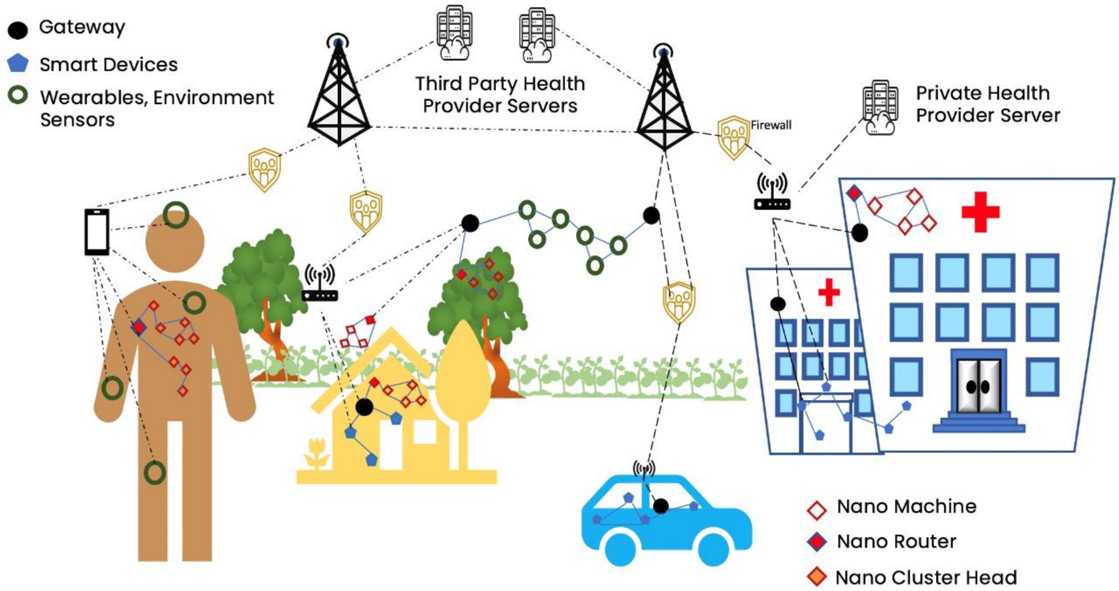
A nano machine is integrated with nano components to perform several tasks. IoNT is envisioned for usage in scenarios where the electromagnetic waves property set the limits for the operating environment such as saline water, intravascular channels where the transmission range is effectively small.

Communications in the paradigm of nano-networks mainly falls under two categories:

- Encoded signal bits being carried with molecules, which follows a diffusion-based mechanism elaborated in Internet of BioNanoThings (IoBNT).
- Plasmonic radiation on metamaterial-based antennas including graphene and carbon nano-tubes operating in the THz band.

Given the scale of Nano Things, energy consumptions will be very small as such devices can be self-powered by different mechanisms.

Besides conducting signal transmission tasks, the nano-things can also perform basic processing and data storage, as well as enabling new nano-sensing capabilities with higher sensitivity.



Internet of Nano Things

IoNT ecosystem will comprise of nano nodes which will be the actual sensors, nano routers which will aggregate and route the data while gateway will act as a remote controller for IoNT devices.

Major uses envisioned for IoNT will include Nano-cameras, On-Chip networks, Nano-Robots.

> "The interconnection of nanoscale devices with existing communication networks and ultimately the Internet defines a new networking paradigm."

Beyond 6G:
Internet of BioNanoThings

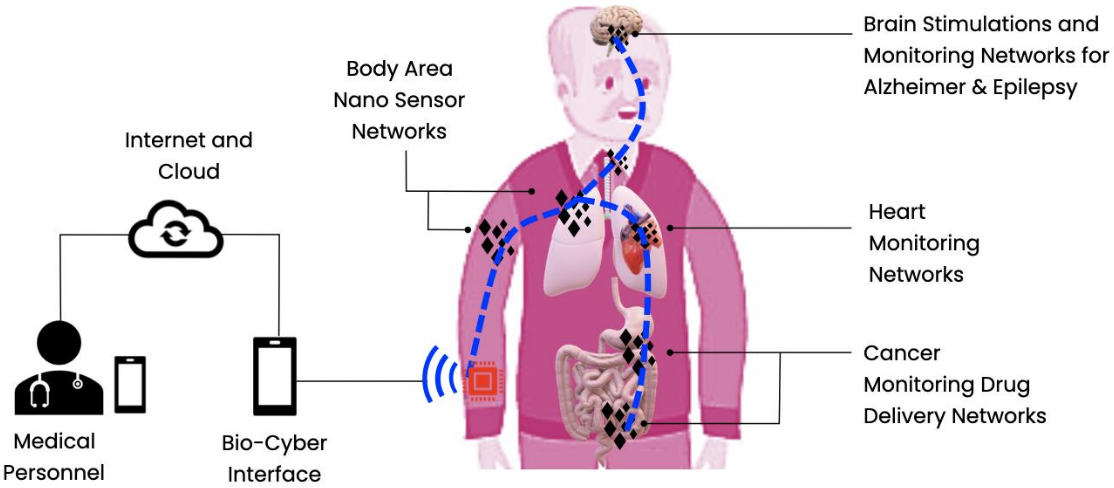
IoBNT architecture is an extended version of the Internet of Things paradigm. IoBNT paradigm stems from synthetic biology and nanotechnology tools and enables the engineering of biological embedded computing devices called nano-machines.

The functionality of these devices is inspired by the behavior of atomic and molecular structures composed of nanoscale components. They not only function as computers but also establish connections with the environment (human body) to detect a physical quantity, as living organisms.

The types of molecular communications include artificial cells which act as gateways to translate between different molecule types, or a bio-cyber interface which can convert molecular signals to electrical ones and transmit to external devices for further processing.

In applications related to human healthcare, the IoBNT harbors many unique challenges and opportunities like:

- Interdisciplinary research on both communications and data analytics for facilitating the modeling of biological processes, including cancer cell formations and Alzheimer's disease, etc. and further design effective control measures for such diseases.
- Expressions of genetic codes at the cell- and organ-level vary remarkably, in a manner analogous to various types of data applications in wireless networks, communication models can be developed and exploited to conceive a generally applicable health information framework.



Applications of IoBNT in public health applications include the usage of biosensors for detection of different types of microorganism based on the significant biological process, unique to each type of microorganism for better detection.

The IoBNT serves a unique role as a holistic solution to not only monitor limited type of cells but also across different tissues and systems which can help in early detection and prevention of different sorts of conditions which are precursor to different diseases.

Recent studies have included AI based statistical learning to provide increasingly refined solutions for modelling sophisticated molecular information exchange processes.

> “The Internet of Bio-NanoThings (IoBNT), envisions the heterogeneous collaborative networks of natural and artificial nano-biological functional devices seamlessly integrated to the internet”

Beyond 6G:
Quantum Communications

As the networks evolve beyond 6G, networks are expected to incorporate more spectrum and complex network elements, computation requirements would also increase dramatically. Quantum computing is accepted as the key enabling technology for the increased computational needs.

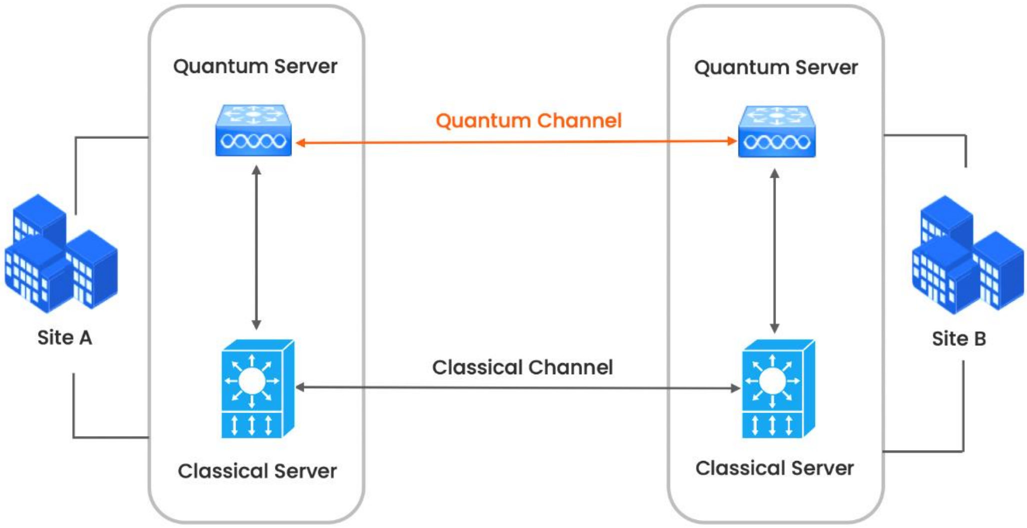
Computationally intense task would require large number of qubits which cannot be accommodated in a single chip. Quantum Communication will help interconnecting such systems at large enabling computations at scale which is impossible in a single quantum chip.

Quantum communications still has a lot of challenges like Quantum Error correction, Entanglement Distribution and Deployment challenge which are under study.

Quantum communications is indispensable for operating quantum systems at scale. More specifically, quantum communications is defined as the exchange of information that adheres to the laws of quantum mechanics and offers several key advantages.

The following physical entities constitute quantum network:

1. capability of large-scale parallel computation
2. ability to transfer data in a tamper-proof manner and
3. potential to encode and transmit many multiple data streams simultaneously.



There are thousands of kilometers of fiber on public property along with manholes. There is extensive span of aerial fiber as well. Tapping is easy with barely inexpensive equipment. It is impossible to police this vast geographically spread infrastructure, more so because, tapping does not require a fiber cut and services continue as usual even when the fiber is tapped. With such vulnerabilies being a reality, Quantum Communication is well suited for deployment in any present cryptographic system. It protects the critical infrastructure unfailingly, providing quantum resilience and ensuring that your data is safe at all times.

The quantum layer provided in the solution sits on the top of the existing network, making the deployment and adoption seamless. With the Quantum-Safe Link, not only it is possible to prevent an attack but even an attempt for attack is prevented. Quantum Key Distribution (QKD) to provide point to point secure connectivity between two enterprise locations. The basic principle is to exploit Quantum mechanics by utilizing encoded photons or “Qubits” to transmit the key from one end to the other, over a single fiber called the quantum channel.

> “Quantum networks are key to the success of distributed quantum computing and rely on the ability to share quantum states between different quantum devices.”

Conclusions

Each generation of communication systems bring new and exciting features. 6G networks will be able to use higher frequencies than 5G networks and this will enable higher data rates to be achieved and have a much greater overall capacity. Newer generations of wireless technology will involve more advanced digital encoding capabilities compared to previous generations.

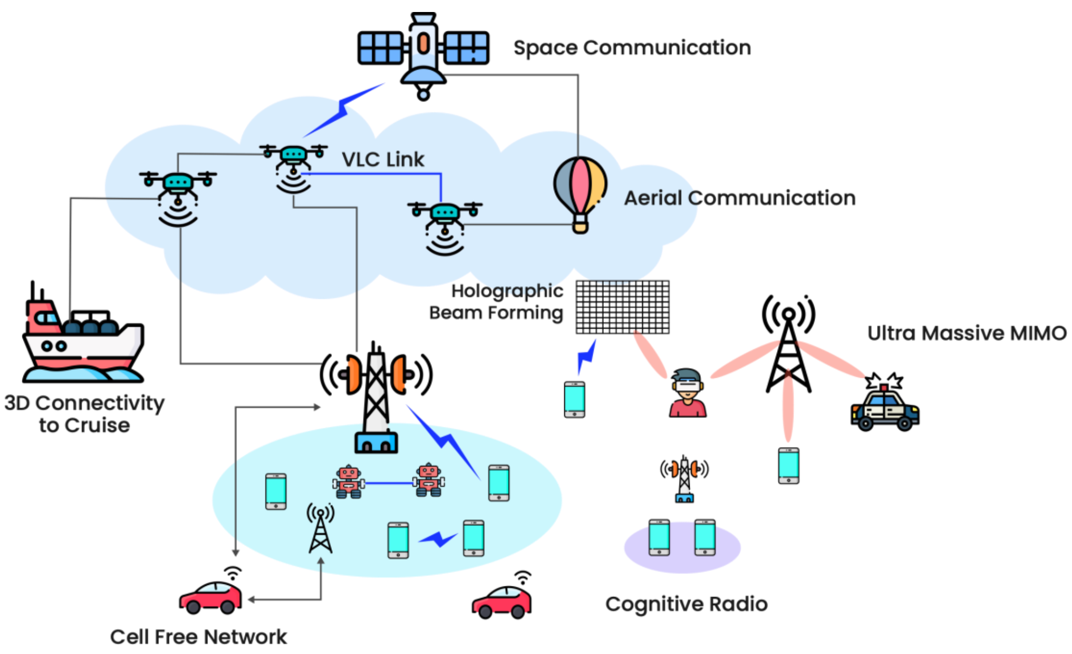
These are possible due to new advancements in hardware design, such as the increase in internal computing power and having more complex antennas.

“6G and beyond" wireless systems will be largely driven by a focus on wireless ubiquity, i.e., the unrestricted availability of high-quality wireless access.

The 6th generation (6G) wireless mobile communication network will also integrate with satellites for global coverage. It can be a combination of nanocore and artificial intelligence, where all the network operators will be connected to one single core.

6G will improve the network performance, integrate different technologies and increase the QoS providing super-smart society with everything connected to the network.

Future Communication Scenario



Acronyms

Acronym	Definition
AR	Augmented Reality
CAV	Connected Autonomous Vehicle
eMBB	Enhanced Mobile Broadband
ERF	Electromagnetic Radio Frequency
GEO	Geostationary Equatorial Orbit
IoBNT	Internet of Bio Nano Things
IoNT	Internet of Nano Things
IoST	Internet of Space Things
IRS	Intelligent Reflective Surfaces
LEO	Low Earth Orbit
MAC	Media Access Control
MEC	Multi-access Edge Computing
MEMS	Meta Electro Mechanical Materials
mMTC	Massive Machine Type Communication
MIMO	Multiple Input Multiple Output
NFV	Network Function Visualization
NST	Network Slice Template
QoE	Quality of Experience
QoS	Quality of Service
RIS	Reflective Intelligent Surfaces
RRH	Remote Radio Head
SDG	Sustainable Development Goals
SDN	Software Defined Networking
SHF	Super High Frequency
SSR	Secondary Surveillance Radar
THz	Tera Hertz
UAV	Unmanned Aerial Vehicle
uRLLC	Ultra Reliable Low Latency
VLC	Visible Light Communication
VNF	Virtual Network Function
VR	Virtual Reality
XR	Extended Reality

References

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2	6G Whitepaper	Macquarie University
3	Speeding up 6G Research	University of Oulu
4	6G Whitepaper on Machine Learning	Cornel University
5	Towards 6G wireless communication networks	Springer Link
6	Whitepaper on RF Enabling 6G	6G Channel
7	5G Evolution and 6G	iEEE
8	6G & Beyond	iEEE